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Justification of the operating parameters of the drive of the vibrating machine for cleaning and changing the properties of water

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ABSTRACT

The work presents the results of the study of the impact of hydrocavitation on the change in the properties of water and its purification in the vibrating machine. The design of the vibration machine is proposed to change the properties of water and purification. Due to the reciprocating motion of the piston with a hole in a water tank, there is a cavity process in a liquid passing through the hole. At certain frequencies of oscillations in the hole there is a catering cavernous, in which the process of splitting of water molecules into active radicals and rupture of hydrogen bonds in water molecules occurs. The analytical model of motion of ideal fluid in the piston opening is investigated and the interconnection of the parameters and modes of the actuator is established. The dependence of maximum pressure in the opening in the piston on the frequency of vibrations for real liquid was experimentally established and the effects of cavitation on the operating modes of the drive of the machine were detected. The rational frequency limits of the machine actuator of the machine, which are in the range from 13 to 15 Hz with amplitude of oscillations of 0.002 m and in the diameter of the piston 0.1 m are recommended to use the diameter of the hole in the piston from 0.01 m. Calculation of maximum pressure in the hole in the piston with a hole, which makes it possible to justify the optimal modes of operation of the drive of the machine. In order to confirm the practical use of the vibration machine, studies were conducted, which showed a decrease in the content of salts and an increase in pH from 7.3 to 9 units, the total mineralization rate - TDS is reduced after cavitation processing. The reduction of the or 180 units of or 180 indicates an increase in the oxidation of fluid renewable potential. The results of the change in the time of settling make it possible to argue that the cavitation effect changes the structure of fluid and reduces surface tension and other indicators when settling is stabilized at a new qualitative level.

Keywords: vibration machine, hydrocavitation cleaning, changes in water properties, drive modes.

INTRODUCTION

Water is the basis of our life and today water consumption is increasing all over the planet. Therefore, the problem of using fresh water and, especially, cleaning the growing volumes of wastewater, as well as the organization of closed water consumption systems in industry, agriculture and municipal services is becoming increasingly important [1–5]. Water is an important component of the life process. It plays the role of not only a chemical solvent, but is a keeper and carrier of information, carries the codes of life processes, and as science develops, new processes of influence on humans and technology are discovered through the influence on water, through new physical principles and phenomena of activation of water and water systems.

Currently, many designs of equipment have been created for the purification of any industrial and municipal waters. Unfortunately, most of them are being mastered very slowly, or not mastered at all. Therefore, the development of technologies and equipment for reagent-free water purification, changes in water properties and activation is an urgent problem.

The complex organization of the water structure, as a single ensemble, including super supramolecular complexes, leads to the fact that the properties of the water system are not a simple sum of the properties of individual structural elements, but a new quality arises – the property of corporatism. For reagent-free purification and change in water properties, the greatest technological interest is represented by hydrodynamic cavitation devices, in which a local pressure drop is formed in the flow of the treated liquid and hydrodynamic cavitation develops due to a sharp change in the geometry of the liquid flow. The energy for the occurrence of cavitation is supplied directly by the technological flow of the liquid (static hydrodynamic devices) or by a rotating cavitator (dynamic hydrodynamic devices).

In a liquid, cavitation occurs on a single nucleus. Then, over time, in several dozen oscillation periods, microbubbles develop into a stable region consisting of many cavitation bubbles. The process of development of the cavitation region is presented as follows. When splashing, a cavitation bubble can lose stability and break into parts, and despite the fact that the pressure and temperature in the bubble at this moment are maximum, the pressure and temperature of the vapor-gas mixture in the fragments that have formed are also increased. In the stretching phase, they easily expand and become new cavitation nuclei, less strong than those present in the liquid. Cavitation cavities that have arisen in these nuclei generate new ones. Inside the cavitation region, there is a continuous process of reproduction and coagulation of cavitation bubbles, and the cavitation threshold decreases slightly, because in the established mode, the role of cavitation nuclei begins to be performed by equilibrium bubbles, the volume and gas content of which are greater than that of the nuclei.

Of great importance for water quality is the change in the coefficient of surface tension of water. Tap water is very different from the water surrounding the tissues and cells of the human body. Hydrocavitation is able to reduce the surface tension of the liquid to values almost equal to the surface tension of human blood [6,7]. This facilitates the transport of nutrients directly into the cells and promotes the removal of toxins from the body. When using structured water, the electrical conductivity of the body increases, which leads to a decrease in energy expenditure for the penetration of water molecules through the cell membrane, and the body is also supplied with electrons necessary for the exchange of information at the cellular level.

Many authors [8–17] note that as a result of the activation of water systems by hydrocavitation, the surface tension, viscosity, electrical conductivity, gas solubility, the width of nuclear resonance lines, the speed and nature of precipitation from solutions of some salts change, and the biological activity of aqueous solutions also increases. Water saturated with hydroxyls, entering plant cells, enriches them with electrons, which sharply enhances electron-proton transport, which is the basis of metabolism. The rate of synthesis of ATP, proteins, nucleic acids and other cell components increases sharply.

In existing studies [16, 17], the determination of the productivity of a vibrating machine for cleaning the surfaces of parts and the cavitation effect on the aqueous medium of a membrane-type vibrating machine were considered. The authors proposed the results of studies of multiple passage of liquid through the hole in the piston of a pulsating equipment, which performs a reciprocating movement of the liquid and increases the cavitation effect on the aqueous medium over the processing time.

RELEVANCE OF RESEARCH

The creation of small-sized vibration machines for individual use, in which hydrocavitation occurs to change the properties of water, and the determination of optimal operating parameters of the vibration machine drive are urgent tasks.

METHODS

Experimental equipment was created to conduct research into the impact of hydrogenation on water – a piston type vibration cavitator (Figure 1, Figure 2).

The vibration machine works as follows – the water is poured through the inlet fitting into a cylindrical capacity with a diameter *D*, in which the piston 4 with a hole *d* is fixed on the rod 3. The stem 3 is connected to the eccentric vibration drive 2, which is driven by the DC electric motor. The use of a DC motor makes it possible to change the frequency of oscillations, and the change in the magnitude of the amplitude of oscillations is made by change of eccentric with eccentricity 1,2,3 mm. After switching on the motor 1, the eccentric begins to rotate and leads to reciprocating motion of the rod 3 and a piston 4. Through the hole *d* with sharp edges, water passes repeatedly. When passing water through the hole with sharp edges in the piston periodically, a cavity in the hole is periodically formed, and in the lower part of the container under the piston periodically, receipt bubbles occur when it goes up, which energy and its properties.

To measure water parameters, namely: pH, oxidative-restorative potential, general mineralization, devices were used: PH Meter (PH-061), ORP Tester 169B, TDS-3.

In order to find out the nature of the water leakage processes (20 °C), a transparent layout was developed through the reciprocating motion through the hole (narrowing of the fluid flow) on which the necessary modes could be implemented (Figure 3). The movement of the liquid was recorded by a digital camcorder with subsequent processing and conversion of information into a computer file. In Figure 3 shows the experimental installation for speeding of the picture of water movement.

Figure 1. The general appearance of the piston type vibration cavitator

To measure the instantaneous value of the maximum hydrodynamic pressure of the pulsating jet from the hole, a tensometric pressure sensor MRM489 and USB oscilloscope VM8020, which is connected to a personal computer through a USB port, is used and serviced by the Disco software. The MRM489 pressure sensor is installed above the nozzle at a distance of 10 mm in the initial section of the hole (Figure. 4). The sensor was calibrated on a bench under different pressures with an accuracy of 0.001 MPa. The results of the research were evaluated by measuring five points on the oscillogram and determining the average value.

Based on the results of previous studies [18], the productivity of the purification process and changes in the properties of water is influenced by many factors: frequency and amplitude of oscillations, the ratio of the piston diameter to the diameter of the opening, but the speed of fluid flow is dominant when passing through the nozzles.

EXPERIMENT

To determine the interconnection of the parameters of the vibration actuator, consider the movement of ideal liquid through the hole in the piston. We believe that there are no cavitation processes.

The volume of the liquid, which is squeezed through the piston into the piston when walking down (Figure. 5).

$$V = 2AS = 2A\frac{\pi D^2}{4} \tag{1}$$

where: V – the volume of fluid squeezed through the piston into the piston; A – amplitude of vibrations of the piston; S – piston area.

The mass of fluid squeezed through the piston into the piston during the movement of it.

$$m = 2\rho AS = 2\rho A\frac{\pi D^2}{4} \tag{2}$$

where: ρ – water density.

We apply the theorem about kinetic energy. Provided that the maximum effort on the rod

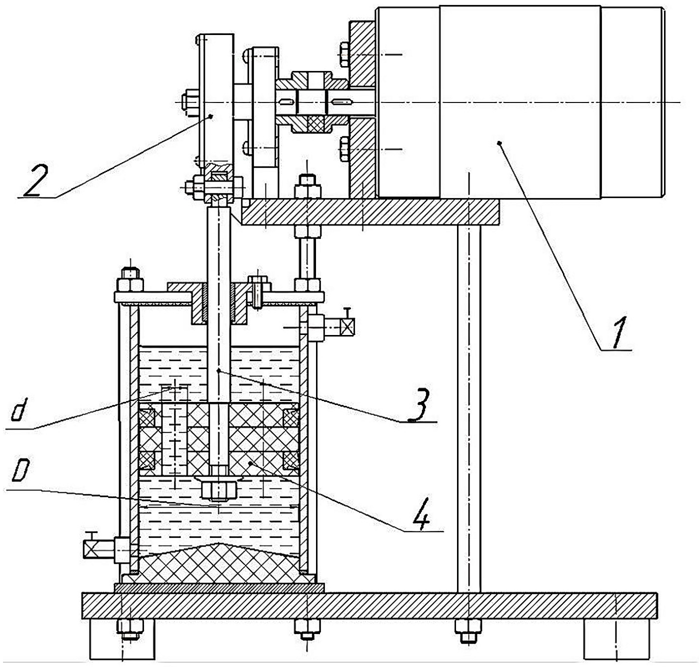

Figure 2. Constructive scheme of vibration cavitator of the piston type: 1 – DC electric motor; 2 – vibration drive; 3 – stem; 4 – piston

occurs when the eccentric of points C,B (Figure 5).

$$F_{max}A = \frac{AmU_{max}^2}{2} \quad (3)$$

$$F_{max} = \frac{\pi D^2}{4}\frac{U_{\mu\alpha\xi}^2}{2}$$

Where do we get:

$$U_{max} = \sqrt{\frac{4F_{max}}{\rho \pi D^2}} \quad (4)$$

To determine the dependence of the maximum speed, you need to know the magnitude of the force at the F_{max} rod on the speed.

To determine the force on the F_{max} rod, a kinematic and dynamic analysis of the eccentric mechanism for the real dimensions of the installation was performed and the dependence of the force on the F_{max} rod on the speed of rotation was established by assuming that $F_{max} = F_{in}$.

For this purpose, a 3D model of the eccentric with the rod in SolidWorks (Figure 6) was created and the calculations were conducted in Mathcad.

The coordinates of the center of the mass of the rod are determined using the method of closed vector contours by formulas:

- the coordinate of the center of mass along the axis X

$$x_{S2}(\varphi_1) := \frac{\left(a_2 \cdot b_2 \cdot \cos(\varphi_1)\right)}{\sqrt{b_2^{\,2} \cdot \cos(\varphi_1)^2 + a_2^{\,2} \cdot \sin(\varphi_1)^2}} \quad (5)$$

- the coordinate of the center of mass along the axis Y

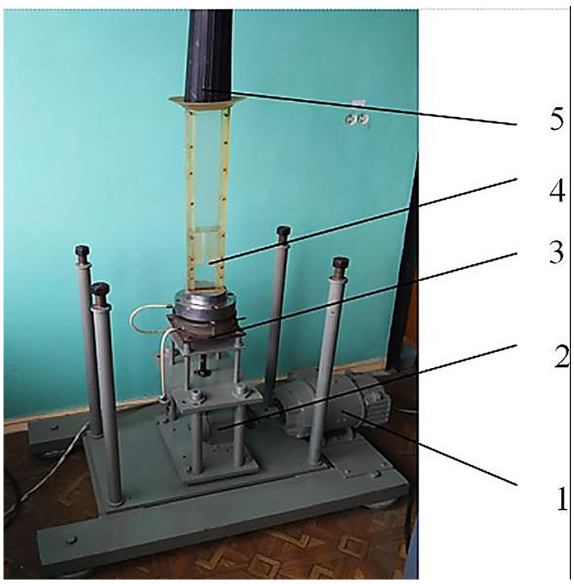

Figure 3. Installation of visualization of the formation of cavity processes of fluid in the pulsation chamber: 1 – vibration drive; 2 – DC electric motor; 3 – pulsation chamber; 4 – transparent channel; 5 – a fluid oscillation capacity

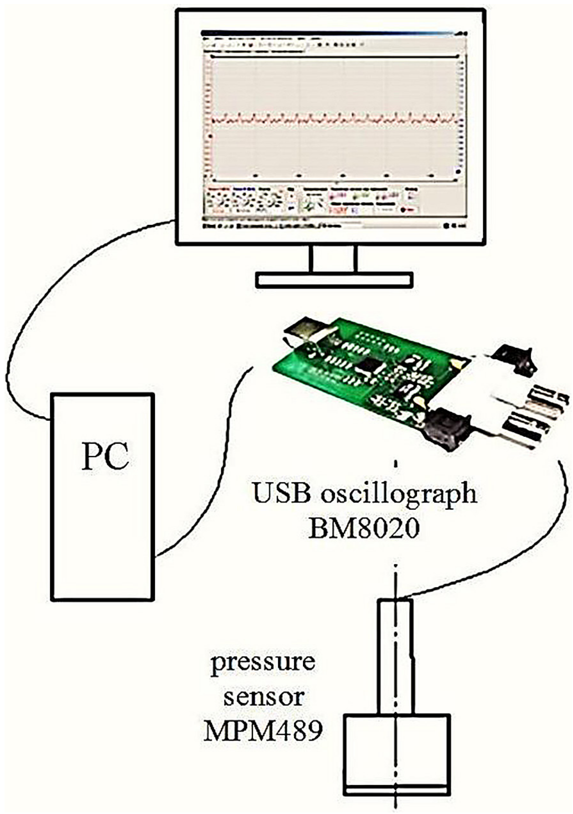

Figure. 4. Scheme of the sensor connection to measure the maximum pressure of the pulsating jet

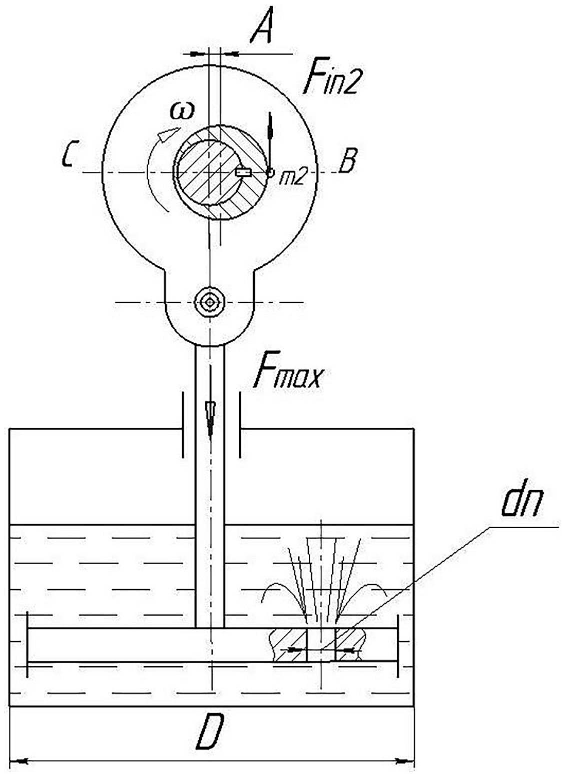

Figure 5. Scheme for calculating the value of the maximum fluid velocity in the hole in the piston for the perfect liquid

$$y_{S2}(\varphi_1) := \frac{a_2 \cdot b_2 \cdot \sin(\varphi_1)}{\sqrt{b_2^{\,2} \cdot \cos(\varphi_1)^2 + a_2^{\,2} \cdot \sin(\varphi_1)^2}} - y_{S2.fi90} + r \quad (6)$$

Analogues of the corresponding speeds and accelerations of the points of the connecting rod is determined by formulas:

$$\varphi_2^{'} = \frac{d\varphi_2}{d\varphi_1} \quad (7)$$

- analogue of the angular acceleration of the rod

$$\varphi_2^{''} = \frac{d^2\varphi_2}{d\varphi_1^2} \quad (8)$$

- analogue of acceleration of the center of mass of rod

$$s_{S2}^{''} = \sqrt{x_{S2}^{''\,2} + y_{S2}^{''\,2}} \quad (9)$$

- angular acceleration of the rod

$$\varepsilon_2 = \omega_1^2 \varphi_2^{''} \quad (10)$$

The force of inertia rod is defined by the formula:

$$F_{in\,2} = m_2 a_{S2} \quad (11)$$

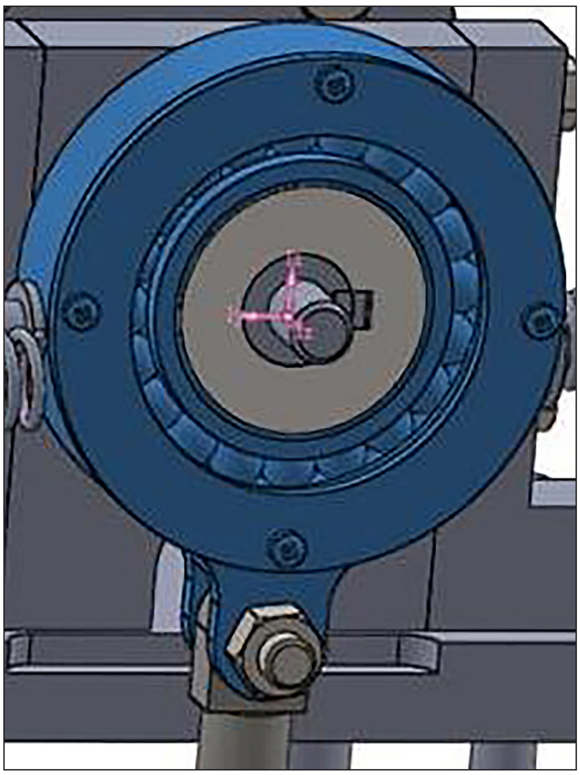

Figure 6. 3D model eccentric with a rod to calculate the force on the rod depending on the speed of the drive

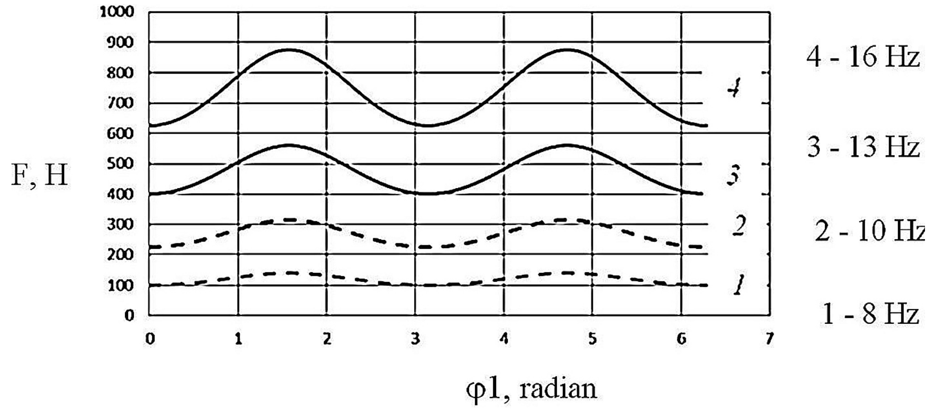

Figure 7. Graph of change of force of inertia rod from the angle of rotation eccentric φ1 with eccentricity r = 2 mm at different frequencies of vibration actuator oscillations

According to the results of calculations, MathCAD was constructed a schedule of change of maximum force *F* on the rod piston, depending on the frequency of oscillation and direction of inertia (Figure 7).

Calculations of maximum fluid speed in the piston by dependence (4) were calculated. But in further studies, the most convenient parameter for measurement will be not the speed of fluid movement in the hole, but the value of the hydrodynamic pressure of the jet from the hole on its cut. The force of maximum hydrodynamic pressure in the hole is calculated by the formula:

$$P_{max} = 0.95\frac{\gamma}{g}\frac{\pi d_n^2}{4}U_{max}^2 \qquad (12)$$

where: d_n – hole diameter.

The results of the calculation of the maximum force of hydrodynamic pressure are applied to the Figure 8, curve 1.

Consider the movement of real liquid through the hole in the piston when it moves up, taking into account that cavitational processes occur in the hole. To do this, we will perform a speed video of the fluid movement in the piston opening with the stand (Figure 3).

Figures 9 and 10 show a transparent channel with liquid at the time of ejection and of further ejection of fluid through the hole in the piston.

After analyzing the results of the video recording of the movement of the liquid, it was established that when the liquid is drawn in through the hole in the piston during its upward motion (Figure 5), a cavitation cavity and a swarm of cavitation bubbles which appear at certain frequencies of the drive oscillations (Figure 9), which reduces the volume of liquid under the piston. However, as the piston continues to move up (Figure 10), they burst (play the role of an elastic element) and this leads to a decrease in the maximum pressure at the exit from the hole.

To measure the hydrodynamic pressure of the jet that exits from the piston opening, a membrane pressure sensor and stand are used 4. The obtained values of the maximum hydrodynamic pressure on the cut of the hole, depending on the frequency of oscillations of

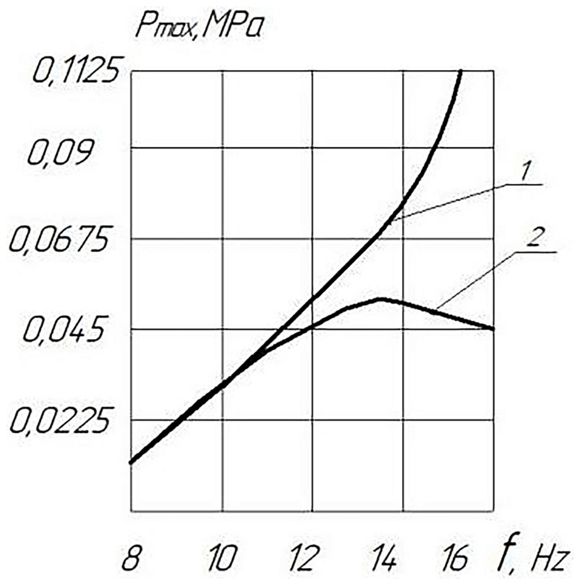

Figure 8. Graphs of changes in hydrodynamic pressure in the hole in the piston from the frequency of vibrating actuators: 1 – calculated for the ideal liquid according to f. 12; 2 – experimental for real liquid at A = 0.02 m; D = 0.10 m; d_n = 0.01 m

Figure 9. Photograph of a transparent channel with liquid at the time of ejection of fluid through the hole in the piston when it moves up with the emergence of cavitational caverns in the hole and the appearance 12 Hz

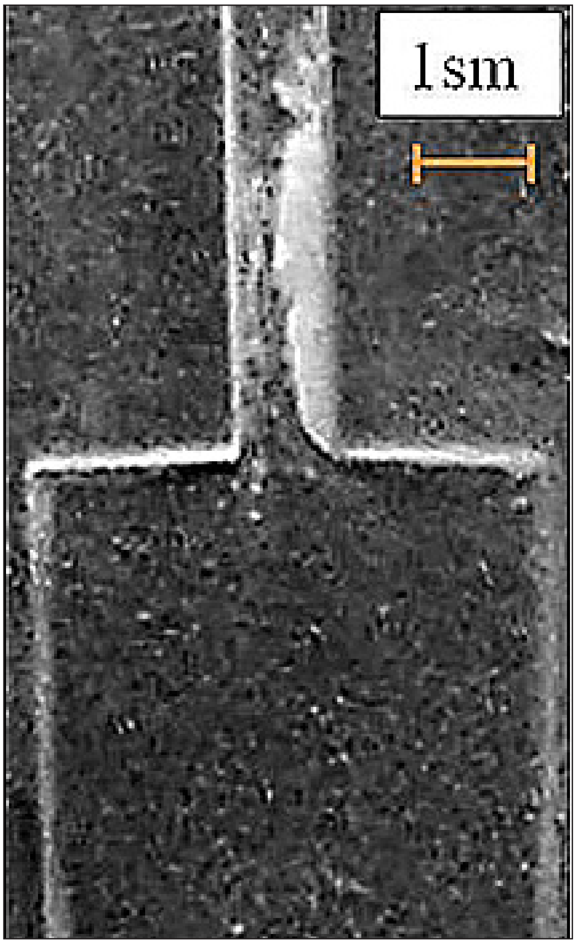

Figure 10. Photograph of a transparent channel with liquid at the time of further ejection of liquid through the hole in the piston when it moves up with a cavity cavernous in the hole and bubbles that have already clapped at the frequency of oscillations 12 Hz

the actuator is applied to the Figure 8, curve 2. From the analysis of which it is evident that the change in the maximum pressure of the jet of the real liquid from the opening from the frequency of oscillations of the piston, due to the emergence of cavitational processes, is non -linear and its value is less than the increase in frequency of oscillations than it is calculated for the ideal fluid.

Therefore, to determine the analytical dependence of the maximum pressure on the parameters of the actuator and the design ratios of the machine, a three-factor experiment was conducted using a rototable plan, taking on variable parameters: oscillation amplitude A, frequency of vibrations f and piston size D at a constant diameter of the opening d = 10 mm.

As a result of the studies, after transformation into natural quantities, the regression Equation 13 was obtained.

$$\begin{gathered} P_{max} = 0.91 + 0.007D + 0.006f + \\ +0.18A - 0.000065Df - 0.00126DA \\ -0.00005D^5 - 0.00146f^2 - 0.02A^2 \end{gathered} \quad (13)$$

The obtained regression Equation 13 can be used to determine the maximum pressure in the piston hole taking into account cavitation processes depending on the ratio of the piston diameter to the hole diameter, the frequency of oscillations of the actuator, the amplitude of oscillations of the actuator within the following limits of variable input factors:

$$\begin{gathered} 60 \leq (D/d_n) \leq 120 \text{ (mm)}; \\ 6 \leq f \leq 20 \text{(Hz)};\ 1 \leq A \leq 3 \text{ (mm)} \end{gathered} \quad (14)$$

The hypothesis of the adequacy of the obtained model was tested using the Fisher criterion:

$$F = \frac{S_H^2}{S_n^2} \tag{15}$$

where: S_i – the adequacy variance.

The obtained Fisher criterion is less than the tabular $F < F_T$, therefore the obtained model is considered adequate, it can be used to describe the process under study. From the analysis of the regression model, it was established that the amplitude and frequency of oscillations of the pulsating equipment drive have a significant impact on the maximum pressure.

RESULTS AND DISCUSSION

Based on the conducted research, it is possible to recommend the obtained regression dependence for determining the optimal parameters of the drive of the vibrating machine within (14), and for the proposed design of the vibrating machine, it is recommended to use the vibration frequency of the drive from 13 to 15 Hz with a ratio = 10 and an amplitude of oscillations of 2 mm.

In order to confirm the practical implementation of the proposed design of the vibrating machine, a study of the changes in the composition and properties of water treated by hydrocavitation in the vibrating machine was conducted, both during processing and during settling time. The results of the research are shown in Figure 11.

To confirm the practical implementation of the proposed design of pulsation equipment on an experimental installation (Figure 1), studies were conducted, as a result of which it was found: an increase in the pH value from 7.3 to 9, respectively by 19% (Figure 11); a decrease in total mineralization during cavitation treatment to 350, respectively by 22%. This indicates the oxidation of carbonates $CaCO_3$, $MgCO_3$, oxycarbonates $Mg_2(OH)_2CO_3$, which float to the surface of the tank during water settling, and hydroxide $Fe(OH)_2$, which subsequently precipitates. A decrease in ORP from 300 to 220 units, respectively by 27%, indicates an increase in the redox potential of the liquid.

This is confirmed by studies of the type of formed crystal structures of sediment during the natural drying of a drop of liquid under normal conditions according to [19]. Their appearance depends on the received energy conditions of crystallization. Figure 12 shows the crystal structure of the sediment of a dried drop of river water without cavitation treatment, and Figure 13 shows the crystal structure of the sediment of a dried drop of river water treated with cavitation. From the given photograph (Figure 12) of the crystalline structure of the sediment of a dried drop of river water, it was established that in water without cavitation treatment, a cluster structure is observed due to hydrogen bonds, which manifests itself in the form of crystalline dendrites, which were formed during drying of water with an uneven energy state and under by the influence of radicals of dissolved salts.

In the photo (Figure 13) of the crystal structure of the sediment of a dried drop of river water, which has been treated by cavitation, a uniform structural structure is observed, obtained due to

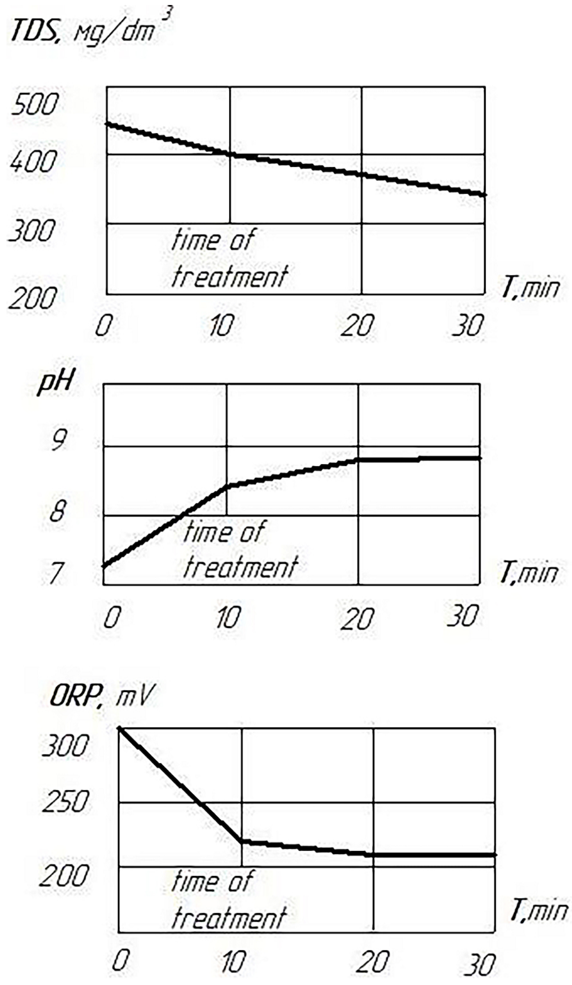

Figure 11. Change in TDS, pH, ORP indicators with the time of treatment with hydrocavitation and water settling

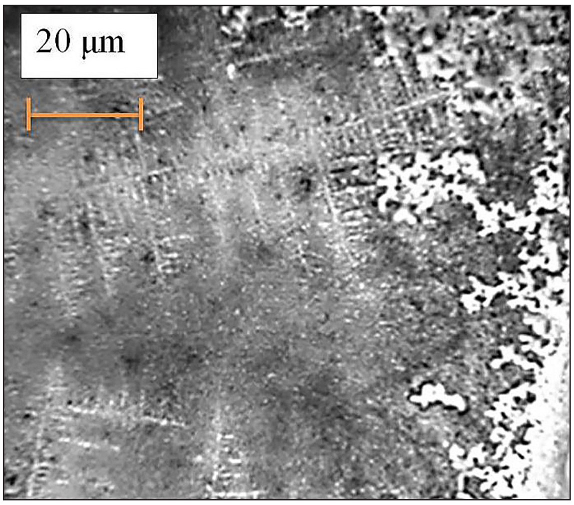

Figure 12. Photograph of the crystal structure of the sediment of a dried drop of river water without cavitation treatment in a vibrating machine

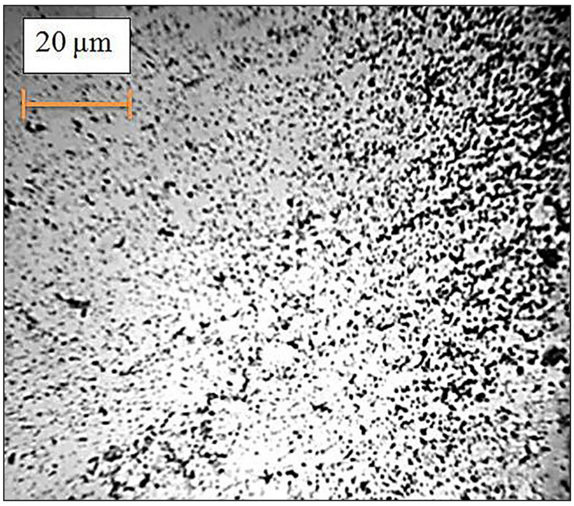

Figure 13. Photograph of the crystal structure of the sediment of a dried drop of river water processed by cavitation in a vibrating machine

broken hydrogen bonds, which reduced the surface tension of the liquid and gave the water a structure with new properties.

CONCLUSIONS

An analytical model of the movement of an ideal fluid in the piston hole of a pulsating equipment was constructed and investigated, and a relationship was established between the design parameters and operating modes of the pulsating equipment drive. The analytical calculation of the maximum pressure does not take into account the presence of dissolved gases in a real liquid.

The dependence of the maximum pressure in the piston hole on the oscillation frequency for a real liquid with the influence of cavitation processes on the operating modes of the pulsating equipment drive was experimentally established. The frequency limits of the operation of the pulsating equipment were determined, which are in the range from 13 to 15 s-1 with an oscillation range of 0.002 m at a ratio of the piston diameter to the diameter of the hole in the piston of 10:1. A multifactor experiment was conducted and a regression dependence was obtained for calculating the maximum pressure in the hole in the piston, which allows us to substantiate the optimal operating modes of the machine drive.

Analysis of the results of studies of the appearance of the crystal structures of the samples indicates that the cavitation effect changes the structure of the liquid and changes other indicators, namely: TDS, pH, ORP, which leads to an improvement in its properties.

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