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# ELABORATION OF PROCESSES OF VIBRO-BLOWING DEHYDRATION OF DAMP DISPERSIVE MATERIALS IN A CLOSED PRESS-FORM

*A task of increase of efficiency of dehydration processes of damp dispersive materials is actual for several branches of food and processing productions. In particular to these processes belongs a processing of damp dispersive wastes (alcoholic bard, beer pellets, beet press, coffee and barley slime). In case of decrease of their humidity to 20 – 25% solid phase of the waste can be used as a valuable additive to agricultural fodders or as a high-calorie fuel. This allows to resolve problems of waste utilization and environment protection. Results of previously conducting experiments and calculations demonstrate high efficiency of a method vibro-blowing loading in a closed press-form for dehydration of food industry wastes (alcoholic bard, beer pellets and coffee slime), that provides productivity of removal of liquid phase up to 20 ÷ 25 t / h, specific power consuming 2,7 ÷ 3,2 kW / t and final humidity of wastes 20 ÷ 25%. An aim of the article is to analyze known approaches to study of processing of dispersive materials (pressing, vibration and vibro-blowing loading), to examine a mechanism of fulfilment and efficiency of the process of vibro-blowing dehydration of damp dispersive materials in a closed press-form and to determine dependencies between designated efficiency parameters, working parameters of the dehydration process and physical-mechanical characteristics of processed material. Such analysis should carry out from positions of the mechanics, hydraulics and rheology of damp dispersive materials, separately for their solid and liquid phases and also for different stages of vibro-blowing loading. Elaborated calculating method will allow to create high effective equipment for vibro-blowing dehydration of damp dispersive materials with consideration of necessary characteristics of the working process and the processed material.*

***Kee words:*** *dehydration, closed press-form, damp dispersive materials, amplitude, frequency, pressure, dynamic and mathematic models.*

***Problem formulation.*** Dehydration processes are wide spread in processing and food industry [1, 2, 3]. In particular to these processes belongs dehydration of damp dispersive wastes (alcoholic bard, beer pellets, beet press, coffee and barley slime). In case of decrease of their humidity to 20 – 25% solid phase of the waste can be used as a valuable additive to agricultural fodders or as a high-calorie fuel. This allows to resolve problems of waste utilization and environment protection [4, 5, 6]. Significant number of researches related with improvement of dehydration methods and an equipment for their realization in a direction of increase of productivity, diminishing of power-consuming and final humidity of processed material [7, 8, 9].

Results of previously conducted experiments and calculations demonstrate high efficiency of a method vibro-blowing loading in a closed press-form for dehydration of food industry wastes (alcoholic bard, beer pellets and coffee slime), that provides productivity of removal of liquid phase up to 20 ÷ 25 t / h, specific power-consuming 2,7 ÷ 3,2 kW / t and final humidity of wastes 20 ÷ 25%.

For provision of optimal ratios between of working parameters of the process of vibro-blowing dehydration, design parameters of the equipment for its realization and physical-mechanical characteristics of the processed material there is need to research the process course, foundations of its fulfilment and connection with main efficiency parameters: productivity, power-consuming and final humidity of the processed material.

***Analysis of last researches and publications.*** There are many researches related with dehydration processes of damp dispersive materials.

Deformations and liquidity of damp dispersed materials during their mechanical processing, including dehydration, studies the relevant section of rheology developed in the works of E. Bibik [10], K. Guchkov, V. Pokrovsky. However, as it noted in [10], the creation of rheological models of the real systems should be approached with caution, because if one takes into account all or almost all properties of the material, the model may be unacceptably difficult for an analysis. But in the same time, if you do not take into account most material properties, the model will be incorrect [11].

By results of theoretical and experimental researches of P. Rebinder, solid particles of above designated damp dispersive wastes of the food industry are colloidal capillary-porous bodies [10], because after removal of liquid from them and compression, they are partially elastic, partially destroyed.

According to the classification of P. Rebinder, supplemented by M. Kazansky, all the liquid that contained in colloidal capillary-porous bodies, by the value of the binding energy $E$ can be divided on: free; capillary-connected (physical-mechanical connections); adsorption-connected (physical-chemical connections); chemically connected. The chemical connections are strongest, because molecules of chemically connected liquid are part of the solid phase and they can be removed only by chemical interactions or calcination. Physical-chemical connection, including osmotic interactions occurs between liquid and solid particles in direct mutual contact. At the same time, liquid molecules remain independent and isolated (although retained near solid molecules) and can be separated by evaporation, desorption or desadsorption [11]. Solid particles, absorbing this liquid, increase their size, but the volume of the swollen system $W_{n.s.}$ is less than the sum of the volumes of solid $W_t$ and liquid $W_p$ phases. The difference $\Delta W = W_t + W_p - W_{ns}$ is the value of compression (contraction) of the system. It is possible to remove adsorbed and osmotic liquid within hygroscopic humidity [10] using known mechanical dehydration methods in some cases [1], but this requires of significant energy and time [1]. As for the free liquid, as well as the liquid that has physical and mechanical connections with solid particles, its content in the considered materials over 65% of the total volume of the liquid phase and is separated quite efficiently [12].

The main rheological physical and mechanical characteristics of damp dispersed materials in the implementation of the processes of their mechanical dehydration include [12]: elasticity, ductility and viscosity. In addition, cohesion, adhesion and internal friction between material particles must be taken into account [11]. In this case, the firmness of solid particles is not taken into account, because their destruction during dehydration is highly undesirable. Firstly, it requires of additional power-consuming, and secondly, it complicates further filtering of the material. With regard to the state of the considered materials their hardness and brittleness are almost absent [13]. In dynamic processes, that are realized under impact of vibration and blows, the inertial properties of the processed material should also be taken into account [12].

In real damp dispersed materials in the process of their static or dynamic loading, the above indicated physical and mechanical characteristics are modeled with using combinations of Hooke, Newton and Saint-Venan elements, reflecting the elasticity, viscosity and plasticity of the material [11] (figure 1). The main models of complex structures built on the basis of simple elements are: Shvedov-Bingham's viscous-plastic model, Kelvin and Maxwell's elastic-viscous models, Bingham's elastic-viscous-plastic model, etc. [14].

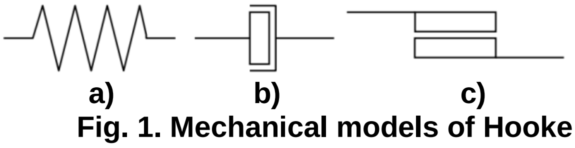
a) b) c)

**Fig. 1. Mechanical models of Hooke (a), Newton (b) and Saint-Venan (c)**

In some of these complex models simple rheological elements can be connected to each other in series and in parallel (figure 2) [14]. Simple rheological models without inertial elements, connected in series, act as links in one chain and therefore they should receive the same tension, while the deformation of the entire sequence of rheological elements will be equal to the sum of the deformations of each element. In parallel connection, simple rheological models without inertial elements perceive the same deformations,

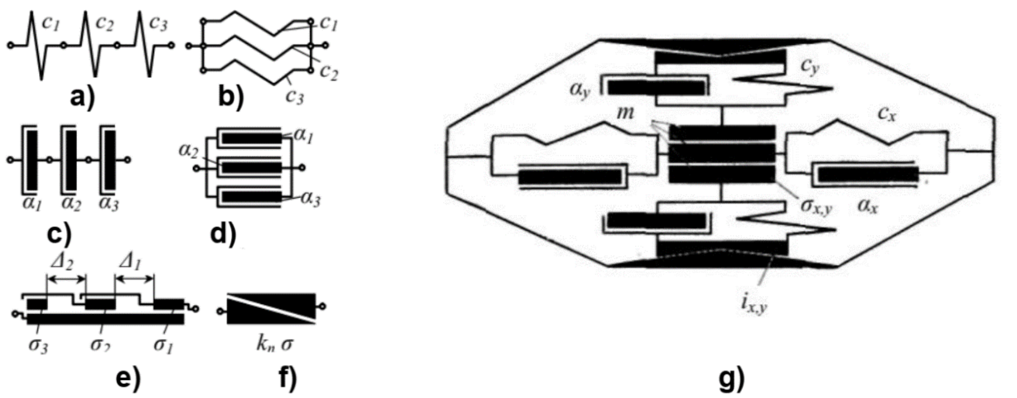

**Figure 2 - Serial and parallel connections of elastic (a, b), viscous (c, d) and plastic (e, f) elements; g - phenomenological mechanic-rheological model**

and the total tension perceived by their set is the sum of tensions perceived by each separate element [13]. Thus, the resulting elasticity in series and parallel connection of the elements (see Figure 2, a, b) is defined as [14]

$$c_\Sigma = \frac{1}{\frac{1}{c_1}+\frac{1}{c_2}+\frac{1}{c_3}}; c_\Sigma = c_1 + c_2 + c_3. \qquad (1)$$

In general, the considered materials are the most complex elastic-viscous-plastic-inertial rheological systems and can be described with using phenomenological mechanic-rheological models [14, 15]. An example of that model is presented on figure 2, g. There are designated: $c_x$, $c_x$ - elasticity coefficients of the processed material relative of the *x, y* axes; $\alpha_x$ , $\alpha_y$ - coefficients of viscous damping of the material relative of the *x, y* axes; $\sigma_{x,y}$ - yield strength of the material relative of the *x, y* axes; *m* - mass of the portion of material. The compaction of the material relative to the *x, y* axes is modeled by wedge elements and with help of the gear ratio $i_{x,y}$ [15].

Humidity $\varphi$ of the considered materials [12] is the ratio of the mass $m_l$ of the liquid phase contained in the portion of the material to the mass of the portion $m_p$

$$\varphi = \frac{m_l}{m_p} = \frac{m_l}{m_d} + m_d, \qquad (2)$$

where $m_d$ is the mass of the absolutely dry solid phase of the portion.

***Purpose formulation.*** The purpose of the work is to analyze known approaches to study of processing of dispersive materials (pressing, vibration and vibro-blowing loading), to examine a mechanism of fulfilment and efficiency of the process of vibro-blowing dehydration of damp dispersive materials in a closed press-form and to determine dependencies between designated efficiency parameters, working parameters of the dehydration process and physical-mechanical characteristics of processed material. Such analysis should carry out from positions of the mechanics, hydraulics and rheology of damp dispersive materials, separately for their solid and liquid phases and also for different stages of vibro-blowing loading. Elaborated calculating method will allow to create high effective equipment for vibro-blowing dehydration of damp dispersive materials with consideration of necessary characteristics of the working process and the processed material.

***Presentation of main material.*** The most important results of research of pressing processes are presented in [16]. In general, pressing is the mechanical processing of a material by its compression by external forces. As a result of the compression of the portion of the damp dispersed material, liquid phase is removed from it with a decrease in volume and mass of the portion. The efficiency of the process is determined by the completeness of the removal of the liquid phase, that depends on the optimal selection of load parameters and technological scheme of the equipment for its implementation.

A portion of the processed material with the volume *W* can be divided by height into three main layers [16]: the lower layer of solid particles with the volume $W_s$ and height $H_s$, the middle layer of liquid phase with the appropriate parameters ($W_l$ and $H_l$), as well as the higher gas layer ($W_g$, $H_g$). This presentation of the portion structure is, of course, very simplistic, because in fact it includes transition layers, moreover, after installation on top of the portion of the punch the gas phase partly goes out in atmosphere and partly distributed in liquid and solid layers of the portion; solid particles converge so much that molecular adhesion forces begin to act between them. By pressing, one can remove only that part of the liquid, which has with solid particles mechanical and structural connections. Liquid removal begins when external influences become more intense than the strength of these connections. The most part of the liquid is removed at the initial stage of pressing, then the intensity of removal decreases and stops completely.

In the general case, in course of pressing in the medium of the processed material, it is necessary to create a pressure that is greater than the capillary pressure $p_\sigma$ of the free portion liquid, which can be determined by the formula [17]

$$p_\sigma = \frac{2 \cdot \sigma_{12}}{r}, \qquad (3)$$

where $\sigma_{12}$ - coefficient of surface tension between the gas and liquid phases; $r$ - radius of capillaries in the particles and between the particles of the solid phase.

In the hygroscopic range, the force $F_c$ holding the liquid in the capillaries is calculated depending from the relative humidity $\varphi_n$, which corresponds to the equilibrium humidity of the material [17]

$$F_c = \frac{R \cdot T}{M_m} \varphi_n, \qquad (4)$$

where $R$ is the universal gas constant; $T$, $M_m$ - working temperature and molecular weight of the material.

The connection energy $E_c$ of the liquid with solid particles of the material in the hygroscopic range is a potential moisture transfer [17], that can be found by the formula [17]

$$E_c = -R \cdot T \cdot ln\varphi_n. \qquad (5)$$

In course of the pressing process in some parts of the internal volume of the portion there is a gradient of humidity and under its influence the liquid moves from volumes with higher humidity to more dehydrated areas [16].

Let us consider the dependences for determination of the pressure on the bottom of the press-form, pressure on the lower end surface of the punch, as well as the pressure distribution over the height of the press-form under using of the static pressing method.

The pressure at the lower end of the punch corresponds to the maximal pressure $p_m$ in the pressed material. It can be defined as the sum of two components: neutral $p_{nt}$ pressure, that depends from the pressure of the liquid, flowing from the press-form and the effective pressure $p_{ef}$, perceiving by the skeleton of solid particles. That is

$$p_m = p_{nt} + p_{ef}. \qquad (6)$$

As the material is compacted, the pressure $p_m$ increases due to the narrowing of the channels between of the solid particles and the increase in the resistance of their compression in the process of convergence of the mass centers. Therefore, the pressure $p_m$ is a function of the porosity of the material, which is characterized by the coefficient $\varepsilon_m$ [17].

The pressure $p_{nt}$ is determined by the resistance that the liquid overcomes when it passes through the channels between the solid particles (pressure $p_{nf}$), as well as through holes in the press-form, closed by a filter net (pressure $p_{n.v}$) [34]

$$p_{nt} = p_{nf} + p_{nv}. \qquad (7)$$

The velocity of liquid flow through the elementary cross section of solid particles in laminar mode can be determined by Darcy 's law

$$v_l = k_f J \frac{1+\varepsilon_m}{\varepsilon_m}, \qquad (8)$$

where $J = \frac{p_l/\rho_l + p_a/\rho_l}{g \cdot l_c}$ - hydraulic gradient - the ratio of the pressure difference between the liquid and atmospheric air to the length of the channel (obviously, $p_l$ will be maximal in the cross section of the contact of the material with the punch, while the value of $l_k$ depends on the size of the press-form); $k_f$ - filtration coefficient.

Since the outflow of liquid from the press-form occurs under atmospheric pressure in the environment, then $p_a = 0$. Then from equation (8) [17]

$$p_{nf} = p_l = \frac{v_l l_c \varepsilon_m}{k_f(1+\varepsilon_m)}. \qquad (9)$$

Then the dependence for determination of the neutral pressure is [16]

$$p_{np} = \frac{v_l l_c \varepsilon_m g \cdot \rho_l}{k_f(1+\varepsilon_m)} + p_{nv}. \qquad (10)$$

Equation (10) allows to determine only some basic operating parameters of the pressing process, including the neutral pressure and flow rate of the liquid removed from the portion of the processed material. Actually, there is a function of the porosity of the material's solid particles. And since the latter parameter is variable and decreases in the directions from the middle to the upper and lower layers of the portion, the flow rate over the height of the press-form decreases in these directions. In this case, the connection between the liquid flow rate and the porosity of solid particles is nonlinear (see equation (8)). Due to the continuous change of porosity and also physical and mechanical properties of the processed material in course of the pressing process, the coefficient $k_f$ will be different in various cross sections of the portion over its height. Also $k_f$ and gradient $J$ depend on the temperature and humidity of the processed material [18].

The theoretical foundations of vibration loading of damp dispersed materials in various processes of the food industry were mainly developed by I. Goncharevich and I. Uriev [15]. In particular, they found that for provision of higher efficiency of vibration processing (maximal productivity and minimal power-consuming) it is necessary during its implementation to increase the speed of separation of particles and accelerate their movement [15]. As a result, the material can be transferred into a state of liquidization or vibration boiling. Pseudo-liquefaction is a decrease in the resistance to deformation with a rapture of the connections between all particles, their continuous movement and some reduction in the volume of the layer [15]. Vibration boiling - reduction to a minimum of rheological resistance to deformation, complete destruction of the initial structure, mutual movement of particles with complete separation, achievement of maximal homogeneity of phase distribution and increasing of the layer volume.

According to [15], the main advantages of the method of vibration loading are: first, a possibility to transfer to a portion of the processed material of significant energy in a very short period of time and with minimal displacement of particles; secondly, the ability to adjust in a wide range of frequency and amplitude of vibration loading. The last allows to realize an efficient processing of both large volumes of material and layers with several micrometers thick.

Studies [15] have shown, that as a result of vibration loading of a portion of damp dispersed material, solid particles with the highest density and size move to the upper layers. In the same way, the authors found that increasing of the frequency or amplitude of the vibrating load provides an increase in the degree of compaction of solid particles only to a certain extent, and under high enough frequency or amplitude there is possible a loosening of the material. To prevent the latter, in course of increasing of vibration loading frequency, it is necessary to ensure an adequate reduction of the amplitude and vice versa [15].

The process of vibratory compaction of solid particles over time is uneven with decreasing productivity, due to the increase in the contact area of solid particles per unit of the volume [15].

With the rise of dimensions of solid particles of the processed material, the maximum possible degree of its compaction decreases. This brings to necessity of increase of the acceleration of the executive element of the equipment to maintain the efficiency of the process [15].

In case of high humidity of the processed material for provision of the maximum degree of compaction of solid particles, it is also necessary to increase their acceleration. In most processes, increasing the latter to the value of the free fall acceleration does not allow to achieve proper compaction, because the material passes only into a liquidization state. At the same time, increasing of the acceleration to values $> g$ leads to the conversion of the portion into the state of vibration boiling with loosening of its lower layers. That can be prevented with the use of a static pressing of the punch to the portion of material [15].

Also, with decreasing of layer thickness of the processed material, the value of accelerations of solid particles can be reduced up to the value of $g$ without reducing of their compaction degree [15].

Damping in the considered dispersed systems is a rather complex phenomenon and can occur as a result of mutual dry or hydrodynamic friction of solid particles, resistance to particles movement in liquid or gas phases, passage of the latter through solid phase pores, deformation of insufficiently elastic phases, different adhesion forces. An influence of the damping forces causes nonlinear effects in the system in course of its vibration loading and complicates its study. In practice, various methods are used to approximate real types of viscous damping. Some methods have been developed that allow to reduce complex nonlinear systems to simpler linear ones. In particular, using of the method of energy balance (an equation of the energy, that dissipated by the cycle due to real resistances to energy losses from viscous resistances), complex types of resistance can be reduced to viscous and elastic resistance. Thus, any multiphase dispersed systems, as well as patterns of their behavior under the influence of vibration can be modeled with using of standard elastic-viscous-plastic-inertial phenomenological models and methods of phenomenological rheology [15].

In liquid and gaseous highly dispersed systems, due to the large active interfacial surface, the free surface energy at the interface is increased, as well as the role of molecular forces of adhesion between the particles. As a result, there are appeared separate units of particles and spatial structures. In coarse-dispersive systems, there is no adhesion between the particles, but only frictional forces. Spatial structures do not arise in such systems. As a result, mass transfer processes are realized under impact of a low intensity vibration [15].

The forces of gravity and the forces of inertia, arising in the medium of the material, are summarized, as a result, it is turned out under the influence of periodic pulsating load transmitted by waves from the lower to the upper layers. In the process of this transmission, the load pulses are weakened. The degree of their attenuation depends on the properties of the material, as well as the intensity and nature of vibrations. In addition, the pulses are transmitted with a phase shift. The value of the shift can reach 180° for fine materials with poor gas permeability [15]. Rarefaction may occur during loading between the executive element of the vibrating equipment and the lower layer of the finely processed material adjacent to it [15].

The above-mentioned phenomenological models should also reflect the damping of oscillations of solid particles of the processed material during its vibration load, that stipulated by hysteresis losses. At the same time, these attenuations can be observed in materials with low hysteresis losses if impacts frequency is lower than the own frequency of the medium. In this case, exponential waves are created in the medium and the amplitude of these oscillations decreases exponentially as they move away from the oscillations source. So, to ensure deeper vibration processing of dispersed systems, it is necessary to increase the value impacts frequency above the lower frequency of the natural oscillations of the medium. Thus, for determination of energy consumption, it is necessary to use a rheological model that would take into account the variability of the amplitude of oscillations of the medium, as well as the fact that part of it may not participate in oscillations [15].

Then the equations of motion of the dispersed system under impact of vibrations in the direction of $x$ -axis and y-axis can be presented as [15]

$$\begin{aligned} q_y m_y \ddot{y} &= -q_y m_y \ddot{y}' - c_y y - \alpha_y \dot{y} - \alpha'_y(\dot{y}+\dot{y}') - \\ &-(1-q_x)m_x g - sign(\dot{y})\mu_x(1-q_x)m_x g; \\ q_x m_x \ddot{x} &= -q_x m_x \ddot{x}' - c_x x - \alpha_x \dot{x} - \alpha'_x(\dot{x}+\dot{x}') - \\ &-(1-q_x)m_x g - sign(\dot{x})\mu_x(1-q_y)m_y g, \end{aligned} \quad (11)$$

where $m_x$, $m_y$ - the total mass of the portion of the processed material; $q_x$, $q_y$ - coefficients that take into account the part of the total mass of the portion that is involved in fluctuations; $\mu_x$ - coefficient of dry friction in the direction of the $x$-axis.

The law of motion of the dispersed system under the influence of two-component harmonic oscillations with amplitudes $A_x$, $A_y$, circular frequency $\omega$ and phase shift $\gamma$ between component motions has an appearance [15]

$$\begin{aligned} x' &= A_x \sin\omega\cdot t; \dot{x}' = A_x\omega\cdot\cos\omega\cdot t; \\ y' &= A_y \sin(\omega\cdot t+\gamma); \dot{y}' = A_y\omega\cdot\cos(\omega\cdot t+\gamma). \end{aligned} \quad (12)$$

After substitution (11) into (12), fulfilment of linearization and transformation of the obtained equations, we can get dependences for determination of optimal vibration load parameters of the portion of the processed material, in particular for realization of the regime of vibration boiling [15].

The resonant-structural theory, developed by R. Iskovich-Lototsky [19], explains the mechanism of vibro-blowing loading of non-plastic powders on inertial vibro-press hammers with a hydraulic pulse drive, reveals their efficiency and allows to determine the optimal load parameters of the material based on its physical and mechanical characteristics.

On figure 3 the basic system of the bound structure of the blank in the container of the press-form is presented **-** a solid particle of powder material with mass $m_i$, which interacts with other immovable particles of the processed material that surround it. According to the experimentally proven resonance-structural theory [15], in the process of vibro-blowing pressing under inertial loading deformation or shaping due to increasing residual deformations in the blank. There is a discrete process, and the deformations value decreases with increasing of current density of the blank for each subsequent load cycle.

The high efficiency of the method of vibro-impact inertial pressing in the formation of blanks from non-plastic powder materials is due to the presence in each pulse of external forces transmitted from the lower executive element of the vibro-press to particles of the blank components in the form of a package $n$ of monoharmonic sinusoidal waves. The range of angular frequencies of the packet $\Delta\omega = \omega_n - \omega_1$ is wide enough and contains the angular frequencies of the particles of the blank material. The latter causes their oscillations in the field of resonance, and hence slipping and turning, with denser stacking and destruction of structural formations such as "arches" and "bridges". These oscillations are transmitted to the particles of the upper layers of the blank, thus, in the medium of the material there are created tangential and compressive stresses in the direction from the bottom of the press-form to the punch and vice versa. As a result, a uniform compaction of the processed material throughout the volume is provided, with minimal energy and time expenses [15]. Possible displacements of stress waves in the blank are determined by boundary conditions, by values of phase velocities $v_{fi}$ and impulses of external forces.

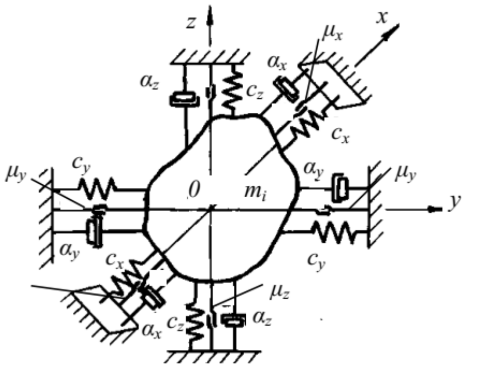

**Fig. 3. Basic system of the connected structure of the blank in the container of the press-form**

In the work [2] there is presented a mechanism of realization and efficiency of the processes vibro-blowing dehydration of damp dispersive materials in the closed press-form on the equipment with the hydraulic pulse drive. In particular, there were elaborated schemes of loading and movement of hard particles of the processed material in the press-form in course of four stages of a working cycle of the hydraulic pulse drive in an axial section and in a cross-section. There were proposed without inertia rheological models and equations of the damp dispersive material in course of the loading, that take in consideration elasticity and viscosity of hard and liquid phases of the material and also plasticity of its hard particles. Dynamical models of movement of hard and liquid particles of the processed material are presented on the fig. 4 [2]. On the model of the hard particle is taken into account a decrease of its mass $m_m$ that caused by an impact of the buoyancy Archimedean force.

On a basis of the models (fig. 4) and elaborated schemes of vibro-loading of hard and liquid particles of the processed material there were created mathematic models of the vibro-blowing dehydration process, that consisted of differential equation of movement and interaction of hard and liquid particles of the processed material and executive elements of the vibro-press in course of four stages of functioning of its hydraulic pulse drive. The equation and formulas of the mathematic models connect working parameters of the dehydration process (pressure in the medium of processed material in the press-form, amplitude and frequency of its fluctuations), physical-mechanical characteristics of the material (see fig. 4) and main parameters of dehydration efficiency (productivity by the removed liquid phase, power-consuming and final humidity of the material). The proposed in the work [1] schemes and models are quite complex and unsuitable for creation of a method of engineer design calculation of the processes and equipment for vibro-blowing dehydration of damp dispersive materials in the closed press-form.

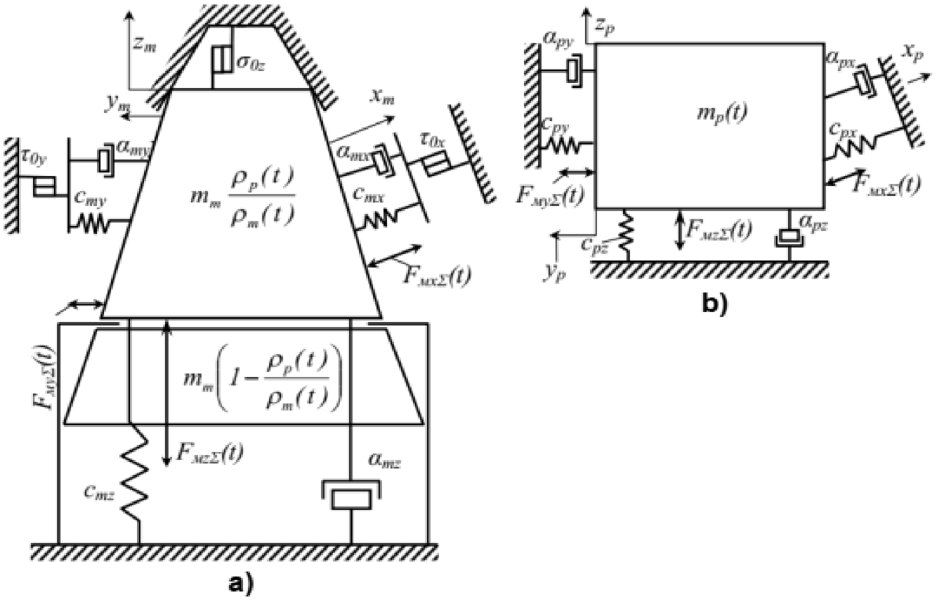

**Figure 4 - Dynamic models of particle motion of solid (a) and liquid (b) phases of the portion of damp dispersed material in the course of its preliminary vibro-shock dehydration in the closed press-form****Figure 4 - Dynamic models of particle motion of solid (a) and liquid (b) phases of the portion of damp dispersed material in the course of its preliminary vibro-shock dehydration in the closed press-form**

Let us examine with consideration of the results of the previous researches a course and foundations of efficiency of vibro-blowing dehydration processes.

There are schemes of movements of solid particles of the processed material under impact of its vibro-blowing loading in the closed press-form presented on the fig. 5. The working process is realized on the equipment with the hydraulic pulse drive [2, 7, 20] with a generator impulses of pressure “on the exit” [19].

In course of a working cycle of the vibro-press dehydration installation the punch 1 (upper executive element), connected with a cylinder of the hydraulic drive makes a continuous vertical movement downwards, providing its static loading, as the press-form 2 with the portion of the processed material (lower executive element), connected with a cylinder of the hydraulic pulse drive carries out periodic vertical reciprocal movements with amplitude up to 4 mm and frequency to 150 Hz [19], creating inertia vibro-blowing loading of the material. A working cycle of the vibro-press dehydration installation [2, 7, 19, 20] with the generator impulses of pressure “on the exit” can be separated at two stages:

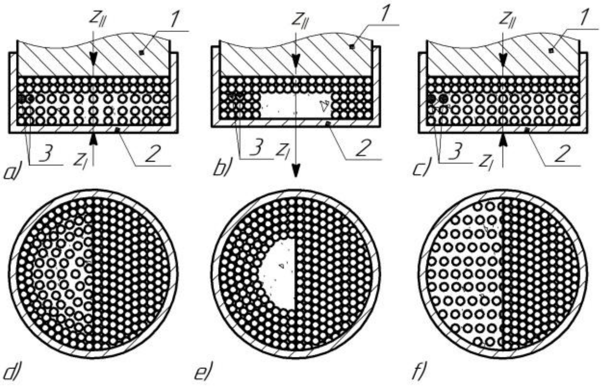

**Fig. 5. Schemes of movements of solid particles of the processed material under impact of its vibro-blowing loading in the closed press-form at the I stage (a, d) and at the II stage (b, c, d, e) of the working cycle of the hydraulic pulse drive in the axial section (a, b, c) and in the cross-section (d, e, f) of the press-form:**
**1 – punch; 2 - press-form; 3 – solid particles of the processed material**

I stage – movement of the press-form 2 with the portion of the processed material from the initial low position in the upper position (see fig. 5, a, d);

II stage – movement of the press-form 2 with the portion of the processed material from the upper position in the initial low position (see fig. 5, b, c, d, e).

At the I stage in the axial section in course of the press-form movement $z_I$ to upper position (see fig. 5, a) the solid particles of the material, contacting with the press-form’s bottom, draw together. As a result, channel’s cross-sections between the particles are decreased, with pressing from them of liquid phase. The removing liquid moves partly in a direction of the vertical axle of the press-form (see fig. 5, d) and partly it is flown out through holes in walls and bottom of the press-form, that closed from inside by a filtering net (the holes and the net are not shown at the scheme). At the same time the punch 1 makes slow movement $z_{II}$ downwards. The solid particles, contacting with the punch 1 are tightly compressed and move together in correspondence with the volume of liquid removed from the press-form.

In the very beginning of the II stage of the hydraulic pulse drive’s working cycle the solid particles of upper layers of the processed material in the axial section (fig. 5, b) are compressed to the punch 1. In the upper cross-section the particles are evenly distributed between internal surfaces of the press-form with tight mutual contacts (see right part of the fig. 5, e). In middle and lower layers of the portion in its axial section the solid particles make a tight ring along of internal surfaces of the press-form (fig. 5, b, e) and in course of the II stage they will move downwards and to the vertical axle of the press-form. The stage entails with decrease of pressure and relaxation of internal tensions in middle and lower layers of the portion with even overdistribution of the particles. Removal of the liquid phase at this stage is less intensive then in course of the I stage and is provided mainly by loading from the punch 1 (fig. 5, c, f).

By our notion, efficiency of the method vibro-blowing dehydration in the closed press-form is provided at the expense of periodical high frequency loading and unloading of particles of the processed material in course of realization of the working process. Unlike of static dehydration on a hydraulic press under using of the examined method dispersed material in the press-form is loaded from two sides. There is provided a more even loading in the axial section. Besides, in course of press-form movement in the lower position the processed material is unloaded from the impact of vertical forces. This creates conditions for even overdistribution of material’s solid particles in the press-form volume with more tight setting in comparison with previous cycles of vibro-blowing loading. A periodical levelling of tensions and loading in the portion decreases resistance for further punch movement downwards and allows to remove liquid from the processed material with higher productivity. Vibrations and blows in the medium of the dispersed material create conditions for effective destruction of structural mechanical and adsorption connections between solid and liquid particles of the processed material. This also promotes to intensification of the working process.

Let as determine dependencies between main efficiency parameters of vibro-blowing dehydration in the closed press-form, working parameters of the process and physical-mechanical characteristics of processed material. These dependencies will give to us a possibility to define optimal values of loading parameters for provision of the necessary efficiency indicators. The main vibro-loading parameters are [1]: the pressure $p_m(t)$ in the medium of the processed material in the press-form in course of a working cycle, amplitude $z_{Ia}$ and frequency $v$ of fluctuations of the press-form.

An analysis of diagrams of movements of executive elements of vibro-presses with the hydraulic pulse drive, that equipped with a generator pressure impulses “on the exit” allows to us to consider motion of the press-form at the I stage of a working cycle as uniform [19], especially under high frequencies of fluctuations of the executive element. So, the middle speed of the motion can be determined as

$$v_I = \frac{Q_p}{S_{pI}}, \tag{13}$$

where $Q_p$ – feeding from the pump of the hydraulic pulse drive (we can change $Q_p$ with help of a throttle, that installed in a control cavity of the drive's generator pressure impulses [19]; $S_{pI}$ - cross-section area of a hydraulic cylinder of the hydraulic pulse drive.

Then the amplitude $z_{Ia}$ we can determine from the equation

$$p_1 S_{pI} = c_p\left(z_{Ia} + z_p\right) + R_I + m_I g, \tag{14}$$

where $p_1$ – maximal pressure of working liquid in the cavity of the cylinder of the hydraulic pulse drive (it can be changed with help of the generator pressure impulses [19]); $c_p$ – coefficient of elasticity of springs for return of the press-form with portion of processed material in the initial position in course of the II stage [19]; $z_p$ – previous compression of the springs; $R_I$ – force of dry friction in course of movement of plunger or piston of the cylinder of the hydraulic pulse drive (in accordance with results of calculations and experiments [19] one can consider, that $R_I = 0,1\cdot p_1 S_{pI}$); $m_I$- mass of the lower executive element of the vibro-press, with consideration of masses of connected elements (plunger or piston of the cylinder of the hydraulic pulse drive, press-form and portion of the processed material [2, 19]).

From the equation (14) we can find

$$z_{Ia} = \frac{0,9\cdot p_1 S_{pI} - c_p z_p - m_I g}{c_p}. \tag{15}$$

For calculation of the duration $t_I$ of the I stage one can use the known formula [20]

$$\frac{\Delta V}{V} = -\frac{\Delta p}{K}, \tag{16}$$

where $\Delta V$ – change of volume of working liquid in the system of the hydraulic pulse drive in course of the I stage; $V$ – initial volume of the system in the very beginning of the I stage; $\Delta p$ - change of pressure of working liquid in the system of the hydraulic pulse drive in course of the I stage; $K$ – modulus of volume elasticity of the working liquid. From the formula (16) we can get

$$\Delta V = \frac{Q_p}{t_I} - S_{pI} z_{Ia} = \frac{\Delta p\cdot V}{K} = \frac{(p_1 - p_2)\cdot V}{K}, \tag{17}$$

where $p_2$ – minimal pressure of working liquid in the cavity of the cylinder of the hydraulic pulse drive [19]. Then, from the formula (17)

$$t_I = \frac{Q_p}{\frac{(p_1 - p_2)\cdot V}{K} + S_{pI} z_{Ia}}. \tag{18}$$

For definition of the duration of the II stage - $t_{II}$ there is need to draw up the corresponding equation of movement for the mass $m_I$

$$m_I a_I = \mathrm{g}(m_I + m_{II}) + \\ + c_p\left(z_{Ia} + z_p\right) + 0,9\cdot p_2 S_{pI} + 0,9\cdot p_h S_{pII}, \tag{19}$$

where $a_I$ – acceleration of the $m_I$; $m_{II}$- mass of the upper executive element of the vibro-press, with consideration of masses of connected elements (cross-arm with inertia loads, piston and rod of an auxiliary hydraulic cylinder of the vibro-press, providing static clamp of the punch to the portion of the processed material [2, 19]); $S_{pII}$ - cross-section area of the piston of the auxiliary hydraulic cylinder; $p_h$ - pressure of the working liquid in its cavity. In the equation (19) the coefficient 0,9 takes into account an impact of the friction forces in the compactions of the cylinders of hydraulic pulse drive and auxiliary drive of the vibro-press (see above).

From the equation (19) we can find $a_I$ and after that one should calculate $t_{II}$ by the formula

$$t_{II} = \sqrt{\frac{2\cdot z_{Ia}}{a_I}}. \tag{20}$$

All this allow to us to define a duration of the period of fluctuations – $T$ of the lower executive element of the vibro-press and frequency of the fluctuations – $\nu$:

$$T = t_I + t_{II};\quad \nu = \frac{1}{T}. \tag{21}$$

The maximal pressure $p_{mImax}$ in the medium of the processed material in the press-form in course of the I stage one can determine as

$$p_{mImax} = \begin{bmatrix} 0,9\cdot p_1 S_{pI} - c_p\left(z_{Ia} + z_p\right) - \\ -m_I(g + a_I) + \\ +0,9\cdot p_h S_{pII} + m_{II} g \end{bmatrix} \Big/ S_{pf}, \tag{22}$$

where $S_{pf}$ – cross-section area of an internal cavity of the press-form.

The minimal pressure in the medium of the processed material in the press-form in course of the I stage: $p_{mImin} = 0$. Then with consideration of linear character of change of pressure of working liquid in the cylinder chamber of the hydraulic pulse drive with the generator impulses of pressure "on the exit" (see above), we can assume, that the pressure in the medium of the processed material in course of the I stage also increases linearly from $p_{mImin}$ up to $p_{mImax}$. So, the middle pressure in the middle of the processed material at this stage

$$p_{mI} = (p_{mImax} + p_{mImin})/2 = \frac{p_{mImax}}{2}. \tag{23}$$

In course of the II stage of a cycle as a result of unloading of lower layers of the portion in the press-form the constant pressure in its medium is created by the punch. Approximate value of this pressure one can calculate by the equation

$$p_{mII} = \frac{0,9\cdot p_h S_{pII} + m_{II} g}{S_{pf}}. \tag{24}$$

The volume of removed liquid phase from the portion of the processed material in the press-form in course of an *i*-cycle of the vibro-blowing loading) can be calculated with help of formula [1]

$$V_{l.i} = \frac{\pi\cdot p_m T\cdot r_i^4 s_{is} z_i}{8\cdot\mu\cdot l_i}, \tag{25}$$

where $r_i$, $l_i$ – middle radius and length of capillaries between of solid particles of the material in course of an *i*-cycle; $p_m$- pressure in the medium of the processed material, that provides removal of the liquid; $S_{is}$ – area of an internal surface of the press-form with opening and filtering net, that provides diversion of removed liquid phase; $z_i$ – middle number of the capillaries in unit of volume of the material in the press-form; $\mu$ - coefficient of dynamic viscosity of the liquid.

For using of the formula (25) there is need by an experimental method determine a change of $r_i$, $l_i$, $z_i$ depending from humidity $\varphi$ of the processed material.

With provision of this data, the volume of removed liquid phase from the portion in course of the I and II stages of an *i*-cycle of dehydration is

$$V_{l.iI} = \frac{\pi \cdot p_{mI} t_I r(\varphi_{i-1})^4 S_{is} z(\varphi_{i-1})}{8 \cdot \mu \cdot l(\varphi_{i-1})};$$

$$V_{l.iII} = \frac{\pi \cdot p_{mII} t_{II} r(\varphi_{i-1})^4 S_{is} z(\varphi_{i-1})}{8 \cdot \mu \cdot l(\varphi_{i-1})}, \qquad (26)$$

where $t_I$, $t_{II}$, $p_{mI}, p_{mII}$ are determined by formulas (18, 20, 23, 24); $r(\varphi_{i-1}), l(\varphi_{i-1}), z(\varphi_{i-1})$ - middle radius and length of a capillary and middle number of the capillaries in unit of the volume, depending from humidity $\varphi$ in course of the *i-1*-cycle (previous cycle). For the I cycle of the dehydration these parameters are determined from the initial humidity of the processed material.

Then the middle productivity of the of vibro-blowing dehydration in course of an *i*-cycle of vibro-blowing dehydration can be found as

$$Q_{d.i} = \frac{V_{l.iI} + V_{l.iII}}{T}. \qquad (27)$$

Humidity of the processed material after an *i*-cycle of its vibro-blowing dehydration as

$$\varphi_i = \frac{\rho_l (V_{l.i-1I} + V_{l.i-1II})}{\rho_l (V_{l.i-1I} + V_{l.i-1II}) + m_s}, \qquad (28)$$

where $V_{l.i-1I}, V_{l.i-1II}$ – volumes of delated liquid phase from the portion of the processed material in course of the I and II stages of the previous *i – 1*-cycle of vibro-blowing dehydration, determined by the formulas (26); $\rho_l$ - density of liquid phase of the processed material; $m_s$- mass of absolutely dry solid phase of the portion. For calculation of the $\varphi_1$ for the first cycle of vibro-loading in the formula (28) one should set the initial parameters of the processed material.

Dependencies $r(\varphi), l(\varphi), z(\varphi)$ - are quite different for free, capillary-connected and adsorption-connected liquid of the same portion of the processed material, because, as it pointed out in the work [21] the free liquid is located in channels between of solid particles, capillary-connected liquid – in channels inside of the solid particles and adsorption-connected liquid – inside of channels walls of the solid particles.

The dependencies $r(\varphi), l(\varphi), z(\varphi)$ can differ for various damp dispersive materials, therefore for their receipt there are need additional experimental researches. Besides, it is necessary data about of content in the concrete processed material free, capillary-connected and adsorption-connected liquid – $W_f$, $W_c$, $W_a$.

The condition for setting in the formulas (26) data from dependencies $r(\varphi), l(\varphi), z(\varphi)$ for free liquid has the appearance

$$\rho_l \sum_{i=1}^{f} (V_{l.iI} + V_{l.iII}) = m_p \varphi_p W_f, \qquad (29)$$

where $m_p, \varphi_p$ – initial mass of the portion of the processed material and its humidity; *f* – the number of cycles of the vibro-blowing loading, providing removal of necessary quantity of liquid.

Analogical conditions for setting in the formulas (26) data from dependencies $r(\varphi), l(\varphi), z(\varphi)$ for capillary-connected and adsorption-connected liquid can be presented as

$$\rho_l \sum_{i=f+1}^{c} (V_{l.iI} + V_{l.iII}) = m_p \varphi_p W_c;$$

$$\rho_l \sum_{i=c+1}^{a} (V_{l.iI} + V_{l.iII}) = m_p \varphi_p W_a, \qquad (30)$$

where *c*, *a* – number of cycles of the vibro-blowing loading, providing removal of all capillary-connected and adsorption-connected liquid.

Then the number of cycles of the vibro-blowing loading for achievement of the necessary final humidity $\varphi_f$ of the processed material is determined by the formula

$$\rho_l \sum_{i=1}^{n} (V_{l.iI} + V_{l.iII}) = m_p \varphi_f, \qquad (31)$$

where *n* – corresponding number of the cycles of vibro-blowing loading for getting $\varphi_f$ .

Duration of the all working process of vibro-blowing dehydration of one portion of the processed material is

$$T_\Sigma = n \cdot T + T_h = n \cdot \frac{1}{\nu} + T_h, \qquad (32)$$

where $T_h$ – auxiliary time for loading and unloading of the press-form after dehydration.

And the middle productivity of the vibro-blowing dehydration by removed liquid is

$$Q_{d\Sigma l} = \frac{m_p \varphi_f}{T_\Sigma \rho_l}. \qquad (33)$$

Middle productivity of the vibro-blowing dehydration by processed material is

$$Q_{d\Sigma m} = \frac{m_p}{T_\Sigma}. \qquad (34)$$

Power inputs in course of a cycle of the vibro-blowing dehydration we can find as

$$A_d = 0{,}5 \cdot Q_p t_I \eta_{dm} (p_1 + p_2) +$$

$$+ Q_p t_{II} \eta_{dm} p_d + Q_h T \cdot \eta_{dh} p_h, \qquad (35)$$

where $p_d$ - the pressure of the working liquid in a discharge line of the hydraulic pulse drive [2, 19]; $Q_h$ - nominal flow of the pump of the auxiliary hydraulic drive; $\eta_{dm}, \eta_{dh}$ – coefficients of efficiency of the hydraulic pulse drive and the auxiliary hydraulic drive of the using equipment for vibro-blowing dehydration

$$\eta_{dm} = \eta_{dh} = \eta_p \cdot \eta_m \cdot \eta_c, \qquad (36)$$

where $\eta_p$; $\eta_m$; $\eta_c$ – coefficients of efficiency of a gear pump; three-phase electric motor and coupling in the hydraulic pulse drive and in the auxiliary hydraulic drive of the installation.

Power inputs for dehydration of one portion one can calculate by the formula

$$A_{d\Sigma} = A_d \cdot n + Q_h T_h \eta_{dh} p_h. \qquad (37)$$

And middle power consuming of vibro-blowing dehydration we can find as

$$C_d = \frac{A_{d\Sigma}}{T_\Sigma m_p \varphi_f}. \qquad (38)$$

***Conclusions.*** 1. There were analyzed the main rheological properties of damp dispersive materials, their rheological models and the results of previous researches of processes of static pressing, vibration and vibro-blowing loading of damp and dry dispersive materials in this work.

2. These data were used for determination of a mechanism of fulfilment and efficiency of processes of vibro-blowing dehydration of damp dispersive materials in a closed press-form on an equipment with the hydraulic pulse drive. In particular there were elaborated schemes of movements of solid particles of the processed material under impact of the vibro-blowing loading at two main stages of a working cycle of the hydraulic pulse drive in an axial section and in a cross-section of the press-form.

3. There were received formulas and equations that connect main efficiency parameters (productivity of the dehydration, power-consuming and final humidity of the processed material), parameters of the working process, design parameters of the equipment and physical mechanical characteristics of the processed material. These formulas and equations allow to determine optimal working parameters of the vibro-blowing dehydration processes of damp dispersive materials depending from given efficiency indicators and can be used as a base for elaboration of an engineering method of projecting of high effective equipment with the hydraulic pulse drive for the vibro-blowing dehydration of damp dispersive materials.

### *References*

1. Cherevko, O. I., Poperechny, A. M. (2014) *Procesy i aparaty harchovyh vyrobnycztv [Processes and apparatuses of food productions]* Harkiv: Svit Knyg [in Ukrainian].

2. Sevostianov, I. V. (2020) *Tekhnolohiia ta obladnannia dlia vibroudarnoho znevodnennia volohykh dyspersnykh materialiv : monohrafiia [Technology and equipment for vibro-blowing dehydration of damp dispersive materials : monograph]* Vinnytsia: VNAU [in Ukrainian].

3. Biletskyi, V.S., Oliinyk, T.A., Smyrnov, V.O., Skliar, L.V. (2019) *Tekhnika ta tekhnolohiia zbahachennia korysnykh kopalyn. Chastyna III. Zakliuchni protsesy. [Technique and technology mineral enrichment. Part III. Final processes].* Kryvyi Rih: Kryvorizkyi natsionalnyi universytet [in Ukrainian].

4. Zamizkyi, O., Omelchuk, D. (2018) *Analiz isnuyuchykh sposobiv sushky tonkodyspersnykh materialiv [Analysis of existing methods of drying fine materials].* Hirnychyy visnyk, 103, 191-197 [in Ukrainian].

5. Bogdanov, A. (2016) *Tekhnologiya mekhanicheskogo obezvozhivaniya. Monografia [Mechanical dewatering technology. Monograph]. Dnepropetrovsk: NGU* [in Russian].

6. Gosovsky, R. (2018) *Zakonomirnosti filtratsiinoho sushinnia orhanichnoi syrovyny dlia vyhotovlennia alternatyvnoho palyva [Regularities of filtering drying of organic raw materials for manufacturing of alternative fuel]*. Dissertation of candidate of technical sciences. Lviv: National University “Lvivska Politehnica” [in Ukrainian].

7. Sevostianov, I. V. Polishchuk, O. V., Slabkyi, A. V. (2015) *Rozrobka ta doslidzhennia ustanovky dlia dvokomponentnoho vibroudarnoho znevodnennia vidkhodiv kharchovykh vyrobnytstv [Elaboration and research of installation for two-component vibro-blowing dehydration of food productions waste]*, 5/7 (77), 40 - 46 Vostochno-evropeiskyi zhurnal peredovykh tekhnolohyi [in Ukrainian].

8. Kaletnik H., Sevostianov I., Bulgakov V., Holovach I., Melnik V., Ihnatiev Ye, Olt J. Development and examination of high-performance liquidisedbed vibration drier for processing food production waste. *Agronomy Research.* 18(4), 2020. P. 2391-2409.

9. Bulgakov V., Sevostianov I., Kaletnik G., Babyn I., Ivanovs S., Holovach I., Ihnatiev Y. Theoretical Studies of the Vibration Process of the Dryer for Waste of Food. *Rural sustainability research* 44(339), 2020.

10. Bibik E. E. (1991) *Reologiya dispersnyh system [Rheology of dispersive systems]* Leningrad: Edition of LGU [in Russian].

11. Heldman, D. R., Singh, R. P. (2011) *Food Process Engineering. Westport*, CT: AVI Publishing.

12. Sherman P. (2009) *Food Texture and Rheology*. NY.: Academic Press.

13. Bistany, K. L., Kokini, J. L. (2002) Dynamic viscoelastic properties of foods in texture control. *J. Rheol*, No. 27, 605-620.

14. Steffe, J. F. (2012) *Rheological Methods in Food Process Engineering*. East Lansing, MI: Freeman Press.

15. Goncharevich I. F. Ur'ev I. B., Talejsnik M. A. (1998) *Vibracionnaja tehnika v pishhevoj promyshlennosti [Vibration technique in the food industry]*. Moscow: Pishhevaja promyshlennost [in Russian].

16. Sokolov A. (2001) *Pressy pishhevyh i kormovyh proizvodstv [Presses for food and fodder productions]*. Moscow: Mashinostroenie

17. Lykov, A. V. (2006) *Teorija sushki [Drying theory]*. Moscow: Jenergija [in Russian].

18. Kokini, J. L. (2012) Rheological properties of foods. Handbook of Food Engineering/ Heldman D. R. and Lund D. B. (eds.). NY.: Marcel Dekker, 1-39.

19. Iskovych-Lototskyi (2006) *Osnovy teorii rozrahunku processive ta obladnannya dlya vibroudarnoho pressuvannya. Monografiya [Foudations of calculation theory and elaboration of processes and equipment for vibro-blowing pressing. Monograph]*. Vinnytsia: UNIVERSUM-Vinnytsia [in Ukrainian].

20. Bashta, T. M., Nekrasov, B. B. (1982) Gidravlika, gidromashiny i gidroprivody [Hydraulic, hydraulic machines and hydraulic drives]. *Moscow: Mashinostroenie* [in Russian].

21. Sevostianov, I. V. (2021) *Processy ta obladnannia dlia vibroudarnoho filtruvannia volohykh dyspersnykh seredovisch : monohrafiia [Processes and equipment for vibro-blowing filtering of damp dispersive mediums : monograph]* Vinnytsia: VNAU [in Ukrainian].

## РОЗРОБКА ПРОЦЕСІВ ВІБРОУДАРНОГО ЗНЕВОДНЕННЯ ВОЛОГИХ ДИСПЕРСНИХ МАТЕРІАЛІВ У ПРЕС-ФОРМІ ЗАКРИТОГО ТИПУ

Завдання підвищення ефективності процесів зневоднення вологих дисперсних матеріалів є актуальним для низки галузей харчових та переробних виробництв. Зокрема, до цих процесів належить переробка вологих дисперсних відходів (спиртової барди, пивної дробини, бурякового жому, кавового та ячмінного шламу). При зниженні їх вологості до 20 - 25% тверда фаза відходів може бути використана як цінна добавка до сільськогосподарських кормів або в якості висококалорійного палива. Це дозволяє вирішити проблеми утилізації відходів та захисту навколишнього середовища. Результати раніше проведених експериментів та розрахунків демонструють високу ефективність методу віброударного навантаження в прес-формі закритого типу для зневоднення відходів харчових виробництв (спиртової барди, пивної дробини та кавового шламу), що забезпечує продуктивність видалення рідкої фази до 20 ÷ 25 т/год, енергоємність 2,7 ÷ 3,2 кВт/т та кінцеву вологість відходів 20 ÷ 25%. Мета статті - проаналізувати відомі підходи до дослідження процесів обробки дисперсних матеріалів (пресування, вібраційного та віброударного навантаження), розглянути механізм здійснення та ефективності процесу віброударного зневоднення вологих дисперсних матеріалів у прес-формі закритого типу та встановити залежності між заданими параметрами ефективності, робочими параметрами процесу та фізико-механічними характеристиками матеріалу, що переробляється. Такий аналіз слід проводити з позицій механіки, гідравліки та реології вологих дисперсних матеріалів, окремо для їх твердої та рідкої фаз, а також для різних стадій віброударного навантаження. Розроблена розрахункова методика дозволить створити високоефективне обладнання для віброударного зневоднення вологих дисперсних матеріалів з урахуванням необхідних характеристик робочого процесу та матеріалу, що обробляється.

***Ключові слова:*** зневоднення, прес-форма закритого типу, вологі дисперсні матеріали, амплітуда, частота, тиск, динамічна та математична моделі.

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