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MODELLING OF WORKING PROCESS OF EQUIPMENT WITH HYDRAULIC DRIVE FOR SEPARATION OF DAMP DISPERSIVE MATERIALS

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A task of introduction of separation processes of damp dispersive materials are very actual for food and processing industry of Ukraine and other countries, because its solution will allow to resolve by most effective way a problem of utilization of such waste as alcoholic bard, beer pellets, beet press, coffee and barley slime. In most cases this waste is poured out in nearest reservoirs or on ground and that leads to environment pollution. But after separation from the waste of the liquid phase (waste dehydration) its hard phase can be used as a valuable additive to agricultural fodders or as a high calorie fuel. By article's authors notion the most prospective method of separation of the damp dispersive waste is mechanical dehydration, that provides high productivity of the working process, low consumption of energy (in 240 – 800 times lower then under realization of thermal methods) and necessary final humidity of the waste (20 – 25% in case of utilization by a method of vibro-blowing dehydration). One of the most prospective types of equipment for mechanical separation of the damp dispersive waste are presses with hydraulic drive that have relatively compact dimensions, high energy efficiency and reliability and provide a possibility for wide-range and infinitely variable control of main parameters of a loading regime of the waste processing. There is a scheme of an improved and high effective installation with hydraulic drive for separation of damp dispersive materials is presented in the article. Besides there are elaborated equations of its mathematic model that connect working parameters of separation, design parameters of the installation and physical-mechanical characteristics of the processed material. These equations can be used for optimization of the installation's design and for creation of its method of projecting calculation.

Kee words: *hydraulic drive, dispersed system, separation process, productivity, energy consumption.*
F. 19. Fig. 2. Ref. 10.

1. Problem formulation

Processes of separation of damp dispersive materials are very widespread in food and processing branches of industry for extraction of a liquid phase (in a production of fruit juices, sugar, sunflower-seed and olive oil [1]), a hard phase (utilization of a waste of food productions – alcoholic bard, beer pellets, beet press, coffee and barley slime [2, 3]) and both of main phases (separation of cocoa powder for receipt of cocoa oil and cocoa press [1]). Dehydration of the damp dispersive waste of food and processing enterprises of Ukraine allows to use its hard phase as a valuable additive to agricultural fodders or as a high calorie fuel [2, 3].

Known mechanical methods of separation of damp dispersive materials with help of screw presses and decanter centrifuges provide high productivity (up to 5 tons of processed waste per hour) and energy efficiency (5 – 7 kw-hr / t of removed moisture). But high enough final humidity of the waste after processing at this equipment (74 – 76%) makes necessary its additional drying and that leads to significant increase of energy expenses for realization of the separation process.

Chemical and biological separation demands of using of bulky and multi-corpse technological complexes and of considerable spending of time and energy.

In the works [2 – 5] is proposed and elaborated a stream vibro-blowing dehydration of damp dispersive waste of food productions with help of installations with a hydraulic pulse drive [6], that belongs to mechanical methods of separation and provides productivity up to 20 – 25 t / h, energy efficiency 2,7 kw-hr / t and final humidity of the waste 20 – 25%. But the equipment for realization of the method is enough complex and expensive [2 – 5].

By article's authors notion the above indicated efficiency parameters of separation can be achieved under utilization of a method of static pressing with help of improved hydraulic presses [7]. But there is necessary a mathematic model that allows to determine optimal design parameters of the equipment and working parameters of the separation process depending from physical-mechanical characteristics of processed material.

2. Analysis of last researches and publications

In the work [8] there are examined several types of models of press-forging machines including hydraulic presses: ideal, rigid concentrated, resilient concentrated and wave distributed models. For selection of a proper type of the model there is need to take in consideration necessary accuracy of researches results, frequency characteristic of the system, level of its decrement, ratio of masses of executive elements of the equipment and of working liquid of the hydraulic system. In particular the rigid model with concentrated parameters is used for an analysis of dynamics of hydraulic presses and machines of blowing action with a pump and a pump accumulating drive. This model allows to determine main parameters of movement of executive elements when resilient properties of the hydraulic system don't make of significant impact at coarse of the working process [8].

A pressing equipment with a hydraulic pulse drive including installations for stream vibro-blowing dehydration of damp dispersive waste are characterized by quick dynamic processes in their hydraulic system [2 – 5]. Frequency of periodic impact of a vibration exciter of the hydraulic pulse drive at the hydraulic system of this equipment is less, then its first resonance frequency therefore for analysis of machines with this type of drive can be used the resilient concentrated model [2 – 5].

In the work [9] are presented graphical dependences of amperage of an improved electric hydraulic pressing equipment, pressure of working liquid in its system from durability of working process and movement of the executive element. The authors also have determined consumed power of the equipment from executive element's perimeter and its movement. But all these parameters were received by experimental method, without utilization of a mathematic model.

3. Aim of the researches

Elaboration of scheme and mathematic model of an improved equipment with the hydraulic drive for high effective separation of damp dispersive materials; determination of connections of working parameters of separation process, design parameters of the equipment and physical mechanical characteristics of processed material.

4. Results of the researches

There is a scheme of an improved installation with the hydraulic drive for high effective separation of damp dispersive materials presented at the fig. 1.

The processed material with initial humidity 90 – 95% is loaded from the tank 2, through the opened slide-valve 3 and over the tray 5 it gets into the press-form 6. In coarse of the loading the punch 4 is situated in an extreme upper position and plates 10, 11 – in positions are shown at the cross section A – A of the fig. 1.

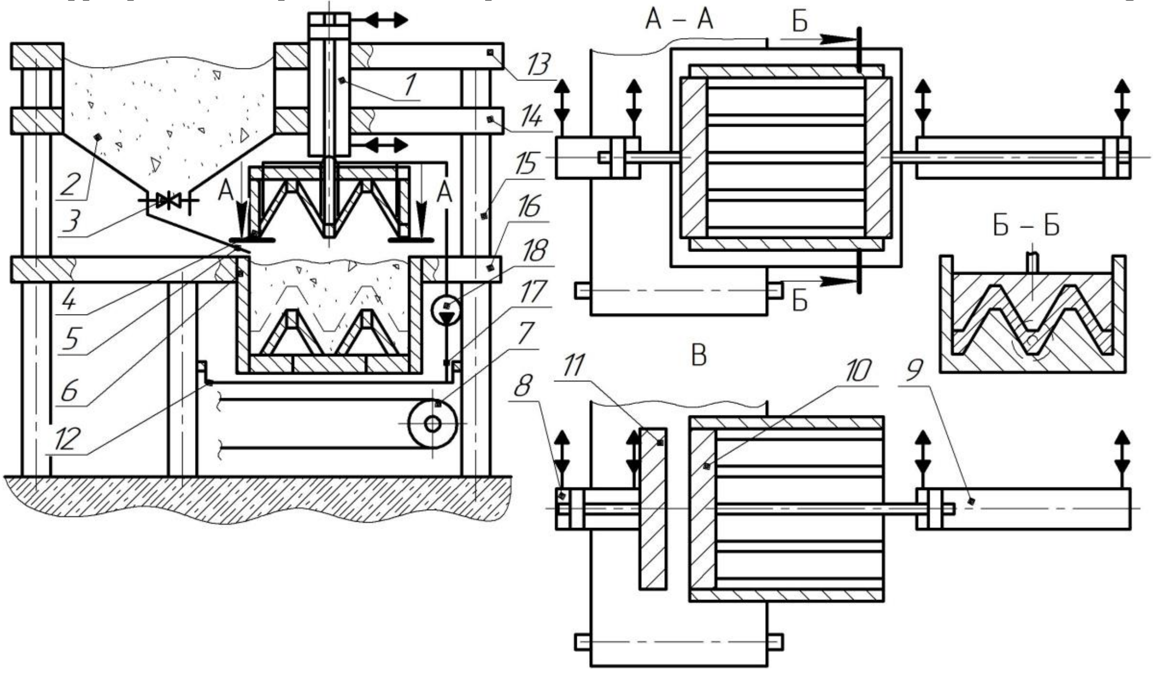

Fig. 1. Scheme of an improved installation with the hydraulic drive for high effective separation of damp dispersive materials: 1, 8, 9 – hydraulic cylinders; 2 – tank with processed material; 3 – slide-valve; 4 – punch; 5 – tray; 6 – press-form; 7 – belt conveyer; 10, 11 – plates; 12 – tank with separated liquid; 13, 14, 16 – cross-bars of the bed; 17 – flexible hose; 18 – pump

After completing of the loading the slide-valve 3 is closed and with help of the hydraulic cylinder 1 the punch 4 is came down, providing pressing of portion of the processed material in the press-form 6. In comparison with usual cylindrical press-forms of similar volume the press-form of the installation at the fig. 1

has larger area of the working surface and provides more even and effective loading of the portion of processed material not only in lower and upper sections but also in the middle layers. All this promotes to more intensive removal of liquid phase of the processed material, that flows out through little through openings in walls of the press-form and in the punch into the tank 12. The openings are closed from inside with filtering metallic net (the openings and the net are not shown at the scheme). Removed liquid is pumped out from internal cavities of the punch through the flexible hose 17 in the tank 12 with help of the pump 18.

At an initial period of the working process from the portion of the material in the press-form is removed free liquid that can be relatively easy separated from the hard particles. So, speed of the movement of the punch in this period of the working cycle is maximal [2]. Lately with beginning of separation of liquid that has structural and adsorbtive connections with hard particles the working process intensity is decreased and the speed of the punch becomes lower. For increase of efficiency of the separation process is recommended from time to time to interrupt the loading of the portion of material, to lead out it upwards for overdistribution of liquid in the portion and its subsequent better removal.

After achievement of the lowest position of the punch (the cross section Б – Б at the fig. 1) the process of separation is stopped and the punch is returned in the initial upper position. Then with help of the hydraulic cylinders 8, 9 the plates 11, 10 are moved in the leftmost positions (see the view В at the fig. 1). As a result, a dehydrated portion of the processed material is removed from the press-form at the belt conveyer 7. After that the plates 11, 10 are returned in the initial positions and into the press-form is loaded the next portion of processed material. The working cycle of the installation is repeated.

For creation of a mathematic model of the installation we use schemes of loading for the piston of the hydraulic cylinder 1 (fig. 2) for the first stage (fig. 2, a) – loading with extraction of free liquid (pressing of liquid phase of the portion) and for the second stage (fig. 2, b) – loading with extraction of the liquid that has structural and adsorbtive connections with hard particles (pressing of liquid and hard phases of the portion). At the schemes are designated: $p_c(t)$ – pressure in the head end of the cylinder, that is changed in coarse of time, depending from the loading at the rod, p_o – pressure in the rod end of the cylinder it corresponds to the overflow pressure in a hydraulic system of the installation; m_p – mass of the piston taking into consideration the masses of the rod and the punch 4 (see also the fig. 1); S_p – effective cross section area of the piston (it is the same from the side of the head end and the rod end of the cylinder); $R(t)$ – force of dry friction in coarse of the piston movement (friction in a sealing of the piston and rod of the cylinder); a_p – acceleration of the piston; b_1, b_2 – width of horizontal and inclined surfaces of the punch; $F_{r.l}(t)$ – force of resilient resistance of liquid phase of the portion in coarse of the punch movement; $F_{r.h}(t)$ – force of resilient resistance of hard phase of the portion in coarse of the punch movement; $F_{f.l}(t)$ – force of viscous friction of liquid phase of the portion in coarse of the punch movement; $F_d(t)$ – driving force from the piston side; F_p – force of plastic deformation of hard phase of the portion in coarse of the punch movement [2 - 6]; α – angle of inclination of surfaces of the punch.

An equation of movement for the piston of the hydraulic cylinder 1 at the first stage of loading (fig. 2, a) can be presented as

$$m_p\ddot{z}_p = F_d(t) + m_p g - F_{r.l}(t)cos\alpha - F_{f.l}(t)cos\alpha - R(t); 0 \le t \le t_I, \quad (1)$$

where t_I – durability of the first stage of the loading.

The equation (1) in a detailed presentation

$$m_p\ddot{z}_p = S_p(p_c(t) - p_o) + m_p g - cos\alpha\left(\Delta p_m(t)S_p + \beta_l\dot{z}_p\right) - 0{,}1 \cdot S_p(p_c(t) - p_o); 0 \le t \le t_I, \quad (2)$$

where β_l – coefficient of viscous friction of the liquid phase [2]; $\Delta p_m(t)$ – change of pressure inside of the portion of the processed material in course of its pressing by the punch. Under receipt of the equation (2) was used an allowance that $R(t)$ by value amounts approximately 10% from the value of $F_d(t)$ [2, 6].

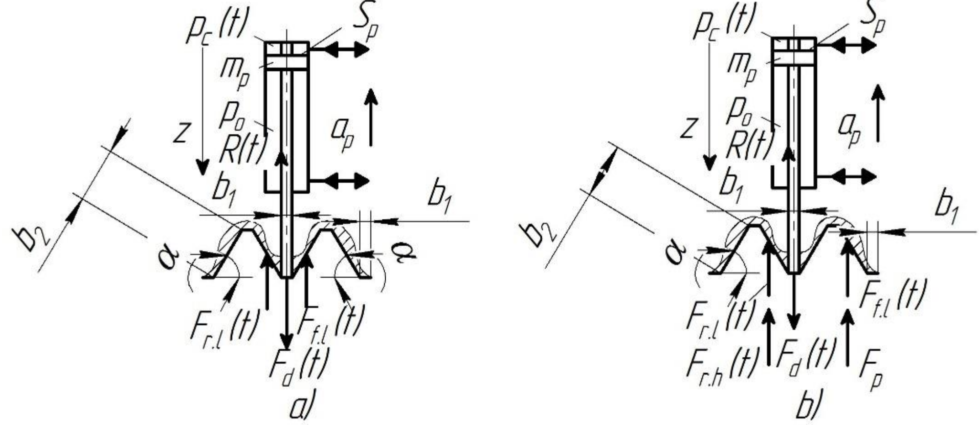

Fig. 2. Schemes of loading for the piston of the hydraulic cylinder of the installation for the first stage (a) and for the second stage (b) of loading

Change of pressure $\Delta p_m(t)$ can be determined by the formula [10]

$$\Delta p_m(t) = \frac{\Delta V_p(t)}{V_p} E_w;\ 0 \le t \le t_I, \tag{3}$$

where $\Delta V_p(t)$ – change of the volume of the portion of the processed material as a result of its pressing; V_p – initial volume of the portion before pressing; E_w - module of volumetric resiliency of liquid phase of the processed material (at the first stage of separation, when humidity of the material amounts 90 – 95%, we can consider, that in the press-form is pressed a Newtonian liquid).

Change of volume $\Delta V_p(t)$ can be calculated by the formula

$$\Delta V_p(t) = 5 \cdot b_1 l \cdot z_p + 4 \cdot b_2 l \cdot z_p cos\alpha = l \cdot z_p (5 \cdot b_1 + 4 \cdot b_2 cos\alpha);\ 0 \le t \le t_I, \tag{4}$$

where l – length of the working surface of the punch.

The initial volume of the portion we can found by the formula

$$V_p = h_p l(5 \cdot b_1 + 4 \cdot b_2 cos\alpha) - 2 \cdot b_2 l cos\alpha \cdot b_2 sin\alpha - 2 \cdot l \cdot b_2 sin\alpha =$$
$$= l \cdot \left[h_p(5 \cdot b_1 + 4 \cdot b_2 cos\alpha) - 2 \cdot b_2(b_2 cos\alpha \cdot sin\alpha + sin\alpha)\right]. \tag{5}$$

Feeding of extracted liquid phase of the processed material we determine as [7, 10]

$$Q_l(t) = \mu_o \frac{\pi \cdot d_o^2}{4} n_o \left[2 \cdot l \cdot (5 \cdot b_1 + 4 \cdot b_2 cos\alpha) + l \cdot \left(h_p - \dot{z}_p t\right)\right] \sqrt{\frac{2 \cdot \Delta p_m(t)}{\rho_w}};\ 0 \le t \le t_I, \tag{6}$$

where μ_o – feeding coefficient of filtering openings in the walls of the punch and the press-form [10]; d_o – diameter of filtering openings; n_o - number of filtering openings on the unit of the area of internal surfaces of the punch and the press-form; ρ_w - density of extracted liquid phase (water). In the formula (6) is taken into consideration decrease of the number of opened filtering openings in course of sinking of the punch.

Feeding of working liquid that is provided by the hydraulic drive in the head end of the hydraulic cylinder 1 (see the fig. 1) we can find as

$$Q_{w.l}(t) = S_p \dot{z}_p;\ 0 \le t \le t_I. \tag{7}$$

In accordance with equation of feeding balance [10]

$$Q_{w.l}(t) = Q_l(t);\ 0 \le t \le t_I. \tag{8}$$

So, we can equate left parts of equations (6) and (7)

$$S_p \dot{z}_p = \mu_o \frac{\pi \cdot d_o^2}{4} n_o \left[2 \cdot l \cdot (5 \cdot b_1 + 4 \cdot b_2 cos\alpha) + l \cdot \left(h_p - \dot{z}_p t\right)\right] \sqrt{\frac{2 \cdot \Delta p_m(t)}{\rho_w}};\ 0 \le t \le t_I. \tag{9}$$

Durability t_I of the first stage we can approximately find with consideration of volumetric content $W_{f.l}$ of free liquid phase in the initial processed material ($W_{f.l}$ can be determined by an experimental method for each kind of the processed waste). So, then a condition for calculation of t_I can be presented as

$$\Delta V_p(t) = V_p\, W_{f.l};\ 0 \le t \le t_I. \tag{10}$$

After joint solution of equations (2 – 5, 9, 10) we can find main working parameters of the proposed installation in course of the first stage of separation process: movements z_p, speeds $\dot{z}_p$ and accelerations $\ddot{z}_p$ of executive element of the installation in each moment of the stage, its durability t_I. Then with help of equations (3, 4, 6) can be determined change of the pressure $\Delta p_m(t)$, change of volume $\Delta V_p(t)$ and feeding of extracted liquid phase of the processed material – $Q_l(t)$ in the course of the first stage.

For provision of a possibility of solution of the equation (2) we can accept that $p_c(t)$ is constant and equal to previously adjusted pressure $p_{f.l}$ of working liquid in the force line of the hydraulic drive of the installation:

$$p_c(t) = p_{f.l}. \tag{11}$$

Equation of movement for the piston of the hydraulic cylinder 1 at the second stage of loading (fig. 2, b) can be presented as

$$m_p \ddot{z}_p = F_d(t) + m_p g - F_{r.l}(t) cos\alpha - F_{f.l}(t) cos\alpha - F_{r.h}(t) cos\alpha - F_p cos\alpha - R(t);\ t_I < t \le t_{II}, \tag{12}$$

where t_{II} – durability of the second stage of loading.

The equation (12) in a detailed presentation

$$m_p \ddot{z}_p = S_p(p_c(t) - p_o) + m_p g - cos\alpha\left(\Delta p_m(t) S_p + \beta_l \dot{z}_p\right) - c_h z_p - \sigma_h - 0{,}1 \cdot S_p(p_c(t) - p_o);$$
$$t_I < t \le t_{II}, \tag{13}$$

where c_h – coefficient of rigidity of hard particles of the processed material; σ_h- tension of plasticity of hard particles [2].

Change of pressure $\Delta p_m(t)$ can be determined by the formula [10]

$$\Delta p_m(t) = \frac{\Delta V_p(t)}{V_p - \Delta V_p(t_I)} E_w;\ t_I < t \le t_{II}, \tag{14}$$

where $\Delta V_p(t_I)$ – change of volume of the portion of the processed material in a moment of finishing of the first stage.

Change of volume $\Delta V_p(t)$ in course of the second stage can be calculated by the formula

$$\Delta V_p(t) = 5 \cdot b_1 l \cdot z_p + 4 \cdot b_2 l \cdot z_p cos\alpha = l \cdot z_p (5 \cdot b_1 + 4 \cdot b_2 cos\alpha); t_I < t \le t_{II}. \quad (15)$$

Initial volume of the portion in the equation (14) we can found by the formula (5).

Equation of feeding of extracted liquid phase of the processed material for the second stage is (see formulas (6 – 9):

$$S_p \dot{z}_p = \mu_o \frac{\pi \cdot d_o^2}{4} n_o \left[2 \cdot l \cdot (5 \cdot b_1 + 4 \cdot b_2 cos\alpha) + l \cdot \left(h_p - z_p(t_I) - \dot{z}_p t\right)\right] \sqrt{\frac{2 \cdot \Delta p_m(t)}{\rho_w}}; t_I < t \le t_{II}, \quad (16)$$

where $z_p(t_I)$ – movement of the punch from the initial position and up to the moment of time $t = t_I$.

Durability t_{II} of the second stage we can approximately find with consideration of volumetric content $W_{sa.l}$ of structural and adsorbtive liquid phase in the initial processed material ($W_{sa.l}$ can be determined by the experimental method for each kind of the processed waste). So, then a condition for calculation of t_{II} can be presented as

$$\Delta V_p(t) = V_p W_{sa.l}; t_I < t \le t_{II}. \quad (17)$$

After joint solution of equations (13 – 17, 5) we can find main working parameters of the proposed installation in course of the second stage of separation process: z_p, $\dot{z}_p$, $\ddot{z}_p$, t_I, $\Delta p_m(t)$, $\Delta V_p(t)$.

Feeding of extracted liquid phase of the processed material - $Q_l(t)$ in course of the second stage we determine with help of the equation

$$Q_l(t) = \mu_o \frac{\pi \cdot d_o^2}{4} n_o \left[2 \cdot l \cdot (5 \cdot b_1 + 4 \cdot b_2 cos\alpha) + l \cdot \left(h_p - z_p(t_I) - \dot{z}_p t\right)\right] \sqrt{\frac{2 \cdot \Delta p_m(t)}{\rho_w}}; t_I < t \le t_{II}, \quad (18)$$

For provision of a possibility of solution of the equation (13) we can accept that $p_c(t)$ is constant and equal to previously adjusted pressure $p_{f.l}$ of working liquid in the force line of the hydraulic drive of the installation (see the formula (11).

Power of a pump for the hydraulic drive of the main hydraulic cylinder of the installation can be calculated as

$$N_d = Q_{l.max} \Delta p_{m.max} \eta_p, \quad (19)$$

where $Q_{l.max}, \Delta p_{m.max} -$ are maximal feeding of extracted liquid phase of the processed material and change of the pressure inside of the portion of the processed material in course of the first and the second stages of separation process by results of calculation these parameters with help of equations (3, 6, 14, 18); $\eta_p -$ efficiency of the drive pump [10].

5. Conclusions

1. A mechanical method is the most effective for separation of damp dispersive materials, that provides higher productivity than chemical and biological methods and lower energy expenses in comparison with a thermal method of separation. One of prospective kinds of the mechanic method of separation is pressing with help of installations with a hydraulic drive.

2. There is need an accurate and adequate mathematic model for optimization of pressing process of damp dispersive materials on an equipment with the hydraulic drive. Known mathematic models of the pressing equipment are not appropriate for research of a proposed improved installation with a hydraulic drive for separation of damp dispersive materials because they are excessively complex and do not take into consideration of peculiarities of the researched separation process and characteristics of a processed material.

3. Authors of the article propose a mathematic model for the improved installation with the hydraulic drive for separation of damp dispersive materials. Equations of the mathematic model determine connections between of working parameters of separation, design parameters of the installation and physical-mechanical characteristics of the processed material. These equations can be used for optimization of the installation's design and for creation of its method of projecting calculation.

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МОДЕЛЮВАННЯ РОБОЧОГО ПРОЦЕСУ ОБЛАДНАННЯ З ГІДРАВЛІЧНИМ ПРИВОДОМ ДЛЯ РОЗДІЛЕННЯ ВОЛОГИХ ДИСПЕРСНИХ МАТЕРІАЛІВ

Завдання впровадження процесів розділення вологих дисперсних матеріалів є дуже актуальним для харчової та переробної промисловості України та інших країн, оскільки її вирішення дозволить найбільш ефективно усунути проблему утилізації таких відходів, як спиртова барда, пивна дробина, буряковий жом, кавовий та ячмінний шлам. У більшості випадків ці відходи виливаються в найближчі водойми або на ґрунт, що призводить до забруднення довкілля. Однак після відокремлення від відходів рідкої фази (зневоднення) її тверда фаза може бути використана як цінна добавка до сільськогосподарських кормів або як висококалорійне паливо. На думку авторів статті, найбільш перспективним методом розділення вологих дисперсних відходів є механічне зневоднення, що забезпечує високу продуктивність робочого процесу, низькі енерговитрати (у 240 - 800 разів нижчі, ніж при реалізації термічних способів) та необхідну кінцеву вологість відходів (20 - 25% при використанні способу віброударного зневоднення). Одним із найбільш перспективних видів обладнання для механічного розділення вологих дисперсних відходів є преси з гідравлічним приводом, які мають відносно компактні розміри, високу енергоефективність та надійність і забезпечують можливість широкодіапазонного та безступінчастого регулювання основних параметрів режиму навантаження під час переробки відходів. У статті представлено схему вдосконаленої високоефективної установки з гідроприводом для сепарування вологих дисперсних матеріалів. Крім того, розроблено рівняння її математичної моделі, що пов'язують між собою робочі параметри сепарування, конструктивні параметри установки та фізико-механічні характеристики оброблюваного матеріалу. Ці рівняння можуть бути використані для оптимізації конструкції установки та створення методики її проектного розрахунку.

Ключові слова: *гідропривод, дисперсна система, процес розподілу, продуктивність, енерговитрати.*

Ф. 19. Рис. 2. Літ. 10.

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