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VIBROIMPACT DEWATERING OF WET DISPERSED MATERIALS USING A HYDRAULIC IMPULSE DRIVE: EXPERIMENTAL VALIDATION AND EFFICIENCY ANALYSIS

The article presents the results of comprehensive experimental studies of the process of vibro-impact dewatering of wet dispersed materials using a hydro-impulse drive (HID). The relevance of the research is обусловлена the need to improve energy efficiency and intensify moisture removal processes from secondary raw materials and agro-industrial waste. An experimental hydro-impulse test bench was developed, designed, and manufactured based on the IVPM-16 vibro-press hammer, which provides the generation of controlled shock-vibration loads applied to the processed material.

During the study, the regularities of dewatering of such materials as coffee sludge, distillery stillage, and sugar beet pulp with an initial moisture content of about 75% were investigated. The influence of key technological parameters, including impulse frequency, vibration amplitude, working fluid pressure, and loading duration, on the intensity of moisture removal was determined. Experimental dependencies of process performance, specific energy consumption, and final moisture content on the operating parameters of the installation were obtained.

Rational operating modes of the hydro-impulse drive were established, ensuring minimum final moisture content: up to 20% for coffee sludge and 22–24% for sugar beet pulp and distillery stillage. A comparative analysis of the efficiency of the proposed method with conventional mechanical and thermal dewatering methods was carried out, demonstrating its advantages in terms of energy consumption and process intensity. The obtained results can be used in the development of energy-efficient technologies for processing wet dispersed materials in the food and agricultural industries.

Keywords: *hydraulic impulse drive, vibratory impact dewatering, wet dispersed materials, food production waste, productivity, energy consumption, final moisture content.*

Problem formulation. Dewatering of wet dispersed food production waste - including distillery stillage, brewery spent grain, sugar beet pulp, and coffee slurry - is one of the most energy-intensive and technologically important processes in the food industry [1, 2]. The key challenge lies in achieving sufficiently low final moisture content in the dewatered product while maintaining acceptable processing throughput and reasonable energy expenditure.

Conventional mechanical dewatering equipment - screw presses, belt presses, decanter centrifuges, and vibratory screens - typically yields a final moisture content of 30-90%, which necessitates subsequent thermal drying, drastically increasing the total energy consumption of the processing line [2, 3]. Thermal drying methods such as drum, spray, and double-roll dryers are characterized by extremely high specific energy consumption, ranging from 740 to 2528 kWh per tonne of removed moisture [2]. The development of improved dewatering methods capable of achieving final moisture content in the range of 20-25% without thermal post-treatment therefore represents an important engineering objective with considerable economic significance.

***Analysis of recent research and publications*.** The vibratory impact method of dewatering wet dispersed materials has been investigated in a number of prior works [4, 5, 6]. It was established that the combined application of static compression and high-frequency vibratory impact loading results in intensive disruption of capillary and adhesive forces retaining moisture within the solid matrix, enabling substantially lower final moisture content values than those achievable by static pressing alone.

Experimental investigations of the vibratory impact dewatering of food production waste carried out on an experimental prototype [4] demonstrated that the final moisture content following vibratory impact dewatering does not exceed 20-25%, with a processing throughput of 20-25 t/h and a specific energy consumption of 2.7 kWh/t - a marked improvement over single-stage mechanical pressing. However, the installations described in [4, 5] are characterised by considerable structural complexity and high material consumption, limiting their practical applicability.

The purpose of the article. The objective of the present investigation is to experimentally determine the efficiency parameters of the vibratory impact dewatering process of wet dispersed food production waste - namely, productivity, specific energy consumption, and final moisture content - as functions of the principal loading parameters, using a purpose-built experimental hydroimpulse stand, and to compare the obtained results with the performance characteristics of alternative dewatering methods.

Results of the researches. For experimental validation of the proposed vibratory impact dewatering method, an experimental hydroimpulse stand was developed and constructed on the basis of the IVPM-16 inertial vibroimpact press-hammer with a hydraulic impulse drive (HID) [7]. The principal hydro-kinematic scheme of the stand is presented in Figure 1; photographs of the stand and its technological tooling are shown in Figure 2.

The stand comprises a frame consisting of upper, middle, and lower crossbeams connected by columns and supported on vibration-isolating mounts. An upper vibratory roll is mounted on the movable traverse loaded with inertia weights; a lower vibratory roll is mounted on the vibrating table driven by the HID plunger. The processed material is placed in a perforated tray fitted with filter fabric between the rolls. The rolls are driven manually by handles, allowing stepless speed adjustment and reversal without a dedicated electric motor.

The HID comprises a pump, safety valve, flow regulator, single-cycle hydraulic accumulator, two-position directional control valve, and a two-stage vibration exciter. During operation, the vibrating table oscillates vertically under the action of the HID, subjecting the material portion between the rolls to combined vibratory impact, inertial, and static loading, which ensures rapid and complete removal of liquid from the material.

Fig. 1. Photographs of the experimental hydroimpulse stand for vibratory impact dewatering of wet dispersed materials and its technological tooling

The principal design parameters and technical characteristics of the stand are summarised in Table 1.

Table 1

Principal design parameters and technical characteristics of the experimental hydroimpulse stand

Parameter	Unit	Value
HID hydraulic cylinder plunger area S_g	m²	1.65×10^{-2}
Auxiliary hydraulic cylinder piston area $S_{d.g}$	m²	7.85×10^{-3}
Total stiffness of return springs c_y	N/m	2.4×10^{6}
Accumulator working volume range W_a	m³	$0 ... 0.93 \times 10^{-3}$
Mass of lower executive element m_I (plunger + table + roll + tray)	kg	120
Mass of upper executive element m_{II} (traverse + weights + roll)	kg	80 ... 300
Frame mass m_c	kg	2100
HID pump flow rate Q_{n1}	m³/s	1.1×10^{-3}
Maximum working pressure in HID system p_{max}	MPa	14
Maximum working pressure in auxiliary drive $p_{n.max}$	MPa	6.3
Maximum force generated by HID $P_{g.max}$	N	23×10^{4}
Maximum force generated by auxiliary drive $P_{d.g.max}$	N	5×10^{4}
HID electric motor power N_{e1}	kW	18.5
Auxiliary drive electric motor power N_{e2}	kW	3.3

Three types of wet dispersed food production waste were investigated: coffee slurry, distillery stillage, and sugar beet pulp, all with initial moisture content u_p = 75%. Processing productivity P [kg/min] was calculated as the ratio of removed liquid mass $m_{r.v}$ to process duration ΣT_z:

$$\Pi_{z.r} = \frac{m_{r.y}}{\sum T_z} \qquad (1)$$

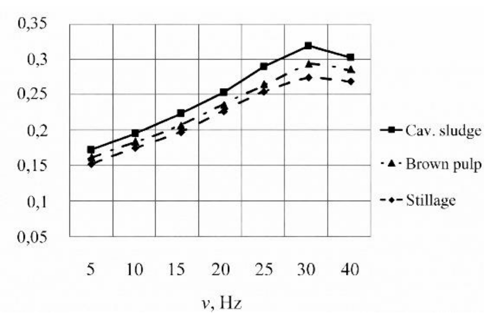
where $m_{r.v} = m_{m.p} - m_{m.k}$ is the difference between initial and final mass of the material portion.

Specific energy consumption E [kWh/t] was calculated as the ratio of total energy expenditure ΣE_z to mass of removed liquid:

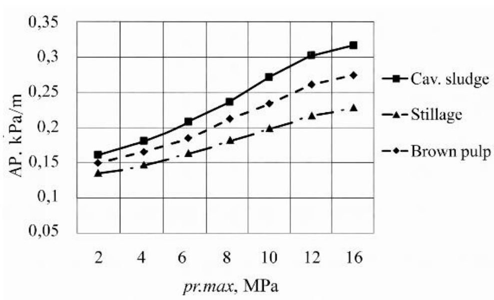
$$E_z = \frac{\sum E_z}{m_{r.y}} = \frac{\sum T_z N_{e\Sigma}}{m_{r.y}} \qquad (2)$$

where $N_e\Sigma$ is the total installed motor power of the experimental stand (see Table 1). Final moisture content Uk was determined by the gravimetric method. All experiments were repeated 10 times for each loading parameter combination, and arithmetic mean values were used for constructing dependency graphs.

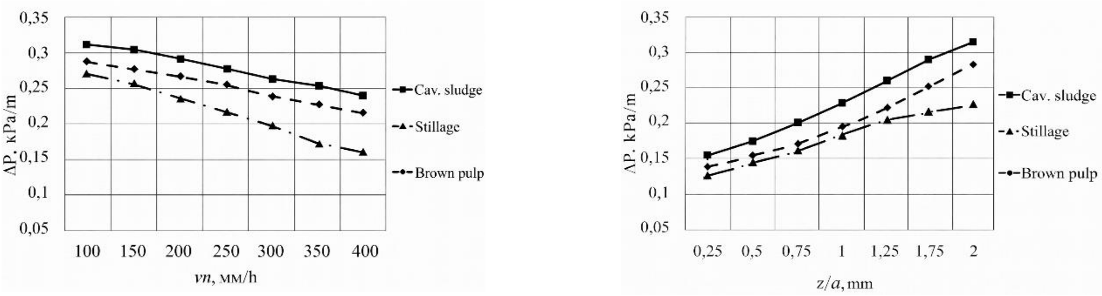
Figures 2-4 present the experimental dependencies of *P, E*, and U_k on the main loading parameters: vibration amplitude zIa, oscillation frequency v, maximum HID cylinder pressure pg.max, and tray displacement speed v_p.



a) vs z_{Ia}



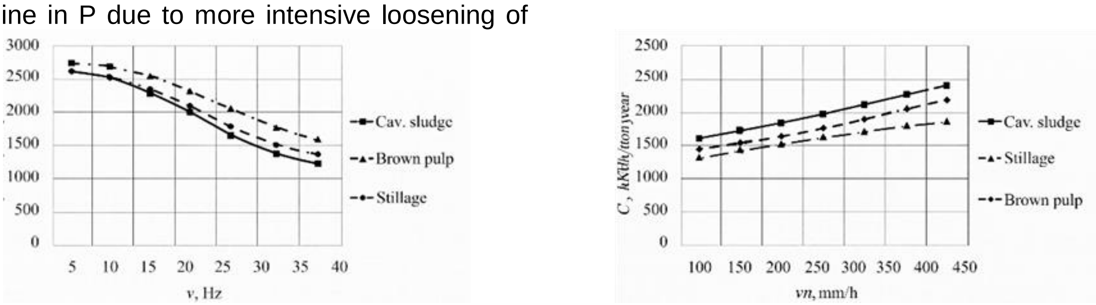
b) vs v



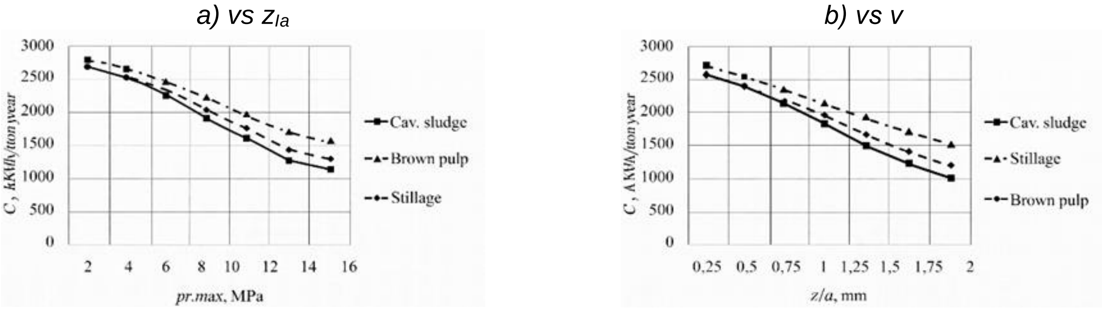
c) vs $p_{g.max}$ d) vs v_p

Fig. 2. Productivity P as a function of loading parameters

Productivity P increases with increasing z_{la}, v, and $p_{g.max}$, and decreases with increasing v_p. Increasing v beyond 35 Hz (coffee slurry) leads to a decline in P due to more intensive loosening of the lower material layers and inability of expelled liquid to drain rapidly enough. The most significant increase in P is achieved by raising $p_{g.max}$.



a) vs z_{la} b) vs v



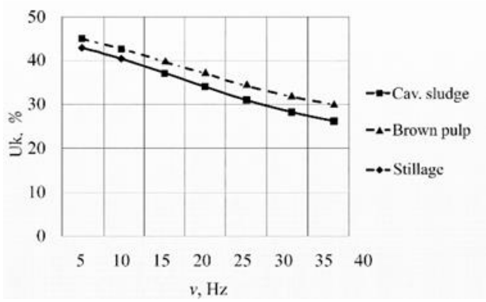
c) vs $p_{g.max}$ d) vs v_p

Fig. 3. Specific energy consumption E as a function of loading parameters

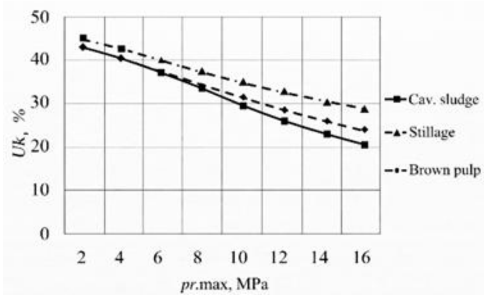
Specific energy consumption E decreases with increasing z_{la}, v, and $p_{g.max}$ (due to increased $m_{r.v}$), and increases with increasing v_p, explained by the reduction in dewatering duration per unit mass of material.

Final moisture content U_k decreases with increasing z_{la}, v, and $p_{g.max}$, and increases with increasing v_p. The lowest U_k of 20% was achieved for coffee slurry; beet pulp and distillery stillage were dewatered to minimum U_k of 22% and 24%, respectively. Overall, differences in efficiency parameters between the studied material types were not significant.

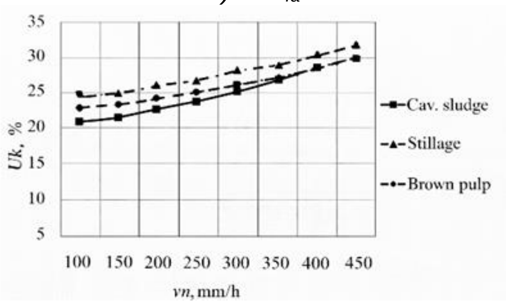
The principal advantage of the proposed vibratory impact dewatering method over other mechanical methods is the achievement of substantially lower final moisture content (U_k = 20-24%). Following dewatering of distillery stillage and brewery spent grain on belt and screw presses, decanter and vibratory centrifuges, U_k = 30-77%; on vibratory screens U_k = 80-90% [2, 3]. Certain screw presses for sugar beet pulp achieve U_k = 30-40%, but only at the cost of intensive clogging and reduced throughput [3].



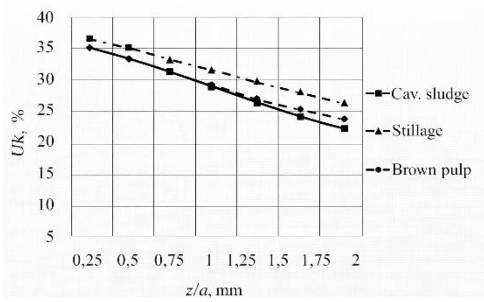
a) vs z_{la}



b) vs v



c) vs $p_{g.max}$



d) vs v_p

Fig. 4 Final moisture content U_k as a function of loading parameters:

A direct comparative experiment between static hydraulic pressing (2P-41 press) and vibratory impact loading on the experimental stand established that the minimum final moisture content after static pressing was no lower than 65%, versus U_k = 55% for the hydroimpulse stand. Duration of static pressing was ≥ 20 min, compared to ΣT_z = 20-25 s for vibratory impact dewatering. The maximum compressive force of the 2P-41 press amounted to 1,271,700 N versus only 30,217.7 N for the hydroimpulse stand [9], resulting in considerably lower energy expenditure for the latter.

Thermal drying of distillery stillage requires 2528 kWh/t on a drum dryer, 2248 kWh/t on a spray dryer, and 1275 kWh/t on a double-roll dryer. Vacuum dryers for beet pulp require E = 740-760 kWh/t [2]. The proposed method thus offers a pathway to complete elimination of energy-intensive thermal post-treatment while achieving the required moisture levels.

Conclusions. An experimental hydroimpulse stand was developed and constructed for the investigation of vibratory impact dewatering of wet dispersed food production waste, based on the IVPM-16 vibroimpact press-hammer with a hydraulic impulse drive.

Quantitative dependencies of productivity P, specific energy consumption E, and final moisture content U_k on loading parameters (z_{la}, v, $p_{g.max}$, v_p) were experimentally determined for coffee slurry, distillery stillage, and sugar beet pulp. The minimum achievable U_k was 20% for coffee slurry and 22-24% for beet pulp and stillage.

Comparative analysis demonstrates that the proposed vibratory impact dewatering method provides substantially lower final moisture content than conventional mechanical dewatering equipment, eliminating the need for energy-intensive thermal drying and offering significant reduction in total specific energy consumption.

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ВІБРОУДАРНЕ ЗНЕВОДНЕННЯ ВОЛОГИХ ДИСПЕРСНИХ МАТЕРІАЛІВ ІЗ ВИКОРИСТАННЯМ ГІДРОІМПУЛЬСНОГО ПРИВОДУ: ЕКСПЕРИМЕНТАЛЬНЕ ОБҐРУНТУВАННЯ ТА АНАЛІЗ ЕФЕКТИВНОСТІ

У статті наведено результати комплексних експериментальних досліджень процесу віброударного зневоднення вологих дисперсних матеріалів із застосуванням гідроімпульсного приводу (ГІП). Актуальність роботи обумовлена необхідністю підвищення енергоефективності та інтенсифікації процесів видалення вологи з вторинної сировини та відходів агропромислового виробництва. Розроблено, спроєктовано та виготовлено експериментальний гідроімпульсний стенд на базі вібропрес-молота ІВПМ-16, який забезпечує формування керованих ударно-вібраційних навантажень на оброблюваний матеріал.

У ході досліджень вивчено закономірності зневоднення таких матеріалів, як кавовий шлам, спиртова барда та буряковий жом із початковою вологістю близько 75%. Встановлено вплив основних технологічних параметрів, зокрема частоти імпульсів, амплітуди коливань, тиску робочої рідини та тривалості навантаження, на інтенсивність видалення вологи. Отримано експериментальні залежності продуктивності процесу, питомої енергоємності та кінцевої вологості від режимних параметрів роботи установки.

Визначено раціональні режими функціонування гідроімпульсного приводу, за яких досягається мінімальна кінцева вологість: до 20% для кавового шламу та 22–24% для бурякового жому і спиртової барди. Проведено порівняльний аналіз ефективності запропонованого способу з традиційними механічними та термічними методами зневоднення, який засвідчив його переваги за показниками енерговитрат та інтенсивності процесу. Отримані результати можуть бути використані при розробці енергоощадних технологій переробки вологих дисперсних матеріалів у харчовій та аграрній промисловості.

Ключові слова: *гідроімпульсний привід, віброударне зневоднення, вологі дисперсні матеріали, відходи харчових виробництв, продуктивність, енергоємність, кінцева вологість.*

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