# DETERMINATION OF OPTIMAL DESIGN AND WORKING PARAMETERS OF A VIBRO-PRESS FOR DEHYDRATION OF DAMP DISPERSIVE WASTES OF FOOD INDUSTRY

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*Vibro-pressing equipment its one from most effective kinds of machines for dehydration of damp dispersive wastes of food industry (alcoholic bard, beer pellets, beet press, coffee and barley slime) for their further using as valuable additives to agricultural fodders or as fuel. In comparison with other equipment for mechanical dehydration (hydraulic, belt and screw presses, centrifuges) vibro-presses with hydraulic pulse, unbalanced or electromagnetic drive provide the same or higher productivity (20 ÷ 25 t / h) and energy efficiency (2,7 ÷ 3,2 kW / t) under lower final humidity of processed wastes (20 ÷ 25% against 70 – 76% - in case of realization of other mechanical methods). The last advantage allows do not conduct an additional drying of the wastes and that provides significant decrease of general power consuming of the working process. For provision of high efficiency parameters of the vibro-blowing dehydration there is need to provide optimal values of working and design parameters of the equipment for their realization. There are several approaches for research of the vibro-press equipment. The approaches that realized with help of differential equations of movement of the machine's executive elements or differential equations of balances their energy provide high accuracy of calculations but because of complexity of these equations they are unsuitable for creation of a method of engineering design calculation of the machines. In the article are proposed algebraic equations and formulas for definition of optimal parameters of the vibro-pressing equipment for dehydration of damp dispersive wastes of food industry for realization of given parameters of efficiency and with consideration of initial and final physical-mechanical characteristics of the processed waste. There are conducted calculated diagrams of these parameters.*

*Key words: dehydration, vibro-press, damp dispersive waste, optimal working and design parameters, productivity, energy efficiency, final humidity.*
*F. 18. Fig. 4. Ref. 13.*

## 1. Problem formulation

An actual problem of enterprises of processing and food industry is utilization of damp dispersive wastes of these productions (alcoholic bard, beer pellets, beet press, coffee and barley slime) for their further using as valuable additives to agricultural fodders or as fuel. Modern enterprises of the food industry use several main technologies of utilization of these wastes [1]. The first group of the technologies is realized on basis of biological methods of utilization – processing of the waste into nutrient yeast, biogas or realizing of proteins coagulation [1]. These processes demand of significant capital outlays for creation of bulky and expensive installations (actually there are multi-corpse technological complexes with quite low specific productivity that demand of additional significant costs of electric energy, water, steam, chemical reagents, organic fuels). Actually, creation and introduction of such complexes can afford only large and powerful enterprises. The second group of the known dehydration technologies is fulfilled on basis of mechanical dehydration methods – pressing and centrifugation, that do not provide low enough humidity of the processed wastes and this leads to necessity of conducting of their additional thermal dehydration with help of power-hungry machines (energy cost in case of using of most effective vacuum drier is 740 – 760 kW h / t dehydrated liquid [1]).

By results of calculations and experiments a vibro-pressing equipment is one from most effective kinds of the machines for dehydration of damp dispersive wastes of food industry. In comparison with other equipment for mechanical dehydration (static hydraulic presses, belt and screw presses, decunter centrifuges) vibro-presses with hydraulic pulse, unbalanced or electromagnetic drive provide the same or higher productivity (20 ÷ 25 t of dehydrated waste / h) and energy efficiency (2,7 ÷ 3,2 kW / t) under significantly lower final humidity of processed wastes (20 ÷ 25% against 70 – 76% in case of realization of other mechanical dehydration methods). The last advantage allows do not conduct of an additional drying of the wastes in most technologies of processing and that provides significant decrease of general power consuming for the working process.

For provision of high efficiency parameters of the vibro-blowing dehydration there is need to select optimal values of working and design parameters of the equipment for its realization with consideration of physical-mechanical characteristics of the processed material. This actual task can be resolved on basis of

results of mathematic modelling of the processes and equipment for the vibro-blowing dehydration of damp dispersive wastes of the food industry.

## 2. Analysis of last researches and publications

There are several approaches for research of the vibro-press equipment. An approach that is based on drawing up of differential equations of movement of executive elements of the equipment, presented in the works [2, 3]. There are examined machines for vibro-blowing formation of blanks from metallic and non-metallic powder materials. The materials by physical and structural-mechanical properties [4] are simpler than the damp dispersive wastes of the food industry [1]. The machines are researched with using of some well founded admissions and nonlinear differential equations that can be resolved with help of numeral methods and computers. Methods of design calculation of the machines, the created on the base of these equations for definition of their optimal working and constructive parameters are quite complex and can't be used in course of previous stages of projection for evaluation of efficiency of possible variants of the equipment and selection of a most rational variant.

In the work [1] is realized one more approach, based on the use of differential equations of energy balances of executive elements of a vibro-pressing equipment for dehydration of damp dispersive wastes of food industry. The approach allows to take into consideration all factors and parameters that determine course of the working process, in particular physical and structural-mechanical properties of the processed material. Because of significant complexity of a mechanism of the vibro-blowing dehydration and design of the equipment for its realization the research of the working process is conducted separately for each phase of the processed material and for each stage of the vibro-blowing loading. As a result there were received differential equations of energy balances providing high accuracy of calculations, but because of complexity of these equations they are unsuitable for creation of the method of engineering design calculation of the vibro-blowing dehydration machines.

Results of experimental researches of a combined method of dehydration with using of internal sources of heat in conditions of electric heating in comparison with known methods of thermal dehydration are presented in the work [5]. One more work [6] connected with experimental researches of efficiency indicators for improved belt and tunnel dryers. But there are absent methods of design calculation of the presented equipment.

The work [7] contains data about conducted experimental and theoretical researches of a filtration drying of grinded sunflower stocks. The author has presented equations and formulas for definitions of coefficients of heat- and mass-emission, dependencies for determination of optimal temperature and duration of heating, other kinetic parameters of researched process, but a method of design calculation of the equipment for its fulfilment is absent in the work.

In the work [8] are presented results of experimental and theoretical studies of thermal dehydration of damp dispersive materials with using of a shelved dryer. There are conducted equations and dependencies for definition of kinetic and dynamic parameters of the working process, but they can't be used as a base for elaboration of a method of design calculation of the corresponding drying equipment.

## 3. Aim of the researches

The aim of this work is elaboration algebraic equations and formulas for definition of optimal design and working parameters of the vibro-pressing equipment for dehydration of damp dispersive wastes of food industry for realization of given efficiency parameters (dehydration productivity, power consuming, final humidity of the processed material). These equations and formulas will allow to receipt diagrams of dependencies of characteristics of dehydration efficiency from parameters of the equipment and to determine optimal regimes of vibro-blowing loading of the processed material.
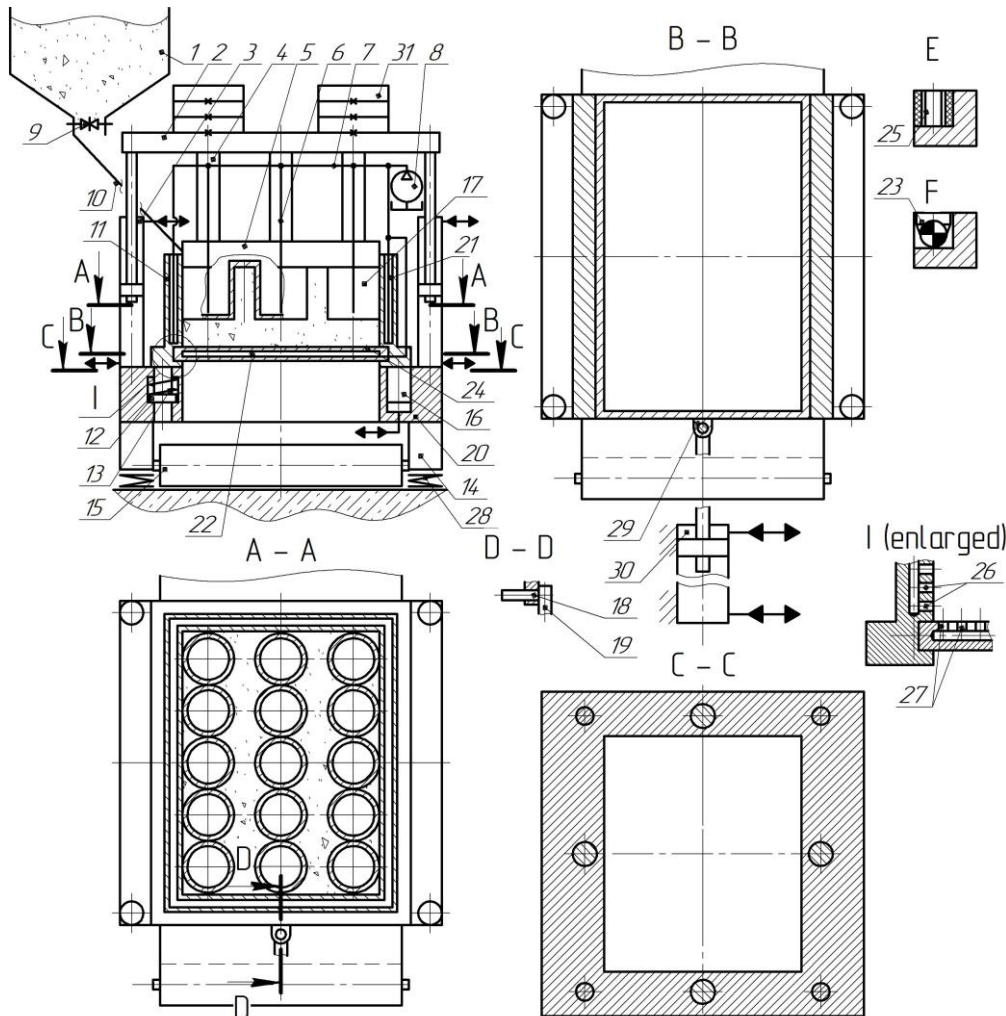
## 4. Results of the researches

Figure 1 presents a scheme of high effective installation for vibro-blowing dehydration of dispersive wastes of food productions that can be equipped with hydraulic pulse, electromagnetic or unbalanced drive.

For realization of dehydration of the portion of waste there is need with using of four hydraulic cylinders 3 to raise cross-arm 2 with inertia loads 31, tubes 4, punch 5 and displacers 17 (see the cross-section A – A in the fig. 1) in the upper position. The portion of waste that should been dehydrated with initial humidity 90 – 95% is fed from the tank 1 through the open slide valve 9 and over the chute 10 in the press-form 11. After its filling the slide-valve 9 is closed and feeding of waste in the press-form is stopped. A hydraulic drive of the cylinders 3 (the drive is not presented in the scheme) is turned over in a regime of feeding of working liquid in rod ends of the cylinders 3 under nominal pressure. As a result, the pistons of the cylinders together with cross-arm 2, tubes 4, punch 5 and displacers 17 make stroke downwards. In course of this stroke the displacers 17 provide static loading and compression of the portion of waste in the press-form 11. Removed from the portion liquid phase flows out through the openings 26, 27 in the walls of the press-form and in the bottom 24 (see element I in the figure 1), that covered from inside by the filtering net (the net is not shown in the scheme). Solid particles of the portion are detained by the net. Other part of the removed liquid goes out

through the little reach-through openings in the displacers 17, closed from outside by a filtering net (the openings and the net are not presented in the scheme). Removed liquid accumulates in channels 21, 22 and in displacers 17.



***Fig. .1. Scheme of high effective installation for vibro-blowing dehydration of dispersive wastes of food productions:***

*1 – tank; 2 – cross-arm; 3, 16, 30 – hydraulic cylinders; 4 – tubes; 5 – punch; 6, 7 – flexible hoses; 8 – vacuum pump; 9 – slide valve; 10 – chute; 11 – press-form; 12 – rods; 13 – springs; 14 – supports; 15 – belt conveyer; 17 – displacers; 18 – pin; 19 – rod; 20 – frame; 21, 22 – channels; 23 – unbalanced vibro-exciter; 24 – movable bottom; 25 – electromagnetic vibro-exciter; 26, 27 – openings; 28 – vibro-supports; 29 – link; 31 – inertia loads*

From there its pumped out with help of flexible hoses 6, 7 and compressor 8. For intensification of the loading of the portion of waste in the press-form 11 there is turned on a main hydraulic pulse drive of the installation with a generator impulses of pressure "at the exit" [2] (the drive is not shown in the scheme). As a result, pressure of working liquid in cavities of the four hydraulic cylinders 16 (see the cross-section C – C in the fig. 1) changes periodically from minimal value $p_2$ to maximal value $p_1$ [2]. The plungers of the cylinders 16 and connected with them elements (press-form 11 with the portion of waste, punch 5 with displacers 17, tubes 4, cross-arm 2, inertia loads 31, rods and pins of the hydraulic cylinders 3) make periodical reciprocal movements with frequency up to 150 Hz and with amplitude up to 4 mm [2, 3]. In course of a stage of the pressure increase the plungers of the cylinders 16 and other movable elements make a working stroke upwards with creation of additional inertia loading of the waste in the press-form from displacers 17 and punch 5. The working stroke is accompanied by movement of the four rods 12 (see the cross-section C – C in the fig. 1) and compression of the springs 13. In course of a stage of decrease of pressure in the cavities of cylinders 16 from $p_1$ to $p_2$ their plungers with other movable elements (see above), including the portion of processing waste make an idle stroke, returning in the initial lower position. The idle stroke is realized under impact of gravitation of the movable elements and elasticity force of the compressed springs 13. The stroke is characterized by unloading of the portion of waste in the press-form from vertical inertia force, even

overdistribution of solid particles of the portion in the press-form volume with mutual relative turns, sliding and movements in positions of more stable balance [1]. All this quite important for further cycle vibro-blowing loading in course of the next raise of the press-form in the upper position and for more effective removal of liquid from areas between of the solid particles.

Conducted experiments and calculations [1, 9, 10, 11] have demonstrated, that such loading provides high productivity of the working process (for dehydration of alcoholic bard, beer pellets an coffee slime) – corresponding to productivity of other mechanical methods, lower power consuming and final humidity of the processed wastes.

After achievement of the necessary final humidity of the waste in the press-form the hydraulic drive of the cross-arm 2 and hydraulic pulse drive of the press-form 11 are turned off. In order to unload the press-form 11 from the portion of dehydrated waste there is need to turn on a hydraulic drive of the cylinder 30 (the cylinder drive is not presented on the scheme). The movable bottom 24 connected with the rod of the cylinder 30 through the link 29 and pin 18 is led out from the press-form (see the cross-sections B – B and D – D in the fig. 1). The dehydrated waste is unloaded on the surface of the belt conveyer 15. For acceleration of this unloading one can be turned on the hydraulic pulse drive, creating vibro-blowing impulses in the medium of the dehydrated portion. A movable joint of the rod of the hydraulic cylinder 30 with the bottom 24 provides possibilities for rigid fastening of the cylinder barrel on separate immovable frame (it not presented in the scheme) and for reciprocal movement of the bottom with the press-form in course of realization of the main technological process.

The design of the installation allows to use for provision of reciprocal movements of the press-form hydraulic pulse, electromagnetic or unbalanced drive. So, on frame 20 of the installation can be fastened correspondingly four cylinders 16 of the hydraulic pulse drive, four electromagnetic vibro-exciters 25 of the electromagnetic drive (see the element E in the figure 1) or four vibro-exciters 23 of the unbalanced drive (see the element F in the figure 1).

As we have pointed out that above, the main parameters of efficiency of dehydration processes of damp dispersive wastes of food industry are: final humidity of the processed waste - $\varphi_f$; middle productivity of the dehydration by removed liquid - $Q_{d\Sigma l}$; middle productivity of the dehydration by the processed waste - $Q_{d\Sigma m}$; middle power consuming of the dehydration process - $C_d$. Experiments, that were conducted by the author with using of vibro-blowing hydraulic impulse installation for dehydration and optimal regimes of vibro-blowing loading in the closed press-form for portions of alcoholic bard, beer pellets and coffee slime, have proved that their final humidity does not exceed 20 – 25% [1]. So, we can hope that under using of the specialized industrial installation for vibro-blowing dehydration (see the fig. 1) this parameter of efficiency will be, at least, in the same limits. Final check of real value $\varphi_f$ in case of using of the proposed installation should be experimental. Therefore, one of the tasks of this article is calculation and analysis of three other efficiency parameters ($Q_{d\Sigma l}, Q_{d\Sigma m}, C_d$) depending from the main parameters vibro-blowing loading, working and design parameters of the using equipment [1].

Early conducted experimental and theoretical researches of processes and equipment for the vibro-blowing dehydration of damp dispersive materials in case of using of the hydraulic pulse drive for provision of vertical periodical fluctuations of the press-form [1, 9, 10, 11] prove that main parameters of the vibro-blowing loading for these processes are: maximal pressure $p_{w.max}$ in the middle of the processed material in the press-form, amplitude $z_{Ia}$ and frequency $v$ of fluctuations of the press-form.

Amplitude $z_{Ia}$ can be found from the equation of movement of the press-form 11 (see the fig. 1) with the portion of the processed waste from initial lower into final upper position (the I stage of a cycle of the vibro-blowing loading [1])

$$z_{Ia} = \frac{0{,}9 \cdot 4 \cdot p_1 S_{pI} - c_p z_p - m_I g}{c_p}, \tag{1}$$

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 [2]; $S_{pI}$ - cross-section area of the hydraulic cylinder 16 of the hydraulic pulse drive; $p_1$ – maximal pressure of working liquid in the cavity of the cylinder 16 of the hydraulic pulse drive (it can be changed with help of the generator pressure impulses [2]); $c_p$ – coefficient of elasticity of the springs 13 for return of the press-form 11 with the portion of processed waste; $z_p$ – previous compression of the springs 13; $m_I$- mass of the lower executive element of the installation, with consideration of masses of the connected movable elements (plungers 16 of the cylinders of the hydraulic pulse drive, press-form 11 and portion of the processed waste).

As we can see from the formula (1) the main design and working parameters of the installation that can be changed with provision of increase or decrease of the $z_{Ia}$are: $p_1, z_p, Q_p$.

For determination of the frequency $v$ may be used the formula

$$v = \frac{1}{T} = \frac{1}{t_I + t_{II}}, \tag{2}$$

where $T$ - duration of a period of fluctuations of the installation executive element (a cycle of vibro-blowing loading); $t_I$; $t_{II}$ – duration of its movement from the lower initial position in the extreme upper position (I stage of a cycle of the vibro-blowing loading) and movement from the upper position in the initial lower position (II stage of a cycle of the vibro-blowing loading).

The time $t_I$ determine by the formula

$$t_I = \frac{Q_p}{\frac{(p_1-p_2)\cdot V}{K}+4\cdot S_{pI}z_{Ia}}, \tag{3}$$

where $p_2$ – minimal pressure of working liquid in the cavity of the cylinder of the hydraulic pulse drive [2]; $V$ – initial volume of the system of the installation hydraulic pulse drive [1, 2], including volumes of the working chambers of the hydraulic cylinders 16; $K$ – modulus of volume elasticity of the working liquid.

The time $t_{II}$ one should calculate by the formula

$$t_{II} = \sqrt{\frac{2\cdot z_{Ia}}{a_I}}, \tag{4}$$

where $a_I$ – acceleration of the mass $m_I$ in course of its movement in the initial lower position, that can be determined from the corresponding equation of movement

$$m_I a_I = g(m_I + m_{II}) + c_p(z_{Ia} + z_p) + 0,9 \cdot 4 \cdot p_2 S_{pI} + 0,9 \cdot 4 \cdot p_h S_{pII}, \tag{5}$$

where $m_{II}$- mass of the upper executive element of the installation, with consideration of masses of connected elements (cross-arm 2 with inertia loads 31, pistons and rods of the auxiliary hydraulic cylinders 3); $S_{pII}$ - cross-section area of the piston of the auxiliary hydraulic cylinder 3; $p_h$ - pressure of the working liquid in its cavity. In the equation (5) 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 installation [1, 2, 3].

As we can see from the formulas (3 - 5) the main design and working parameters of the installation that can be changed to provide increase or decrease of the $v$ are: $p_1, p_h, z_p, Q_p, m_{II}$.

An analysis of cyclograms of hydraulic pulse vibro-presses with a generator of pressure impulses "at exit" [2, 3] allows to make a conclusion that change of pressure of working liquid in a system of the drive in course of a cycle of its functioning has a linear character. The wastes of food industries especially in course of the initial stage of its processing have humidity 90 – 95% and by their structural-mechanical properties are close to the Newtonian liquids. So, with quite high precision we can consider, that a change of pressure in the medium of the portion of dehydrated waste in course of movement in the upper and in the lower position (I stage and II stage of a cycle of vibro-blowing loading) has also the linear character.

The maximal pressure $p_{wImax}$ in the medium of the processed waste in the press-form 11 in course of the I stage one can determine with help of the formula

$$p_{wImax} = \frac{0,9\cdot 4\cdot p_1 S_{pI} - c_p(z_{Ia} + z_p) - m_I(g+a_I) + 0,9\cdot 4\cdot p_h S_{pII} + m_{II}g}{S_{pf}}, \tag{6}$$

where $S_{pf}$ – cross-section area of an internal cavity of the press-form 11.

The minimal pressure in the medium of the processed material in the press-form 11 in course of the I stage: $p_{wImin} = 0$. So, the middle pressure in the medium of the waste portion in course of this stage

$$p_{wI} = (p_{wImax} + p_{wImin})/2 = \frac{p_{wImax}}{2}. \tag{7}$$

During of the II stage of a cycle, as a result of unloading of lower layers of the portion in the press-form 11 the constant pressure in its medium is created by the displacers 17. Approximate value of this pressure one can calculate by the equation

$$p_{wII} = \frac{0,9\cdot 4\cdot p_h S_{pII} + m_{II}g}{S_{pf}}. \tag{8}$$

Then, the middle pressure $p_m$ in the medium of the dehydrated portion in course of a cycle of vibro-blowing loading one can calculate as

$$p_m = (p_{wI} + p_{wII})/2 \tag{9}$$

So, as we can see from the formulas (6 - 9) the main design and working parameters of the installation that can be changed to provide adjustment of the optimal values of $p_m$ are: $p_1, p_h, z_p, Q_p, m_{II}$.

Let us now to set up dependencies between the main parameters of vibro-blowing loading in course of dehydration of damp dispersive waste and efficiency parameters of the researched method ($Q_{d\Sigma l}, Q_{d\Sigma w}, C_d$).

Middle productivity of the vibro-blowing dehydration by removed liquid and by processed material are

$$Q_{d\Sigma l} = \frac{m_p \varphi_f}{T_\Sigma \rho_l}; \quad Q_{d\Sigma w} = \frac{m_p}{T_\Sigma}, \tag{10}$$

where $m_p, \varphi_p$ – initial mass of the portion of the processed waste and its humidity; $T_\Sigma$ - duration of the all working process of vibro-blowing dehydration of one portion of the processed waste; $\rho_l$ - density of its liquid phase.

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

$$T_\Sigma = n \cdot T + T_h = n \cdot \frac{1}{\nu} + T_h, \tag{11}$$

where $T_h$ – auxiliary time for loading and unloading of the press-form after dehydration of a waste portion; $n$ – number of the cycles of vibro-blowing loading for achievement of $\varphi_f$ that can be determined by the condition

$$\rho_l \sum_{i=1}^{n}(V_{l.iI} + V_{l.iII}) = m_p \varphi_f, \tag{12}$$

where $V_{l.iI}$; $V_{l.iII}$ − volumes of removed liquid phase from the portion in course of the I and II stages of an $i$-cycle of vibro-blowing dehydration, that one may calculate as

$$V_{l.iI} = \frac{\pi \cdot p_{wI} t_I r(\varphi_{i-1})^4 S_{is} z(\varphi_{i-1})}{8 \cdot \mu \cdot l(\varphi_{i-1})}; \; V_{l.iII} = \frac{\pi \cdot p_{wII} t_{II} r(\varphi_{i-1})^4 S_{is} z(\varphi_{i-1})}{8 \cdot \mu \cdot l(\varphi_{i-1})}, \tag{13}$$

where $t_I$, $t_{II}$, $p_{wI}, p_{wII}$ are determined by formulas (3 – 8); $r(\varphi_{i-1}), l(\varphi_{i-1}), z(\varphi_{i-1})$ - 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); $S_{is}$ – area of an internal surface of the press-form 11 with opening and filtering net, that provides diversion of removed liquid phase; $\mu$ - coefficient of dynamic viscosity of the liquid phase. For the first cycle of the vibro-blowing dehydration these parameters are determined from the initial humidity of the processed material.

Humidity of the processed material after an $i$-cycle of its vibro-blowing dehydration one can calculate as

$$\varphi_i = \frac{\rho_l(V_{l.i-1I}+V_{l.i-1II})}{\rho_l(V_{l.i-1I}+V_{l.i-1II})+m_s}, \tag{14}$$

where $V_{l.i-1I}, V_{l.i-1II}$ – volumes of delated liquid phase from the portion of the processed waste in course of the I and II stages of the previous $i - 1$-cycle of vibro-blowing dehydration, determined by the formulas (13); $m_s$- 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 (14) 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 [12] 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 $r(\varphi), l(\varphi), z(\varphi)$ are different for various damp dispersive materials, therefore for their receipt there are need additional experimental researches.

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

$$A_d = 0{,}5 \cdot Q_p t_I \eta_{dm}(p_1 + p_2) + Q_p t_{II} \eta_{dm} p_d + Q_h T \cdot \eta_{dh} p_h, \tag{15}$$

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 [2, 7]:

$$\eta_{dm} = \eta_{dh} = \eta_p \cdot \eta_m \cdot \eta_c, \tag{16}$$

where $\eta_p$; $\eta_m$; $\eta_c$ – coefficients of efficiency of a gear pump; three-phase electric motor and coupling of the hydraulic pulse drive and of the auxiliary hydraulic drive of the installation [13].

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

$$A_{d\Sigma} = A_d \cdot n + Q_h T_h \cdot \eta_{dh} p_{hh} + Q_{h2} T_{h2} \cdot \eta_{dh} p_{h2}, \tag{17}$$

where $T_h$– duration of a raise of the punch 5 after finishing of the working dehydration process and its sinking after loading of the next portion; $p_{hh}$ - pressure in cavities of the hydraulic cylinders 3 in course of realization of the auxiliary movements of the punch 5; $Q_{h2}$ – feeding from the pump of the auxiliary hydraulic drive of the cylinder 30, providing movements of the bottom 24 for unloading of the dehydrated waste portion; $T_{h2}$– duration of the bottom's movements; $p_{h2}$ - pressure in cavities of the hydraulic cylinder 30 in course of realization of the auxiliary movements of the bottom 24.

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

$$C_d = \frac{A_{d\Sigma}}{T_\Sigma m_p \varphi_f}. \tag{18}$$

Let us calculate and analyze theoretical dependencies of main vibro-loading parameters ($p_{mI}$, $z_{Ia}, \nu$) in course of dehydration of a portion of damp dispersive waste in the closed press-form with using of the proposed installation (see fig. 1) from its working and design characteristics: $p_1, z_p, Q_p$ (for $z_{Ia}$ and $\nu$); $p_1, z_p, Q_p, m_{II}, p_h$ (for $p_{mI}$). The processed waste – coffee slime with initial humidity $\varphi_i = 90 \div 95\%$ [1]. Calculation and graphing of these theoretical dependencies was realized with help of a computer Excel-program with setting of such initial parameters, that were selected with consideration of corresponding technical characteristics of known vibro-pressing equipment with the hydraulic pulse drive [1 – 3]: $p_1= 8 \div 14$ MPa; $p_2 = 4$ MPa; $p_h = 2 \div 6$ MPa; $S_{pI} = 1{,}65 \cdot 10^{-2}$ m²; $S_{pII} = 7{,}85 \cdot 10^{-3}\ m^2$; $S_{pf} = 0{,}785\ m^2$; $c_p = 2{,}85 \cdot 10^7$ N/m; $z_p = 0{,}5 \div 2{,}7$ mm; $c_{ms} = 4.97 \cdot 10^5$ N/m; $c_{ml} = 1.64 \cdot 10^8$ N/m; $m_I = 500$ kg; $m_{II} = 300 \div 420$ kg; $\propto_m= 1{,}5 \cdot 10^{-3}$ Pa $\cdot$ s; $Q_p= (1 \div 2{,}3) \cdot 10^{-3}\ m^3/s$; K $= 2 \cdot 10^9$ Pa; V $= 0{,}002\ m^3$.
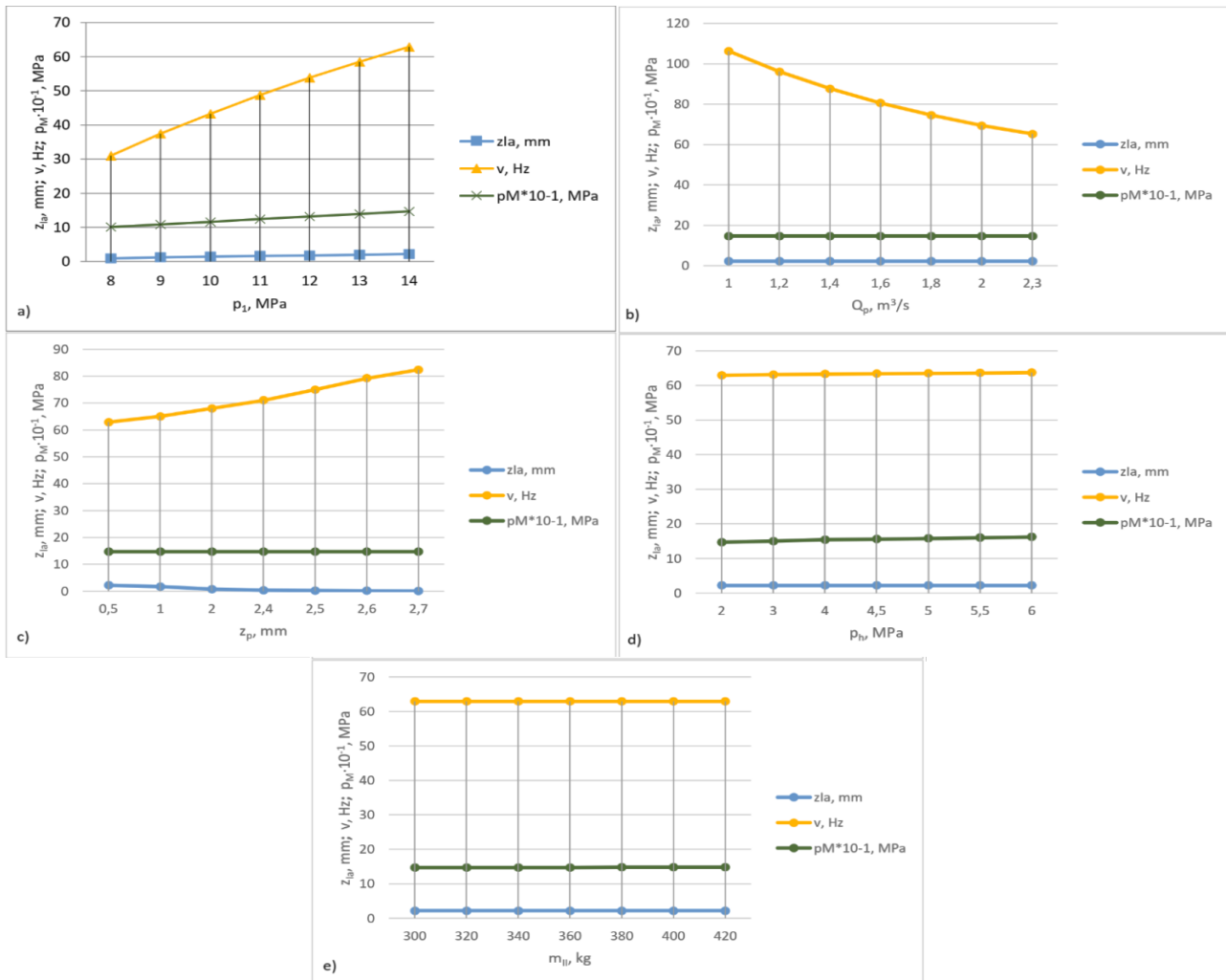
***Fig. 2. Diagrams of theoretical dependencies of the main parameters of vibro-blowing loading of the portion of coffee slime in the closed press-form in course of its dehydration – amplitude $z_{Ia}$ and frequency $\nu$ of the press-form fluctuations and middle pressure $p_m$ inside of the portion in course of a cycle of vibro-blowing loading from***

***$a$ – maximal pressure $p_1$ of working liquid in the cavity of the cylinder of the hydraulic pulse drive ($z_p = 0,05$ mm; $Q_p = 2,3 \cdot 10^{-3}$ $m^3/s$; $m_{II} = 300$ kg; $p_h = 2$ MPa); $b$ – feeding $Q_p$ from the pump of the hydraulic pulse drive ($p_1 = 14$ MPa; $m_{II} = 300$ kg; $z_p = 0,05$ mm; $p_h = 2$ MPa); $c$ – previous compression $z_p$ of the springs for the press-form return ($p_1 = 14$ MPa; $Q_p = 2,3 \cdot 10^{-3}$ $m^3/s$; $m_{II} = 300$ kg; $p_h = 2$ MPa); $d$ – pressure $p_h$ in the working cavity of the auxiliary cylinders ($p_1 = 14$ MPa; $m_{II} = 300$ kg; $z_p = 0,05$ mm; $Q_p = 2,3 \cdot 10^{-3}$ $m^3/s$); $e$ – mass $m_{II}$ of inertia loads ($p_1 = 14$ MPa; $Q_p = 2,3 \cdot 10^{-3}$ $m^3/s$; $z_p = 0,05$ mm; $p_h = 2$ MPa)***

Diagrams of the dependencies, that were received by the results of the calculation are presented in the fig. 2.

As we can see the diagrams the parameters, that have most significant influence frequency $\nu$ are: maximal pressure $p_1$ of working liquid in the cavity of the cylinder of the hydraulic pulse drive (see fig. 2, a), feeding $Q_p$ from the pump of the hydraulic pulse drive (see fig. 2, b) and previous compression $z_p$ of the springs for the press-form return (see fig. 2, c). Regulation of amplitude $z_{Ia}$ of the press-form fluctuations and middle pressure $p_m$ in the medium of the dehydrated portion can be effectively fulfilled by increase and decrease of the pressure $p_1$ (see fig. 2, a). In some extent, change of the pressure $p_m$ may be realized by adjustment of the pressure $p_h$ in the working cavity of the auxiliary cylinders (see fig. 2, d). And tuning of the amplitude $z_{Ia}$ in some narrow range can be achieved at the expense of regulation of the previous compression $z_p$ (see fig. 2, c). The diagram fig. 2, f demonstrates, that change of the mass $m_{II}$ of inertia loads does not make noticeable influence into $z_{Ia}, \nu, \; p_m$ .

Experimental researches for receipt of dependencies $r(\varphi), l(\varphi), z(\varphi)$ for free, capillary-connected and adsorption-connected liquid of main kinds of dispersive food wastes are quite complex and labour-consuming. Therefore, with purpose of receipt of previous data about efficiency of the examined method and equipment for vibro-blowing dehydration of dispersive food waste without consideration of character of interaction of

liquid and solid phases of a portion of processed material, there were elaborated probes of coffee slime before and after its processing under initial and final humidity $\varphi_p$= 95% and $\varphi_f$= 21%.

The researches were conducted with using of the microscope Bresser Biolux LCD Touch with increase from 30x up to 1200x. Received linearized experimental dependencies are presented in the fig. 3.
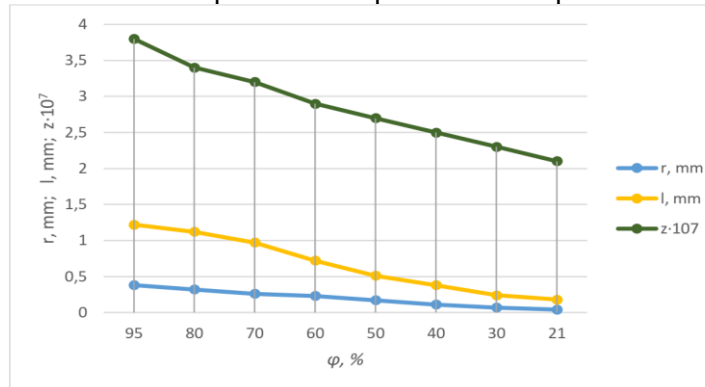


***Fig. 3. Experimental dependencies of middle radius r, length l of a capillary and middle number z of the capillaries in unit of the volume of probes of coffee slime, depending from its humidity φ***

Calculation of the theoretical dependencies of the efficiency characteristics $(Q_{d\Sigma l}, Q_{d\Sigma w}, C_d)$ from the parameters of the vibro-blowing loading $(p_{mI}, \nu)$ there was realized with use of formulas (9 – 18), the diagrams in the fig. 3, computer Excel-program and initial data for calculation: $m_p$= 250 kg; $\rho_l = 1000$ kg/m³; $\mu = 8{,}9 \cdot 10^{-4}$ Pa·s; $S_{is} = 2{,}6$ m²; $m_s = 12{,}5$ kg; $p_1= 8 \div 14$ MPa; $p_h = 2 \div 6$ MPa; $z_p = 0{,}5 \div 2{,}7$ mm; $m_{II} = 300 \div 420$ kg; $Q_p= 1 \div 2{,}3 \cdot 10^{-3}$ $m^3$/s; $Q_h= 1 \cdot 10^{-3}$ $m^3$/s; $\eta_p = 0{,}8$; $\eta_m = 0{,}8$; $\eta_c = 0{,}97$; $p_d = 101300$ Pa; $T_h = 30$ $s$; $p_{hh} = 2$ MPa; $Q_{h2} = 1 \cdot 10^{-3} \frac{m^3}{s}$; $T_{h2} = 60$ s; $p_{h2} = 2$ MPa.
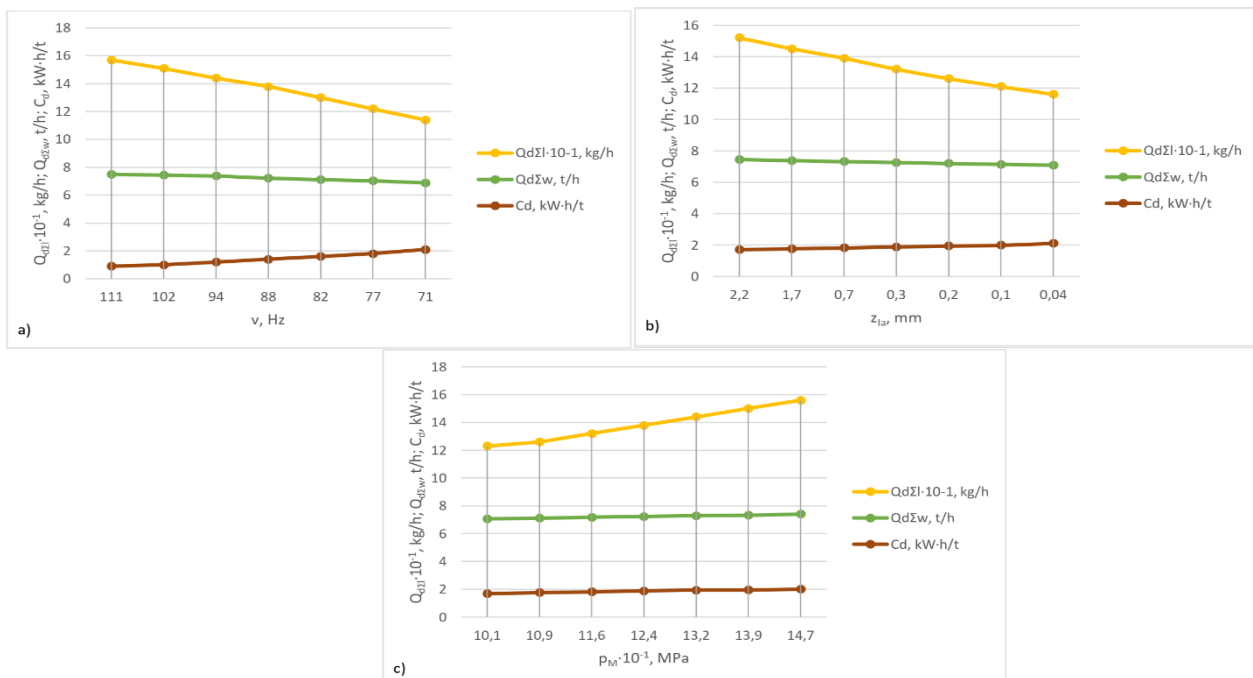


***Fig. 4. Theoretical dependencies of productivity of vibro-blowing dehydration by removed liquid – $Q_{d\Sigma l}$, by processed waste - $Q_{d\Sigma w}$ and middle power consuming – $C_d$ from the main parameters of vibro-blowing loading of the portion of coffee slime in the closed press-form in course of its dehydration: a – frequency ν of the press-form fluctuations; b – amplitude $z_{Ia}$ of the fluctuations; c - middle pressure $p_m$ inside of the portion in course of a cycle of the vibro-blowing loading***

The results of the calculations of the dependencies $Q_{d\Sigma l}, Q_{d\Sigma w}, C_d$ from the main parameters of vibro-blowing loading are presented in the fig. 4 Analysis of the diagrams proves that change of the frequency ν and amplitude $z_{Ia}$ of the press-form fluctuations influences more significant efficiency parameters than increase or decrease of the pressure $p_m$ inside of the portion. With increase of the frequency ν all efficiency parameters

are improved (see fig. 4, a). Rise of the amplitude $z_{Ia}$ provides growth of productivity of the working process (see fig. 4, b) but causes increase of energy expenses for its realization. The similar results ensures growth of the pressure $p_m$ (see fig. 4, c).

By the results of the calculation (see fig. 4) the proposed equipment (see fig. 1) provides higher energy efficiency: $0,9 \div 2,1$ kW / t against $2,7 \div 3,2$ kW / t – for previously elaborated machines for vibro-blowing dehydration [1, 9 – 11], but it has some lower productivity by dehydrated waste $6,9 \div 7,7$ t/h against $20 \div 25$ t / h – for known schemes of an equipment of the same destination.

## 5. Conclusions

1. In previous researches of the dehydration process of damp dispersive materials there were mainly examined foundations, working efficiency parameters for thermal dehydration methods that have quite high power-consuming indicators ($740 \div 2800$ kW / t of removed liquid). The known mathematic models of processes and equipment for mechanical dehydration, that demand significantly lower energy expenses ($2,7 \div 3,2$ kW / t) are enough complex and unsuitable for elaboration of engineering methods of their design calculation.

2. A scheme of a high effective installation for vibro-blowing dehydration of dispersive wastes of food productions in the closed press-form is presented in the article. The installation can be equipped with hydraulic pulse, electromagnetic or unbalanced drive and ensures mechanized loading of waste in the press-form and its unloading after completing of the working process.

3. There were elaborated algebraic equations and formulas for definition of the main parameters of vibro-blowing loading of damp dispersive food production waste in course of its dehydration in the closed press-form of the proposed installation (frequency $\nu$ and amplitude $z_{Ia}$ of the press-form fluctuations, middle pressure $p_m$ inside of the portion in course of a cycle of the vibro-blowing loading) and characteristics of the process efficiency (productivity of the vibro-blowing dehydration by removed liquid – $Q_{d\Sigma l}$, productivity by processed waste - $Q_{d\Sigma w}$ and middle power consuming – $C_d$).

4. The elaborated algebraic equations and formulas were used for creation of a computer Excel-program for calculation of dependencies of the main parameters of vibro-blowing loading ($\nu$, $z_{Ia}$, $p_m$) from basic design and working parameters of the installation: feeding $Q_p$ from the pump of the hydraulic pulse drive; maximal pressure $p_1$ of working liquid in the cavity of the cylinder of the hydraulic pulse drive, previous compression $z_p$ of the springs for the press-form return, mass $m_{II}$ of the upper executive element of the installation, pressure $p_h$ of working liquid in cavities of the auxiliary hydraulic cylinders. Also there were calculated diagrams of efficiency parameters ($Q_{d\Sigma l}, Q_{d\Sigma w}, C_d$) from the main parameters of vibro-blowing loading ($\nu$, $z_{Ia}$, $p_m$). The dependencies allow to define effective methods and parameters of regulation for adjustment of an optimal regime of vibro-blowing loading in course of dehydration of coffee slime. These parameters are: $\nu = 110$ Hz; $z_{Ia}= 2,2$ mm; $p_m = 14,7$ MPa. For realization of this regime there are recommended such design and working parameters of the installation: $p_1= 14$ MPa; $Q_p = 1$ m³/s; $z_p = 2,7$ mm; $p_h = 6$ MPa; $m_{II}= 300$ kg.

5. The proposed algebraic equations and formulas can be used as a base for elaboration of an engineering method of design calculation of the high effective installation for vibro-blowing dehydration of dispersive wastes of food productions in the closed press-form.

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## ВИЗНАЧЕННЯ ОПТИМАЛЬНИХ КОНСТРУКТИВНИХ І РОБОЧИХ ПАРАМЕТРІВ ВІБРОПРЕСІВ ДЛЯ ЗНЕВОДНЕННЯ ВОЛОГИХ ДИСПЕРСНИХ ВІДХОДІВ ХАРЧОВИХ ВИРОБНИЦТВ

*Вібропресове обладнання є одним з найбільш ефективних видів машин для зневоднення вологих дисперсних відходів харчових виробництв (спиртової барди, пивної дробини, бурякового жому, кавового та ячмінного шламів) для подальшого їх використання як цінних добавок до сільськогосподарських кормів або як палива. Порівняно з іншим обладнанням для механічного зневоднення (гідравлічними, стрічковими та шнековими пресами, центрифугами) вібропреси з гідроімпульсним, дебалансним або електромагнітним приводом забезпечують таку саму або більшу продуктивність (20 ÷ 25 т/год) та енергоефективність (2,7 ÷ 3,2 ) кВт/т) при значно меншій кінцевій вологості відходів (20 ÷ 25 % проти 70 – 76 % - за реалізації інших способів механічного зневоднення). Останнє дозволяє не проводити додаткове сушіння відходів, що забезпечує значне зниження загальної енергоємності робочого процесу. Для досягнення високих показників ефективності віброударного зневоднення необхідно забезпечити оптимальні значення робочих та конструктивних параметрів обладнання для їх реалізації. Існує кілька підходів до вивчення вібропресового обладнання. Підходи, що реалізуються за допомогою диференціальних рівнянь руху виконавчих елементів машин або рівнянь балансів їхньої енергії, забезпечують високу точність розрахунків, але через складність вони непридатні для створення методики інженерного розрахунку машини. У статті запропоновані алгебраїчні рівняння та формули для визначення оптимальних параметрів вібропресового обладнання для зневоднення вологих дисперсних відходів харчових виробництв для реалізації заданих параметрів ефективності та з урахуванням початкових та кінцевих фізико-механічних характеристик матеріалів, що переробляються. Наведено та проаналізовано розрахункові графіки цих параметрів.*

*Ключові слова: зневоднення, вібропрес, вологі дисперсні відходи, оптимальні робочі та конструктивні параметри, продуктивність, енергоефективність, кінцева вологість.*

*Ф. 18. Рис. 4. Літ. 13.*

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