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(Німеччина)****УДК 664.8.047****DOI: 10.37128/2306-8744-2026-3-2****EXPERIMENTAL INVESTIGATION OF
VIBROIMPACT DEWATERING OF WET
DISPERSED MATERIALS USING A
HYDRAULIC-PULSE TEST RIG**

The paper presents an experimental substantiation of an energy-efficient method for vibroimpact dewatering of wet dispersed food-production materials using a specially developed hydraulic-pulse test rig based on the IVP-16 inertial vibropress-hammer. The design of the stand, its hydraulic drive, technological tooling and operating cycle are described. The principal loading parameters governing process efficiency are identified as the vibration amplitude and frequency of the vibrating table, the maximum pressure in the hydraulic-pulse cylinder, and the travelling speed of the tray with the processed material. Experimental studies were performed for coffee slurry, distillery stillage and sugar beet pulp with an initial moisture content of 75%. Process performance was evaluated by liquid-removal capacity, specific energy consumption and final moisture content. The experiments demonstrate that increasing vibration amplitude, frequency and maximum hydraulic pressure generally increases dewatering productivity and reduces both specific energy consumption and final moisture content, whereas increasing tray speed produces the opposite tendency. A frequency optimum is observed because excessive vibration intensifies loosening of the lower material layers and can promote re-absorption of the separated liquid. Minimum final moisture contents of 20% for coffee slurry, 22% for sugar beet pulp and 24% for distillery stillage were achieved. Comparison with conventional static pressing shows a substantial reduction in treatment duration and required force, confirming the high technological potential of hydraulic-pulse vibroimpact dewatering for continuous processing of wet dispersed food wastes.

Keywords: vibroimpact dewatering, wet dispersed materials, hydraulic-pulse drive, food-production waste, experimental stand, vibration amplitude, vibration frequency, hydraulic pressure, specific energy consumption, final moisture content.

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Introduction. Wet dispersed wastes of food and processing industries, including coffee slurry, distillery stillage and sugar beet pulp, contain a substantial fraction of mechanically removable liquid. Conventional mechanical dewatering methods often leave a concentrate with excessive residual moisture and therefore require subsequent thermal drying. The additional drying stage sharply increases total energy consumption, complicates the process line and raises production costs. For this reason, the development of mechanical methods capable of removing a larger fraction of

liquid before thermal treatment is a relevant engineering task.

Vibroimpact loading combines static compression, cyclic inertial forces and short-duration impacts. Such a loading regime promotes disruption of inter-particle bonds, intensifies liquid migration through capillary channels and filtration media, and can produce markedly lower final moisture than static pressing. However, the practical efficiency of the method depends on a coordinated selection of vibration amplitude, excitation frequency, hydraulic pressure and material transport speed. Experimental verification

on a controllable test rig is therefore necessary before designing industrial continuous-flow equipment.

Review of recent research and publications. Previous investigations into vibration and vibroimpact technologies have shown that dynamic loading can substantially intensify the treatment of dispersed media. For wet food-production wastes, the most promising schemes use hydraulic-pulse drives because they are capable of generating adjustable high-frequency force pulses and of combining them with a static clamping force. Earlier studies by Sevostianov and co-authors established the feasibility of multistage vibroimpact dehydration and identified the principal physical mechanisms responsible for enhanced liquid separation [1-6].

At the same time, published data indicate that the efficiency of conventional screw presses, belt presses, centrifuges and static hydraulic presses is limited either by relatively high final moisture content, filter clogging, high material wear, or the need for energy-intensive thermal post-treatment. Thus, an experimental assessment of the hydraulic-pulse vibroimpact method under controlled loading conditions is required to quantify its technological advantages and determine rational operating ranges.

Purpose of the study. The purpose of this study is to experimentally substantiate the efficiency of vibroimpact dewatering of wet dispersed materials and to establish the influence of the principal loading parameters on liquid-removal capacity, specific energy consumption and final moisture content. The objectives include development of a hydraulic-pulse experimental rig, selection of measuring equipment, formulation of process-efficiency indicators, investigation of coffee slurry, sugar beet pulp and distillery stillage, and comparison of the proposed method with conventional static and mechanical dewatering.

Materials and methods. The experimental hydraulic-pulse rig was developed on the basis of the IVPM-16 inertial vibropress-hammer. The machine incorporates a rigid frame mounted on vibration isolators, an auxiliary hydraulic cylinder for applying the static clamping force, a moving crosshead with adjustable inertial masses, upper and lower vibroimpact rollers, a vibrating table, return springs, a hydraulic-pulse drive, and a tray for the processed material. The hydraulic-pulse circuit includes a pump, flow regulator, single-cycle hydraulic accumulator, directional valves and a two-stage vibration exciter connected according to an inlet-control scheme.

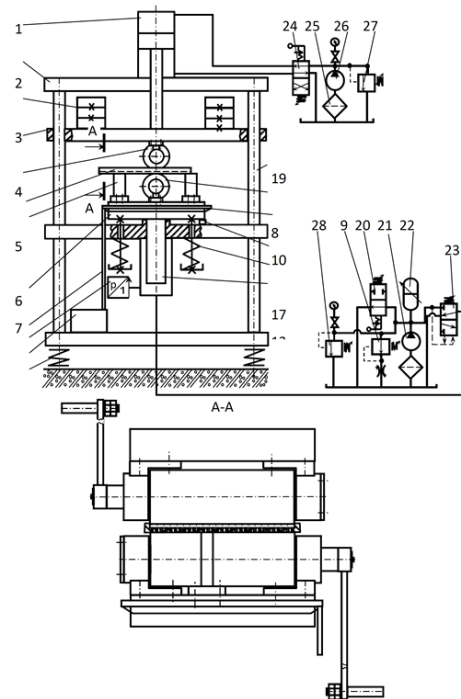


Fig. 1. Principal hydro-kinematic scheme of the experimental hydraulic-pulse rig for vibroimpact dewatering based on the IVPM-16 vibropress

The technological tooling is arranged so that the processed material is uniformly distributed in a 2-5 mm layer on a perforated steel tray covered with a dense filter cloth. The rollers press the material and simultaneously provide horizontal transport of the tray. Liquid passing through the filter fabric and 3 mm tray perforations is collected in an angular channel and discharged to a tank. Reversal of roller rotation permits repeated treatment of each material section and simulates the action of several consecutive roller pairs in a future industrial installation.

Such a design makes it possible to reproduce the main operating conditions of continuous mechanical dewatering while maintaining convenient control of the technological parameters. The thickness of the material layer, roller pressure, rotation speed, number of passes, and residence time in the deformation zone can be varied independently, which allows the influence of individual factors on moisture removal efficiency to be assessed. The perforated support surface ensures free drainage of the separated liquid, while the filter cloth prevents the loss of fine solid particles and reduces the risk of clogging of the tray openings.

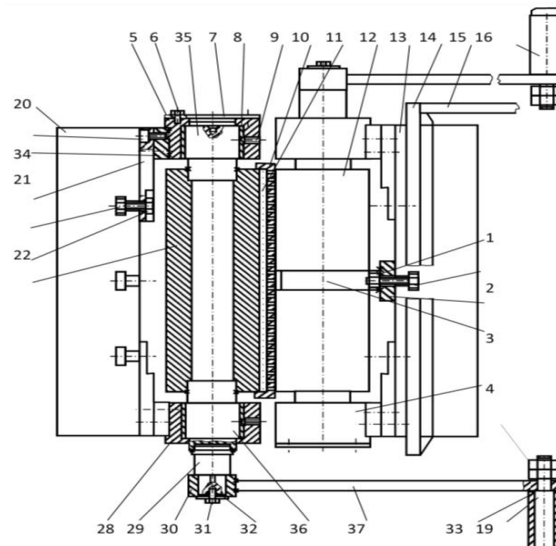


Fig. 2. Structural scheme of the technological tooling of the experimental hydraulic-pulse rig

Table 1

Main design parameters and technical characteristics of the experimental rig

Parameter	Unit	Value
Hydraulic-pulse cylinder plunger area, S_h	m^2	1.65×10^{-2}
Auxiliary cylinder piston area, S_a	m^2	7.85×10^{-3}
Total stiffness of vibrating-table return springs, C_y	N/m	2.4×10^6
Hydraulic accumulator working volume, W_a	m^3	$0-0.93 \times 10^{-3}$
Mass of lower moving assembly, m_I	kg	120
Mass of upper moving assembly, m_{II}	kg	80-300
Frame mass, m_f	kg	2100
Hydraulic-pulse pump delivery, Q_{n1}	m^3/s	1.1×10^{-3}
Maximum hydraulic-pulse pressure, p_{max}	MPa	14
Maximum auxiliary-drive pressure	MPa	6.3
Maximum force generated by hydraulic-pulse drive	N	2.3×10^5
Maximum auxiliary-drive force	N	5.0×10^4
Hydraulic-pulse motor power	kW	18.5
Auxiliary-drive motor power	kW	3.3

During operation, the upper roller is first lifted to insert the tray and then lowered until the required static clamping force is reached. The hydraulic accumulator is charged until the vibration exciter opens at a preset pressure p_1 , after which the working fluid rapidly enters the main cylinder and accelerates the vibrating table upward. When pressure falls to the closing level p_2 , the cylinder is

connected to the return line and the moving system travels downward under gravity and spring forces until impact occurs. Repetition of this cycle generates combined vertical static, inertial and vibroimpact loading. Slow counter-rotation of the rollers moves the tray horizontally through the loading zone.



Fig. 3 - Experimental hydraulic-pulse test rig (left) and its roller technological tooling (right)

The principal loading parameters were the vibration amplitude z_a and frequency ν of the vibrating table, the maximum pressure $p_{\max}$ in the hydraulic-pulse cylinder, and the tray travelling speed v_p . Effective variation of amplitude, frequency and pressure was obtained mainly by changing the flow-regulator opening area and the vibration-exciter opening pressure. The tray speed was controlled by the roller rotational speed and roller diameter.

The vibrating-table displacement and oscillation frequency were measured by a TURCK Ni8-M18-LiU displacement transducer. Hydraulic pressure was recorded by an ADZ-SML-10.0 pressure transducer. The analogue signals were digitised using an E14-140 ADC and processed using LGraph2 software. The displacement-time oscillogram was used to determine vibration amplitude and period, while the pressure channel provided the maximum working pressure during each test.

The liquid-removal capacity P_d [kg/min] was calculated as the ratio of the mass of liquid m_r removed from the material portion to the total dewatering time ΣT_d :

$$P_d = \frac{m_r}{\Sigma T_d} \quad (1)$$

The removed liquid mass was obtained from the difference between the initial mass m_i and final mass m_f of the material portion:

$$m_r = m_i - m_f \quad (2)$$

The specific energy consumption E_d [kWh/t] was determined from the total energy input ΣE_d and the removed liquid mass. The total energy input was calculated from the installed electric power N_{Σ} of the stand motors and the treatment time:

$$E_d = \frac{\Sigma E_d}{m_r}, \quad \Sigma E_d = N_{\Sigma} \cdot \Sigma T_d \quad (3)$$

Final moisture content U_f was determined gravimetrically after complete drying of the solid phase. All investigated materials had an initial moisture content of $U_i = 75\%$. For each setting of z_a , ν , $p_{\max}$ and v_p , experiments were repeated ten times; arithmetic mean values were used to construct the experimental dependencies.

The experimental results show a consistent influence of the loading parameters on all three efficiency indicators. Increasing vibration amplitude raises the liquid-removal capacity because the intensity of inertial and impact action on the dispersed structure increases. At the same time, the greater quantity of liquid removed during a given processing interval reduces the specific energy consumption per tonne of removed liquid and decreases the final moisture content.

Increasing excitation frequency produces a similar beneficial effect only up to a certain limit. For coffee slurry, the liquid-removal capacity reaches its maximum at approximately 35 Hz. Further frequency increase causes more intensive loosening of the lower layers of the material and reduces the time available for the separated liquid to flow through the filtering tray; part of the liquid may therefore be drawn back into the material layer. This explains the observed decrease in productivity beyond the frequency optimum.

Productivity trends obtained in the experiments are illustrated in Figure 4.

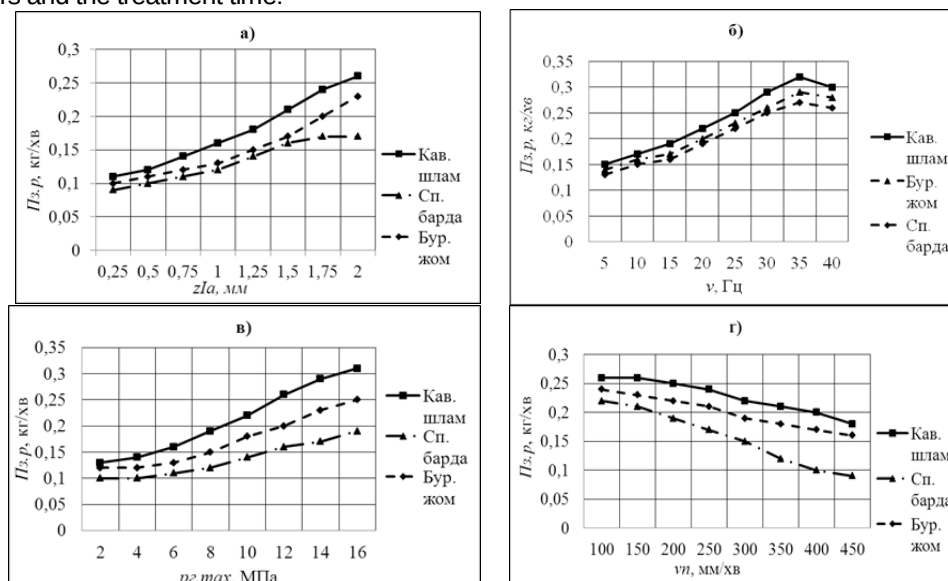


Fig. 4. Experimental liquid-removal capacity as a function of: (a) vibration amplitude; (b) vibration frequency; (c) maximum hydraulic pressure; (d) tray travelling speed. Original curve labels denote coffee slurry, distillery stillage and sugar beet pulp.

Among the studied factors, maximum hydraulic pressure has the strongest positive influence on productivity. Increasing $p_{\max}$ raises the dynamic force transmitted to the material and intensifies liquid

expulsion. In contrast, increasing tray speed reduces the residence time of each material section in the active loading zone. As a result, liquid-removal capacity

decreases, specific energy consumption rises and final moisture content becomes higher.

The final moisture data demonstrate that the method is effective for materials of different structure. The lowest value, 20%, was obtained for coffee slurry; sugar beet pulp reached 22%, and distillery stillage reached 24%. Although the three materials differ in particle structure, capillary network and liquid-binding conditions, the differences in their best efficiency indicators are relatively small, which confirms the broad applicability of the proposed loading principle.

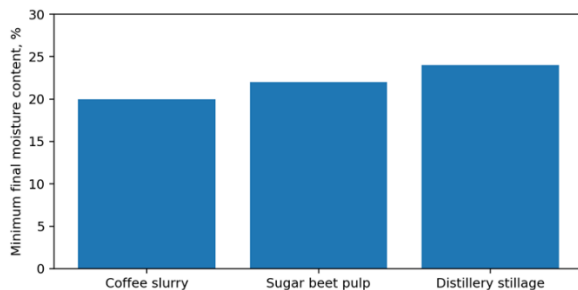


Fig. 5. Minimum experimentally achieved final moisture content for the investigated materials

The principal advantage of the proposed method is the substantially lower final moisture content compared with conventional mechanical dewatering. The source experimental materials report typical final moisture levels of 30-77% after belt presses, screw presses, decanter and vibratory centrifuges, and 80-90% after vibratory screens. In contrast, hydraulic-pulse vibroimpact treatment provided 20-24% final moisture for the investigated food-production wastes.

The experimental stand, being a research machine adapted from equipment originally intended for another process, does not yet outperform industrial screw presses in instantaneous liquid-removal capacity or specific energy consumption. For example, the VPD-7 screw press is reported to provide approximately 23.3 kg/min and 5 kWh/t during dewatering of distillery stillage. However, materials treated by a conventional screw press generally require subsequent thermal drying, which dominates the overall energy balance. The source data cite 2528 kWh/t for drum drying of distillery stillage, 2248 kWh/t for spray drying, 1275 kWh/t for double-roll drying, and 740-760 kWh/t even for comparatively economical vacuum drying of sugar beet pulp.

A direct comparison with static pressing is especially illustrative. Static pressing required at least 20 min and produced a minimum final moisture content not lower than 65%, whereas vibroimpact loading reduced the treatment duration to approximately 20-25 s in the comparative experiments. Moreover, the maximum force applied by the static hydraulic press was 1,271,700 N compared with 30,217.7 N for the hydraulic-pulse stand. These differences indicate that dynamic loading achieves substantially more effective

structural rearrangement and liquid release at much lower peak force.

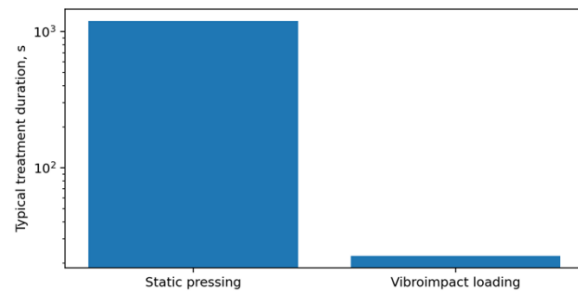


Fig. 6. Order-of-magnitude comparison of treatment duration for static pressing and vibroimpact loading.

Conclusions. 1. An experimental hydraulic-pulse rig based on the IVP-16 inertial vibropress-hammer was developed for studying combined static, inertial and vibroimpact dewatering of wet dispersed materials.

2. The principal process parameters are vibration amplitude, excitation frequency, maximum hydraulic-pulse pressure and tray travelling speed. Increasing amplitude, frequency and pressure generally improves dewatering efficiency, while excessive transport speed reduces residence time and process effectiveness.

3. A distinct frequency optimum exists. For coffee slurry, productivity increased up to approximately 35 Hz and then decreased because excessive vibration loosened the lower material layers and hindered irreversible liquid discharge.

4. At an initial moisture content of 75%, the minimum final moisture contents achieved experimentally were 20% for coffee slurry, 22% for sugar beet pulp and 24% for distillery stillage.

5. Compared with static pressing, vibroimpact treatment reduced the characteristic process time from at least 20 min to about 20-25 s and required a much lower maximum force, while providing substantially lower final moisture content.

6. The obtained results experimentally confirm the feasibility of hydraulic-pulse vibroimpact dewatering as a basis for the design of continuous industrial equipment intended to reduce or eliminate the need for subsequent energy-intensive thermal drying.

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ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ВІБРОУДАРНОГО ЗНЕВОДНЕННЯ ВОЛОГИХ ДИСПЕРСНИХ МАТЕРІАЛІВ НА ГІДРОІМПУЛЬСНОМУ СТЕНДІ

У статті представлено експериментальне обґрунтування енергоефективного способу віброударного зневоднення вологих дисперсних матеріалів харчових виробництв із використанням спеціально розробленого гідроімпульсного експериментального стенда на базі інерційного вібропрес-молота ІВРМ-16. Описано конструкцію стенда, його гідравлічний привід, технологічне оснащення та робочий цикл. Основними

параметрами навантаження, що визначають ефективність процесу, встановлено амплітуду та частоту коливань вібростолу, максимальний тиск у гідроімпульсному циліндрі та швидкість переміщення лотка з оброблюваним матеріалом.

Експериментальні дослідження проведено для кавового шламу, післяспиртової барди та бурякового жому з початковою вологістю 75 %. Ефективність процесу оцінювали за продуктивністю видалення рідини, питомими енергетичними витратами та кінцевою вологістю матеріалу. Експерименти показали, що збільшення амплітуди та частоти коливань, а також максимального гідравлічного тиску загалом підвищує продуктивність зневоднення та знижує як питомі енергетичні витрати, так і кінцеву вологість, тоді як збільшення швидкості переміщення лотка спричиняє протилежну тенденцію.

Встановлено наявність оптимальної частоти коливань, оскільки надмірна вібрація посилює розпушення нижніх шарів матеріалу та може сприяти повторному поглинанню відокремленої рідини. Досягнуто мінімальної кінцевої вологості на рівні 20 % для кавового шламу, 22 % для бурякового жому та 24 % для післяспиртової барди. Порівняння з традиційним статичним пресуванням показало істотне скорочення тривалості обробки та необхідного зусилля пресування, що підтверджує високий технологічний потенціал гідроімпульсного віброударного зневоднення для безперервної переробки вологих дисперсних відходів харчових виробництв.

Keywords: віброударне зневоднення, вологі дисперсні матеріали, гідроімпульсний привід, відходи харчових виробництв, експериментальний стенд, амплітуда коливань, частота коливань, гідравлічний тиск, питомі енергетичні витрати, кінцева вологість.

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