The object of the study is to processing of organic waste using less energy-consuming technologies. This article discusses the issues of improving energy conversion methods aimed at efficient processing of organic waste using less energy-consuming technologies.

Shock waves and local micro sources of high temperatures and pressures destroy cellular and intercellular structures of organic material. In the course of experimental work, it was found that the effective isolation of valuable components from waste organic material depends on the discharge voltage and the capacity of the storage capacitor. During operation, the optimal temperature of the working medium was set in the range of 36–50°C and the maximum product yield was observed at an energy in the range of 120–240 J on the switching device. The maintenance of this temperature range is provided by a hydrodynamic installation, which creates a constant and uniform heating of the working cell of the electrohydroimpulse installation. Due to intensive hydrodynamic processes such as turbulence, cavitation, and local pressure drops, heat is distributed evenly, which ensures efficient processing of organic materials and process stability. The triglyceride fraction is an indispensable source of raw materials not only in the food industry, but also for medicine, construction, and industry (for lubricating machine parts and measuring instruments

Keywords: organic materials, electrohydroimpulse method, cavitation, inertial hydrodynamic installation, valuable components

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IDENTIFYING THE EFFECT OF THE TEMPERATURE REGIME OF A HEAT GENERATING UNIT ON THE EFFICIENCY OF THE ELECTROHYDROIMPULSE DEGREASING OF ORGANIC MATERIALS

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1. Introduction

Currently, work is actively underway to obtain new types of raw materials through the processing of agricultural waste and the development of methods for their use in production. The main goal before any processing industry is the tasks of efficient use of raw materials, reducing production waste, expanding the range of products and improving the quality of manufactured products. The widespread use of waste organic raw materials in the production of various products lies in the fact that it contains a large amount of highly digestible proteins, fats, calcium phosphoric salts, macro-and microelements, vitamins and amino acids. In order to extract the remains of organic raw materials, including valuable components from animal bones, in most cases, acid and alkaline treatments are carried out, which, in turn, worsen the composition and quality of the resulting product and raw materials. For this reason, it is effective to use electrohydroimpulse technology with continuous heating of the working environment with the help of hydrodynamic equipment in the efficient separation of calcium phosphorous salts, protein, fat, without acidic, alkaline effects on organic materials, processing for a short period of time [1].

The secondary use of nutrients from the processing of organic wastes for growing crops is important from an energy, economic [2] and environmental [3] aspect, as it allows the replacement of mineral fertilizer components in crop production without burdening the environment. Animal husbandry waste generated in the meat processing industry represents a large stock of material [4] that can be processed using various technologies.

In this regard, the development of new effective solutions for the extraction of valuable components from organic waste using underwater spark discharges remains an important technological challenge. The process of cavitation during electrohydroimpulse treatment plays a key role in the processing of organic waste.

Shock waves and local micro sources of high temperatures and pressures that occur during the collapse of cavitation bubbles destroy the cellular and intercellular structures of the bone matrix, where fat and protein are localized. This contributes to the destruction of fat cells, the destruction of their bonds with the organic matrix and the intensification of mass transfer. As a result, fat is more easily removed from the bone into the liquid phase, which provides a higher degree of degreasing and reduces processing time.

For effective destruction of cellular structures of organic materials, constant heating of the working cell is necessary. In electrohydroimpulse technology, this heating is provided by a hydrodynamic installation that transfers thermal energy not through direct electric heating, but through intense hydrodynamic processes such as turbulence, cavitation, and local pressure drops that occur when liquid passes through the working elements. This conversion of the mechanical energy of the flow into thermal energy ensures uniform heating of the working medium and at the same time reduces the total energy consumption of the installation.

The widespread use of waste organic raw materials in the production of various products, including a large amount of highly digestible proteins, fats, phosphorus-calcium salts, macro-and microelements, vitamins and amino acids. In most cases, acid and alkaline treatment is carried out to isolate valuable components from waste organic raw materials, which in turn spoils the final product and requires additional costs. Therefore, studies that are devoted development of new technological processes in the processing of materials are scientific relevance.

2. Literature review and problem statement

In the article [5], good results were obtained regarding the behavior of gas in various operating conditions. However, the range of pressures and flow rates limits the ability to study the operating mode. The geometric and structural configuration of the throttle valve is overly simplified and differs from industrial valves.

In the article [6], the temperature of the liquid in aerohydraulic systems is very specific, but they give good results. The effectiveness of the system works, but it limits the ability to generalize and transfer the results to an industrial scale. This does not take into account the external factors that sometimes affect the heating of the liquid.

The patent [7] describes a heat pump system for autonomous heat supply. The idea is very good, but the authors do not provide quantitative performance indicators, and there is also no operational test data. If the authors of the paper showed the limitations of the system's performance, then the result would be positive.

In [8], the efficiency of the heat pump was considered. However, the authors used a limited set of settings for this definition, which reduces the overall performance. To determine the actual performance of the system, the authors did not fully study the ambient temperature, humidity, and operating modes. All these indicators reduce the effectiveness of the received data.

The simplest technology for the disposal of these wastes is incineration in furnaces [9, 10]. However, some minerals are irretrievably lost. Another way is to recycle waste through physical and chemical processing into meat and bone meal. Meat and bone meal (MBM), due to its very high nitrogen and phosphorus content, can be used as an organic fertilizer.

An important role in the efficiency of the process is played by a hydrodynamic heater [11], which ensures stable and uniform heating of the working mixture. Heating is not carried out by direct electrical means, but by intensive hydrodynamic processes such as turbulence, cavitation, and local pressure gradients [12, 13]. This contributes to a more uniform heat and mass transfer and a reduction in overall energy consumption.

Currently, work is actively underway to find effective ways to process not only waste from the agro-industrial complex, but also waste from many processing enterprises at low temperatures. Many organic waste recycling operations are carried out in well-known heated liquids.

All this allows to assert that it is advisable to conduct a study to evaluate the effectiveness of using an alternative inertial hydrodynamic installation with constant heating in combination with electrohydroimpulse technology to intensify the processing of organic materials, determine the optimal processing modes and the degree of destruction of organic compounds while reducing energy consumption and ensuring the environmental safety of the process.

3. The aim and objectives of the study

The aim of the study is to identifying the influence of the electrohydraulic effect and the temperature of the liquid on the degreasing of organic material. This will reduce energy consumption and at the same time ensure the environmental safety of the process.

To achieve this aim, the following objectives were accomplished:

– to determine the effectiveness of using an alternative inertial hydrodynamic installation to maintain the temperature of the working medium;

– to determine the efficiency of constant heating and electrohydroimpulse technology to obtain optimal processing parameters for organic materials;

– to determine the effectiveness of the chosen technology on the degree of destruction of organic compounds.

4. Materials and Methods

The object of the study is to processing of organic waste using less energy-consuming technologies.

The main hypothesis of the study is that electrohydroimpulsive action causes underwater spark discharges with shock waves affecting the liquid inside the bone matrix and simultaneously displacing it, which contributes to the effective release of valuable components onto the surface of the aquatic environment. This process continues continuously for several minutes. The temperature created by the hydrodynamic installation allows to constantly maintain the required temperature regime during the experiment.

The following assumptions were made in the course of the study: the mixture in the working cell does not heat up during electrohydraulic action, and the electrode system does not collapse.

During the study, the following simplifications were adopted: bone mass is not crushed into small particles, and the possibility of extraction allows the use of bone fractions with a diameter of 2–10 mm for further processing. Experimental studies using electrohydroimpulse technology were conducted in the laboratory "Hydrodynamics and Heat Transfer" of the Department of Engineering Thermophysics named after Professor Zh. S. Akylbaev of the Karaganda National Research University named after academician Ye. A. Buketov (Karaganda, Republic of Kazakhstan) [14].

In the heating system proposed by the authors, electrical energy is sequentially converted: first, to the mechanical one due to the rotation of the rotor, then to the hydraulic one due to the movement and rotation of the mass of the coolant, and finally to the thermal one in the process of throttling the flow. Based on this principle, a full-size experimental stand has been developed, designed for experimental research of the efficiency of thermal energy generation.

Fig. 1 shows an alternative inertial hydrodynamic installation.

In the system shown in Fig. 1, an electric motor located in the housing of an inertial hydrodynamic installation rotates the rotor. The rotor design is a hollow cylindrical drum with a conical skirt, the lower part of which is constantly immersed in liquid. Throttle holes with calibrated holes are located on the side surface of the drum. The VESPER frequency converter regulates the speed of rotation of the rotor in the range from 0 to 3000 rpm. A temperature relay is provided to control and limit the maximum water temperature in the radiator.

To confirm the analytical calculations, a full-size experimental stand of an inertial hydrodynamic installation was created (Fig. 1) with the following technical characteristics:

– the volume of liquid in the installation – 0.02 m^3;

– the volume of the rotor cavity – 0.0014 m^3;

– the depth of immersion of the rotor skirt in the liquid – 0.07 m;

– angular rotational speeds of the rotor – 142, 176, 208, 248 rad/s;

– the total area of the throttle openings:

a) $\delta = 31.4 \cdot 10^{-6}$ m^2;

b) $\delta = 64.34 \cdot 10^{-6}$ m^2;

– the initial temperature of the liquid – 20°C [15].

The depth of immersion of the rotor skirt is selected from the condition of stable fluid flow between the cavities of the installation. Based on the averaged results of multiple measurements, graphs of the dependence of the liquid heating temperature on the angular velocity of the rotor and the total area of the throttle openings are constructed. The temperature spread of the experimental points did not exceed 6%.

Based on previous studies [16–18], it has been established that the most effective extraction of a valuable component from an organic residue under the influence of shock waves occurs within the temperature range of 36–50°C of the working medium. At this temperature, the natural balance of adipose tissue and enzyme systems is maintained. The structure of the oil does not change under normal conditions at the same temperature, therefore, during the shock wave, the fat phase is redistributed. It was found that with an increase in the capacitance of the capacitor bank and the interelectrode spacing, the degree of separation of valuable components from the organic residue increases, and the extraction rate stabilizes with increasing capacity. In addition to these parameters, it is also important to determine the optimal energy on the switching device. It is the most important condition for stable and efficient operation of an electrohydroimpulse installation.

The intensity of shock waves and cavitation processes, the degree of destruction of the organic matrix, and the rate of extraction of valuable components depend on the amount of energy released. The control of this parameter makes it possible to ensure high processing efficiency with minimal energy costs and preserve the structure of the source material.

The test sample is placed in the working cell and the cell is filled with water in an amount of 1/3. The samples are the remains of cattle. 1 sample is femoral bone, 2 sample is vertebral bone, 3 sample is thoracic bone. Before the experiment, the samples are mechanically crushed, disassembled into fractions and weighed on an electronic scale. The working cell, which allows the processing of organic waste, is continuously heated using an alternative inertial hydrodynamic installation through the outer mesh of the cell and maintained at a constant temperature (ranging from 36–50°C).

The scheme of the working installation is shown in Fig. 2.

a *b* *c*

Fig. 1. Alternative inertial hydrodynamic installation: *a* – section of the installation; *b* – general view of the installation; *c* – test bench: 1 – rotor, 2 – electric motor, 3 – central fixed disk, 4, 5 – coolant supply and discharge channels, 6 – fixed rack

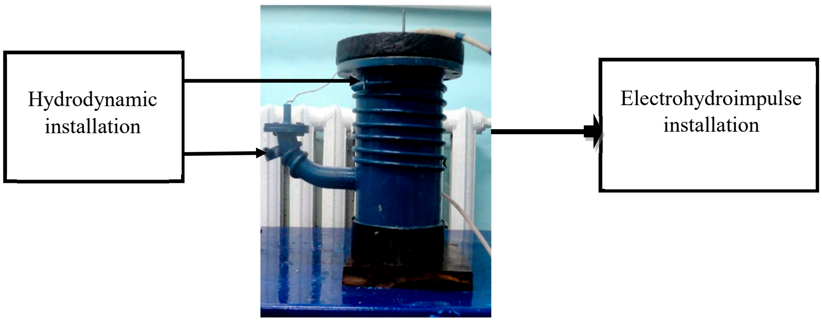

Fig. 2. An installation for extracting valuable components from organic waste

The principle of operation of the electrohydroimpulse installation is described in [16]. In case of pulsed electric discharge, the expansion of the discharge cavity leads to the formation of shock waves. When a shock wave passes through the processed materials, microcracks form in the particles, which contribute to the splitting of valuable components retained by the tissues in the sample structure. In addition, regular heating of the working cell ensures intensive extraction of a valuable component from the remains of organic raw materials. The working cell is wrapped in a tube, with the help of a tube, heated liquid by a hydronamic installation maintains the optimal temperature of the working medium. Maintaining a constant temperature reduces energy consumption by about half and increases plant productivity by 2 times. The maximum discharge voltage in the air gap reaches up to 35 kV. For experimental research work, the voltage varied from 15 to 25 kV. When shock waves occur in an aqueous medium, under the action of pulses of 7–15 Hz, water penetrates into organic raw materials and destroys its structure, so the fat mass moves into solution.

5. The results of the study of the effect of the electrohydraulic effect and the temperature of the liquid on the degreasing of organic material

5. 1. Using an alternative inertial hydrodynamic installation for temperature maintenance

During the testing of the prototype in idle mode, the installation was checked for tightness, structural components were checked for strength, supply and outlet lines were checked, and measuring and recording equipment was adjusted.

The maximum possible limits of the rotor speed have been established, taking into account theoretical calculations. Comparison of indicators of theoretical and experimental studies.

These settings are shown in Table 1.

An increase in the angular velocity of the rotor in a quadratic relationship affects the pressure of the liquid in the channels and in front of the throttle openings. a fixed disk. When the flow flows through the throttle device, a decrease in pressure is observed, accompanied by an increase in the velocity of the liquid. This process causes a change in entropy and, as a result, a change in the temperature of the working medium.

According to research, for the effective destruction of fat cells and their subsequent separation by the electric pulse method, it is necessary to maintain a constant temperature of the girdle heater at 36–50°C.

Practical work began at a temperature of 32°C. This is due to the fact that the melting point of cattle fat is in the range of 32–50°C. At this temperature, the natural balance of adipose tissue and enzyme systems is maintained. The oil structure is stable under normal conditions at this temperature, so the oil phase is redistributed during the shock wave. The results of the study show that the temperature of the mixture, which determines the zone of destruction of the matrix of the starting material, should be at least 32°C. Restrictive flow characteristics of throttle openings with a change in the number of throttles and their maximum area are obtained.

Table 1

Frequency parameters of the converter and the circumferential speed of the rotor

ν, Hz	Revolutions per minute
16.83	1000
18.46	1100
20.14	1200
21.88	1300
23.81	1400
25.29	1500
27.03	1600
28.52	1700
30.17	1800
31.92	1900
33.57	2000
35.26	2100
36.9	2200
38.91	2300
40.19	2400
41.682	2500
43.49	2600
45.17	2700
46.70	2800
48.42	2900

The frequency converter has been adjusted to match its parameters with the circumferential rotation speed of the rotor.

The configured operating modes are of fundamental importance not only for hydrodynamic tests, but also for further use of the installation as part of an electrohydroimpulse system. Since the hydrodynamic installation performs the key function of heating the working mixture, it is important to ensure the stability of turbulent and cavitation flows that occur when liquid passes through the working elements [19].

5. 2. Investigation of constant heating and electrohydroimpulse technology to obtain optimal parameters for the extraction of organic materials

In papers [16, 17], one of the main parameters of an electrohydroimpulse installation for intensive isolation of a valuable component from organic waste was established. The results of the above studies have shown that the temperature of the mixture, which determines the zone of destruction of the matrix of the raw material, should be at least 32°C, the diameter of the processing fraction is less than 10 mm, the applied voltage is $U = 25$ kV, and the capacitor bank capacity is $C = 0.4$ μF. Further, for the efficient operation of the installation, the dependence of the degree of extraction of valuable components from organic waste at different energy levels in a switching device was considered. The results of the study are shown in Fig. 3.

To determine the amount of fat in the waste of organic raw materials, another type of method, the method of mass loss, was used.

The mass fraction of fat (Δm) in percent is determined using the following formula:

$$\Delta m = \frac{(m_1 - m_2)\cdot 100\%}{m_1}, \quad (1)$$

where m_1 – the mass of the sample taken for examination, g; m_2 – the mass of the sample after processing, g.

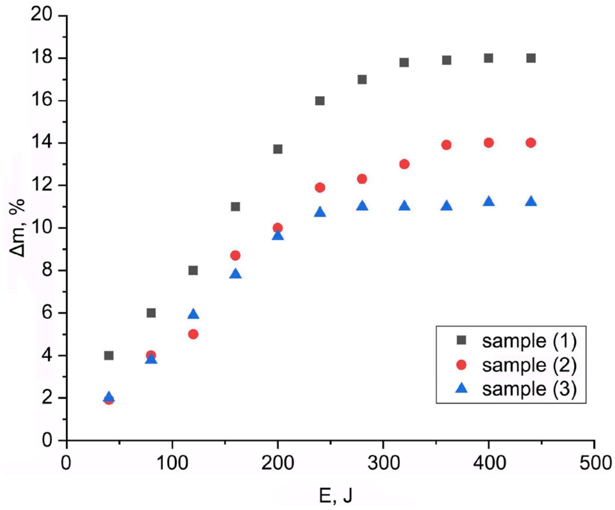

Fig. 3. Dependence of the degree of degreasing of organic waste at a temperature of 36°C on the energy values in the switching installation

In the graph, Δm, % – the amount of fat release, E, J – the energy supplied to the working channel. 1 sample – femoral bone, 2 sample –vertebral bone, 3 sample – thoracic bone.

For sample 1, the most intense increase in the degree of degreasing is observed. At an energy of about 280 J, an indicator of 17% is reached, after which the indicator stabilizes.

Sample 2 shows a more moderate growth, with a maximum of about 12–13%, and also begins to stabilize at $E > 320$ J.

Sample 3 shows the smallest effect, the growth of Δm is limited to about 10–11% and slows down at high energies.

5. 3. Investigation of the effectiveness of the chosen technology on the degree of destruction of organic compounds.

To determine the effectiveness of the applied method, a spectral analysis was carried out on the Fourier spectrometer FSM 1201. Fig. 4 shows the spectrum of organic raw material residues before treatment with electrohydroimpulse technology.

Fig. 5 shows the spectrum of organic raw material residues after treatment with electrohydroimpulse technology.

As a result of electrohydroimpulse treatment, the infra-red spectrum of the sample showed that the organic matrix (collagen, lipids) had undergone structural changes. The weakening of the amide bands and the appearance of new carbonyl signals in the region of 1700–2000 cm^{-1} means partial breakdown of collagen. In addition, the determination of the phosphate mineral zone (500–1200 cm^{-1}) indicates the preservation of the bone mineral and that the mineral phase looks better as a result of the destruction of the organic matrix. It was written in [20] that the main mineral composition of bone is hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$). Due to high electrical discharges in the water, the crystal structure of hydrosipatite is rearranged and mineralized.

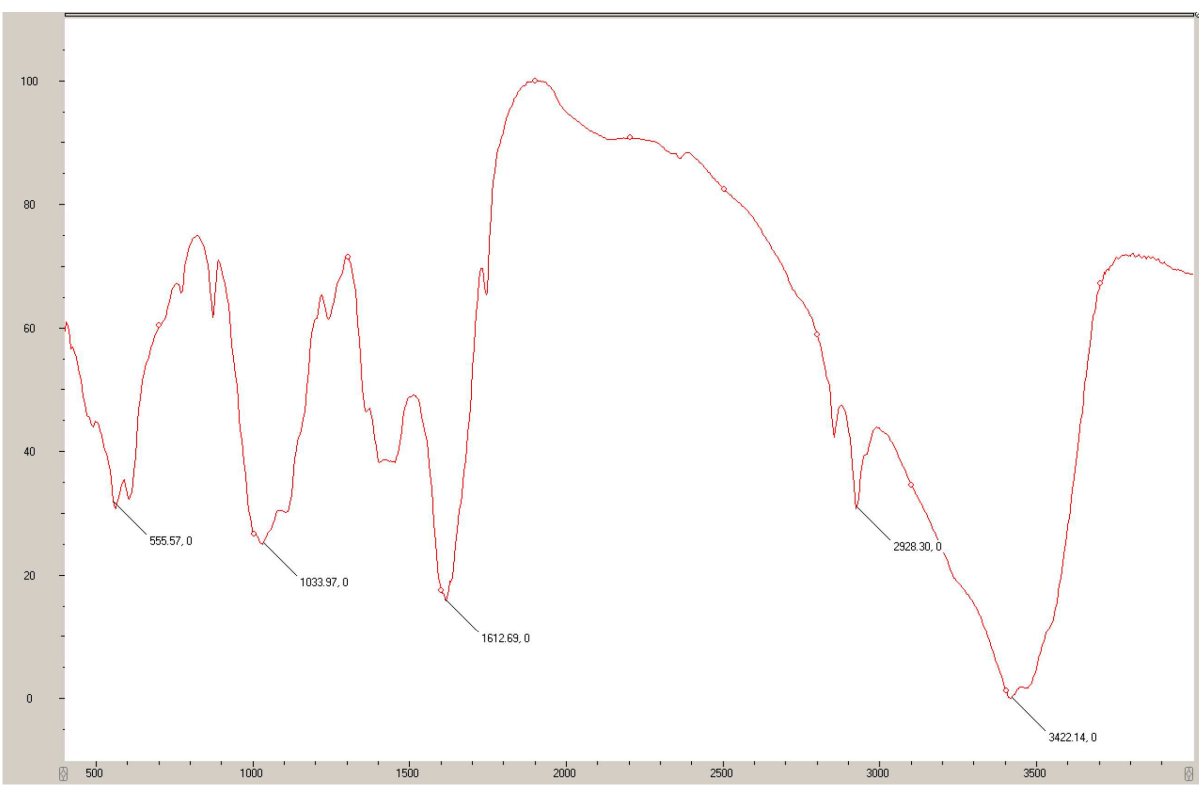

Fig. 4. Infra-red absorption spectrum of organic raw material residue

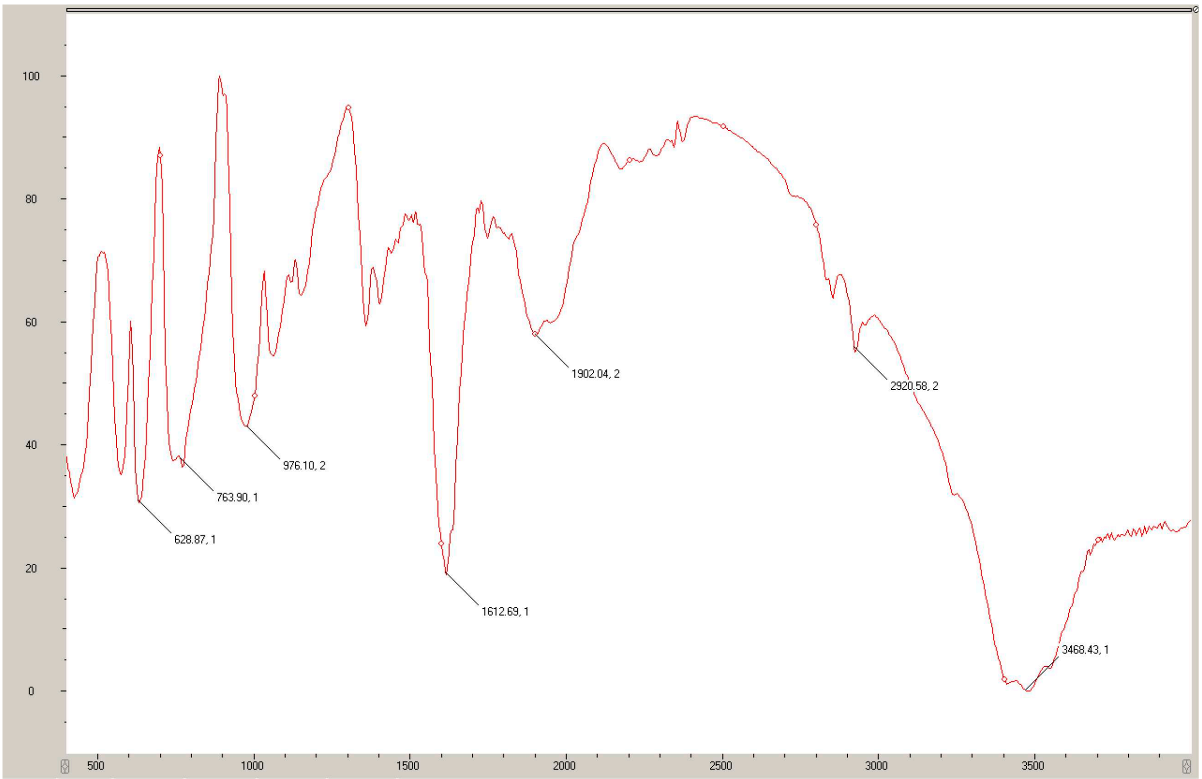

Fig. 5. Infra-red spectrum of organic raw material waste treated with electrohydroimpulse technology

The preservation of aliphatic bands (2920–3000 cm^{-1}) in the high-frequency zone indicates a change in lipid composition. The change from 3422 cm^{-1} to 3468 cm^{-1} indicates a change in hydrogen compounds, i.e., the course of the extraction process under the action of an electrohydroimpulse in the organic residue. And the preserved peak of 1612 cm^{-1} indicates partial preservation of the protein structure. But the pulse energy affected the structure of the raw material, which it is possible to observe by changing the shape of the peak. The formation of a new peak of 1905 cm^{-1} indicates the appearance of new chemical bonds (carbonyl groups). These chemical bonds explain the change in the composition of the element mentioned above.

6. Discussion of the results obtained in the study of the effect of electrohydroimpulse technology and liquid temperature on the degreasing of organic waste

For effective destruction of cellular structures of organic materials, constant heating of the working cell is necessary. In electrohydroimpulse technology, this heating is provided by a hydrodynamic installation that transfers thermal energy not through direct electric heating, but through intense hydrodynamic processes such as turbulence, cavitation, and local pressure drops that occur when liquid passes through the working elements [18]. This conversion of the mechanical energy of the flow into thermal energy ensures uniform heating of the working medium and at the same time reduces the total energy consumption of the installation.

Disadvantages of a large installation, unstable temperature regime, since heating is carried out using a heater, in turn, errors appear in the temperature range from 32 to 50 degrees.

As can be seen in Fig. 3, increasing the temperature of the working mixture with the help of a hydrodynamic installation from 32°C to 50°C accelerates the degreasing process and allows achieving maximum values with lower energy consumption. The efficiency remains the highest for sample 1 and the lowest for sample 3, which confirms the difference in the structure and composition of the initial organic residues.

The results of the conducted study have shown high efficiency in the processing of organic raw material waste from shock wave processes resulting from electrohydroimpulse discharges. In particular, under the influence of shock waves, the structure of the soft tissues of the recycled organic residue is destroyed, and the release of fat and protein compounds is ensured. In addition, after electrohydroimpulse exposure, the mineral composition of organic raw material waste increased, in particular, the relative proportion of the calcium, magnesium, and manganese, which, in turn, expands the scope of application of the final product.

The results of the analysis of the obtained spectra in Fig. 5, 6 indicate the correctness of the laboratory work done, i.e. that the electrohydroimpulse effect is sufficient to destroy the structure of the raw material and release fat and protein.

In Table 1, the restrictive flow characteristics of the throttle openings are obtained with a change in the number of throttles and their maximum area.

The frequency converter has been adjusted to match its parameters with the circumferential rotation speed of the rotor.

The configured operating modes are of fundamental importance not only for hydrodynamic tests, but also for further use of the installation as part of an electrohydroimpulse system. Since the hydrodynamic installation performs a key function – heating the working mixture, it is important to ensure the stability of turbulent and cavitation flows that occur when liquid passes through the working elements.

Fat extracted from organic material is used in the production of tool oils both in its pure form and as a component. They are used to lubricate watch mechanisms, telephone and telegraphic equipment, control and measuring and other precision devices [21].

Thus, electrohydroimpulse technology with an alternative inertial hydrodynamic installation for maintaining the temperature of the working mixture can be considered as a promising and environmentally friendly way of processing organic waste and obtaining secondary raw materials with high added value.

The limitations of this study include the fact that after experimental work, the need to store samples for subsequent processing and obtain a spectrum of organic raw material residues after treatment with electrohydroimpulse technology. Also, experimental work does not allow to fully take into account the impact of scaling the process during the transition to industrial conditions. The results obtained are valid for the studied modes of electrohydroimpulse action, the geometry of the electrodes and the heating parameters of the working medium and may change as they vary.

Further development of the study should be directed to the study of the effect of electrohydroimpulse treatment on various types of organic raw materials, as well as the development of mathematical models describing the processes of cavitation, heat and mass transfer and destruction of the organic matrix. An important area of further work is the assessment of the environmental aspects of the technology and its industrial applicability.

7. Conclusions

1. During the study, it was found that an increase in the angular velocity of rotation of the rotor according to a quadratic dependence leads to an increase in the pressure of the working fluid in the channels and in front of the throttle openings of the fixed disk. When the flow passes through the choke device, a pressure drop occurs, accompanied by an increase in the velocity of the liquid. These processes cause a change in entropy and, as a result, a change in the temperature of the working medium. According to study, for the effective destruction of fat cells and their subsequent separation by the electric pulse method, it is necessary to maintain a constant temperature of the girdle heater at at least 36°C. The specified temperature is stably ensured by the operation of the inertial hydrodynamic installation.

2. In the course of experimental work, it was found that electrohydroimpulse technology is effective even at low temperatures, i.e. at a temperature of 36–50°C, for the destruction of the intercellular tissue of durable organic material while releasing valuable components. It is also determined that the maximum output of the degreasing agent is observed with the supplied energy in the range of 120–240 J in the switching device. It is this range that provides the optimal combination of the intensity of the pulse action and the degree of destruction of lipid structures in organic raw materials.

3. The results of the infra-red spectrum study showed that after the treatment of the studied object, the organic matrix (collagen, lipids) underwent structural changes. The weakening of the amide bands and the appearance of new carbonyl signals in the region of 1700–2000 cm^{-1} means partial breakdown of collagen.

Conflict of interest

The authors declare that there is no conflict of interest regarding this study, including financial, personal, authorship or other nature that could affect the study and its results presented in this article.

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Data availability

Data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies in creating the submitted work.

Authors' contributions

Bekbolat Nussupbekov: Conceptualization; Writing – original draft; Writing – review and editing; Moldir Duisenbayeva: Methodology; Investigation; Writing – original draft; **Yerlan Oshanov**: Investigation; Resources; Project administration; **Amangeldy Satybaldin**: Data curation; Formal analysis; Validation; **Raikhan Turlybekova**: Writing – review and editing; Visualization; Supervision.

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