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Study of the Influence of Cavitation and Magnetic Field on the Change of Water Properties and its Purification in a Vibrating Machine with Determination of Drive Modes

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ABSTRACT

The paper presents the results of research into the influence of low-frequency sound and magnetic fields on the change in the properties of water and its purification in a vibrating machine with an eccentric drive, which allows obtaining a constant amplitude of oscillation when the frequency of oscillations of the drive is changed. A method and construction of a vibrating machine for changing the properties of water and cleaning is proposed. Thanks to its reciprocating movement, and in the pulsation chamber and the nozzle, appropriate reactions take place. At certain oscillation frequencies, a cavitation cavity appears in the nozzle and the pulsation chamber, in which the process of splitting water molecules into active radicals takes place. At the same time, during the reciprocating movement of water through a non-magnetic nozzle, which is covered by permanent magnets, an additional effect of a variable magnetic field direction is exerted on water, which strengthens the breaking of hydrogen bonds in water molecules. Visualization of the hydrocavitation process during operation of a vibrating machine with a transparent nozzle was studied. During the experiment, changes in water parameters were studied, i.e. changes in pH, changes in the oxidation-reduction potential of treatment ORP and the total content of mineralization according to the TDS index with treatment time. The total concentration of dissolved salts decreases from 400 to 300 units, which also indicates an improvement in water quality. The rational frequency limits of the vibration drive of the machine are in the range from 18 to 23 Hz with an amplitude of oscillations of 0.002 m, and the ratio of its design parameters is determined: with a piston diameter of 0.1 m, it is recommended to use a diameter of the hole in the piston from 0.006 to 0.008 m.

Keywords: cavitation, magnetic field, vibration machine, change of water properties, cleaning.

INTRODUCTION

Cavitation processes are widely used in various technologies, namely: in the purification of water from industrial effluents [1–4], textile industry effluents [5, 6], in the woodworking industry [7, 8], printing ink wastewater [9], drugs [10] and decontamination [11–15]. Also, in various branches of industry, the effect of a magnetic field is widely used to change the properties of water [16–18]. The study of cavitation in low-frequency sound fields revealed an analogy in terms of physicochemical effects between low-frequency and ultrasonic cavitation [19, 20].

Models of physical and chemical processes occurring in cavitation bubbles and adjacent liquids are presented in the following form [20]. Water vapor, dissolved gases and vapors of highly elastic substances can penetrate into the cavitation cavity, but ions or molecules of non-volatile dissolved substances cannot penetrate. During the bursting of bubbles, energy is released that stimulates, ionizes and separates molecules of water, gases and substances with high vapor elasticity in the cavitation cavity. At this stage, every gas present is an active ingredient and participates in the transfer of energy for excitation, recharging and other processes. The effect of the sound field on the substance penetrating the cavity is direct, and the effect of active gases O_2, H_2 and N_2 in the cavitation cavity is twofold.

First, O_2 and H_2 participate in the radical transformation reaction:

$$H^o + O_2 \rightarrow HO_2^o, \quad OH^o + H_2 \rightarrow H^o + H_2O \quad (1)$$

Secondly, chemically active gases penetrating into the cavitation cavity, participate as well as noble gases, in the transfer of electronic disorder energy to water molecules in the process of recharging. A symbol $\rightarrow)))$ the chemical action of sound is indicated. During the bursting of the cavitation bubble, H^0, OH^0 radicals, ions and low-energy electrons formed in the gas phase during the splitting of the H_2O molecule and substances with high vapor elasticity, products of their interaction and partial recombinations, as well as metastable excited H_2O molecules pass into the solution. The general scheme of cavitation splitting of water molecules is presented in the following form:

$$N_2 + O_2 \rightarrow)))NO_2, \quad N_2 + H_2 \rightarrow)))NH_3 \quad (2)$$

Probability of reaction:

$$H_2O \rightarrow))) H_2O^+ + e^- \quad (3)$$

large, because the relative number of H_2O^+ ions exceeds the sum of all other primary products of water splitting. The OH radical is formed mainly by the reaction:

$$H_2O \rightarrow))) OH + H^+ + e^- \quad (4)$$

The active particles arising in the system, after entering the solution, are solvated and react with dissolved substances. At this stage, when indirect effects of acoustic vibrations are carried out, almost only chemically active gases O_2 and H_2 can influence the course of the process. Ultimately, the effect of cavitation on aqueous solutions is reduced to a single process: the splitting of water molecules in cavitation bubbles with the breaking of hydrogen bonds.

The possibility of conducting sonochemical reactions during sound frequency fluctuations has been confirmed by the authors [20] and recent research by scientists from Switzerland, Japan, and Finland. In the journal Science Advances, they presented the results of measuring the strength of the hydrogen bond in a single molecule using an atomic force microscope. It was established that the hydrogen bond was very weak, with a length of about 300 picometers. Regardless of the nature of dissolved substances, sound acts on one substance – water, which leads to a change in its physical and chemical properties: an increase in pH, electrical conductivity of water, an increase in the number of free ions and active radicals, structuring and activation of molecules [21, 22].

To intensify the process of water purification, the authors of [16, 18] proposed a method using a magnetic field – the so-called method of magnetic activation of ions. In this way, a non-uniform magnetic field disrupts the orientation of spins, reduces the energy of intermolecular interactions of water in its supramolecular formations. At certain values of magnetic field induction, which are used in the magnetic treatment of water systems, the connection between the vectors of magnetic moments of the nucleus and electrons is broken, electrons and nuclei are oriented and precess independently of each other. The data obtained by the authors [23–25] can also be evidence that due to the action of the magnetic field, the energy of hydrogen bonds between water molecules decreases. There are many methods of its formation and equipment designs for cavitation effect on water [26–31]. Combined methods are gaining significant popularity: ultrasonic with superposition of vibrations, jet with superposition of magnetic field, hydrocavitation with superposition of pressure pulses.

The creation of small-sized vibrating machines for individual use, in which hydrocavitation occurs, with the simultaneous influence of a magnetic field, which affects the change in the properties of water and its purification, is an urgent task of our time.

METHODS AND RESULTS

The experimental setup is based on an eccentric vibration drive, which allows you to quickly adjust the vibration amplitude, which is a stable and fixed value of eccentricity. The frequency of oscillations is regulated by changing the DC motor voltage. Permanent magnets are attached to the non-magnetic nozzle. The general view of the experimental setup is shown in Figure 1.

In Figure 2 shows the setup for studying visualization of the hydrocavitation process during operation of the vibrating machine. The installation is equipped with a container with a transparent nozzle and a pulsation camera is installed. The bottom of the pulsation chamber is made elastic and fixed on both sides by discs with a rod connected to an eccentric vibration drive.

In Figure 3, and *a* photograph of the beginning of the movement of liquid with bubbles into the pulsation chamber (at the bottom of the frame), which grow in size as the pressure drops, and a photograph of the movement of liquid with cavitation bubbles when the minimum value of pressure in the pulsation chamber is reached (Fig. 3,b). In Figure 4, and a photo of the beginning of compression and movement of liquid with bubbles in the nozzle (located from the top of the frame), which begin to deform as the pressure increases, is presented in the pulsation chamber, and a photo of the movement of liquid with cavitation bubbles that begin to burst when the maximum pressure value in the chamber is reached pulsations (Fig. 4b). As a result of the conducted research, the occurrence of cavitation processes in the pulsation chamber of the vibrating machine was confirmed under certain modes of operation of the vibrating drive with a nozzle with sharp edges.

The authors of the work conducted experimental studies of the influence of hydrocavitation and magnetic field and the determination of the storage period of the main indicators of the state of water taken from various sources, as well as an assessment of the structural state of the liquid by analyzing the structure of the crystalline structures of the sediment during the evaporation of a drop of liquid [32] from various sources. During the experiment, changes in water parameters

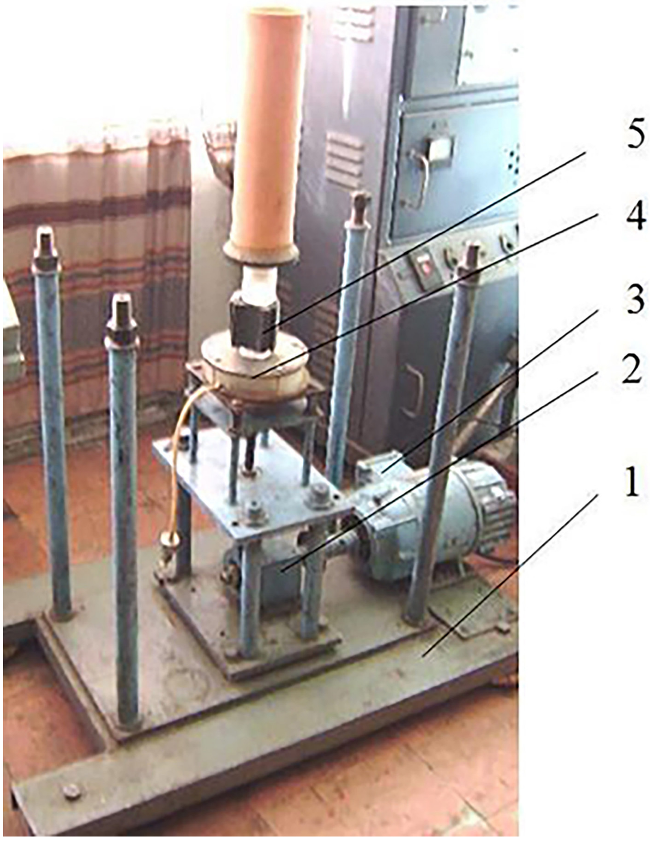

Figure 1. Installation for studying the influence of the hydrocavitation process and magnetic field on the properties of water: 1 – base; 2 – eccentric drive; 3 – engine; 4 – pulsation chamber; 5 – permanent magnets (autor's development)

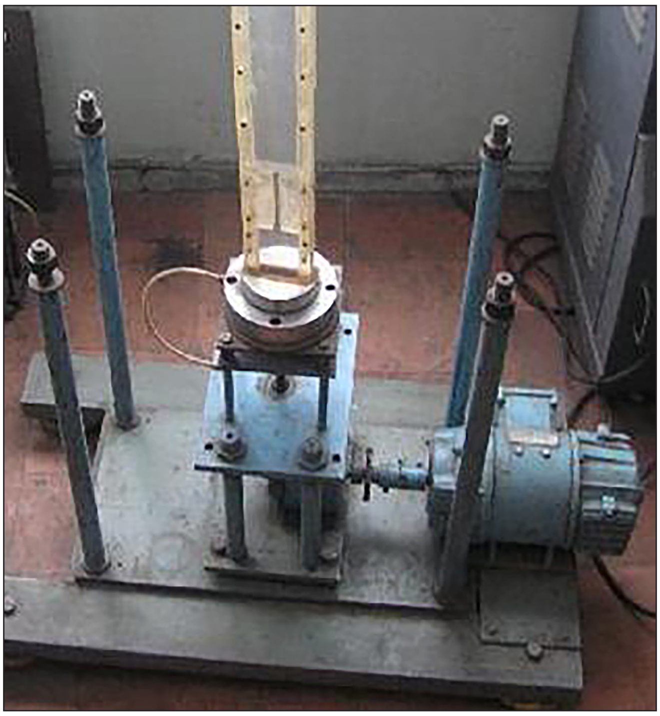

Figure 2. Installation for studying visualization of the hydrocavitation process during the operation of a vibrating machine with a transparent nozzle (autors development)

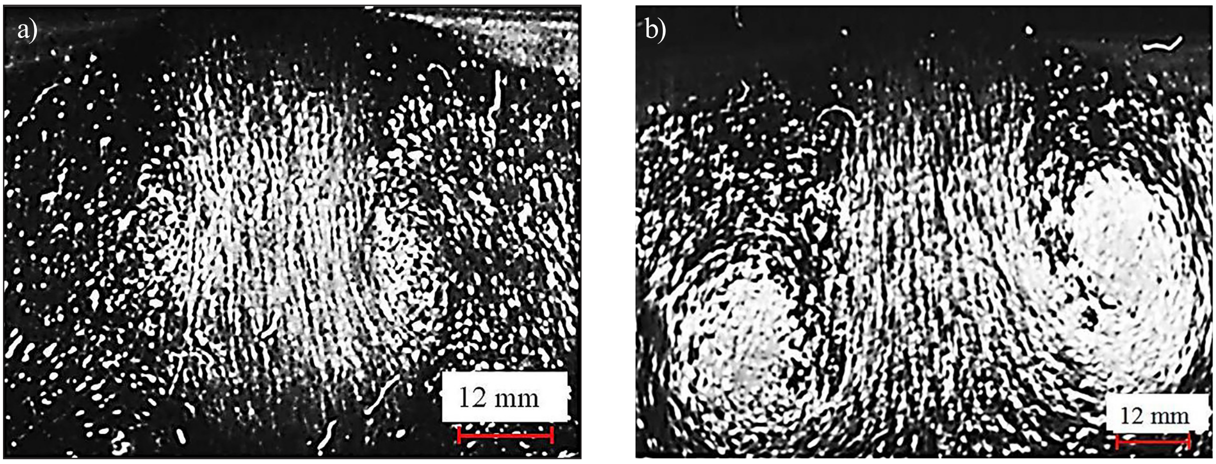

Figure 3. The stages of drawing liquid through the nozzle into the pulsation chamber: (a) the beginning of retraction, (b) the end of retraction (original photos)

were studied, i.e. changes in pH, changes in the oxidation-reduction potential of treatment ORP and the total content of mineralization according to the TDS index with treatment time. The results of the study are shown in Figure 5. Experiments conducted at the experimental facility (Fig. 1) showed an increase in the hydrogen index of pH water from 7.2 to 8.5 units, which indicates the rupture of hydrogen bonds.

The indicator of total mineralization – TDS increases during the cavitation treatment period of 10 minutes, and then decreases. This means that after 20 minutes of treatment, the formation of water-insoluble carbonates $CaCO_3$, $MgCO_3$, oxycarbonates $Mg_2(ON)_2CO_3$ and hydroxide $Fe(OH)_2$ occurs, which over time precipitate and therefore the total concentration of dissolved salts decreases. An increase in the pH indicator during the treatment period indicates the breaking of hydrogen bonds in the molecules, but later it stabilizes at the level of 8.2 pH. A decrease in the ORP indicator from 300 to 180 units indicates

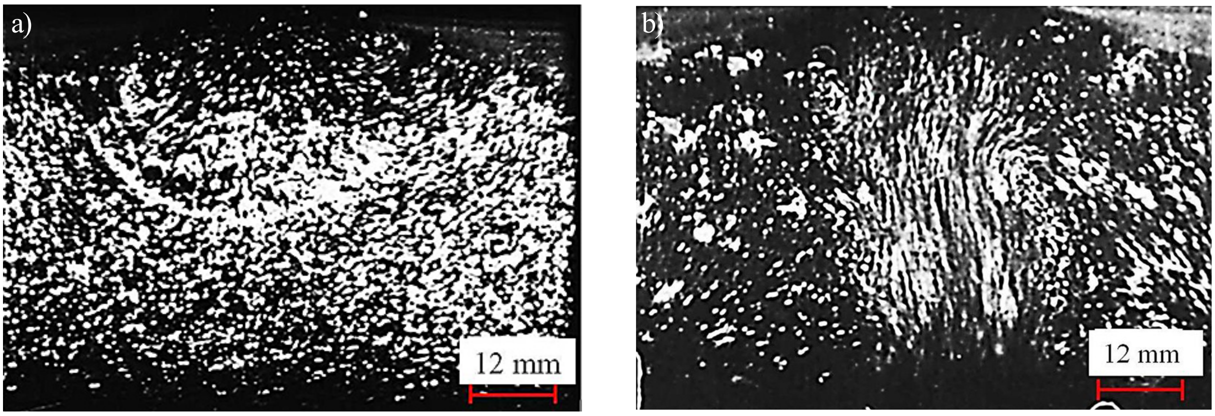

Figure 4. The stages of liquid compression and pushing it out of the pulsation chamber through thenozzle: a – beginning of compression; b – the end of the compression process (original photos)

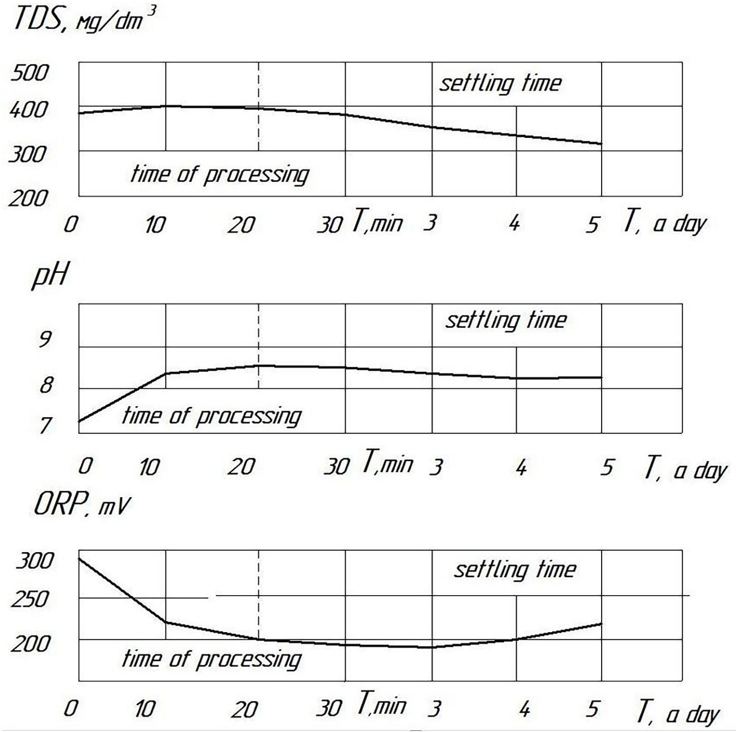

Figure 5. Change in tap water parameters with time of cavitation treatment and settling time (vibration parameters: frequency of oscillations f = 14 Hz and amplitude of oscillations A = 2 mm); TDS – total level of mineralization; pH – hydrogen indicator; ORP – redox potential; T – time

an increase in the redox potential of the liquid, which increases over time to 205 units.

The obtained results of changes in time indicators make it possible to state that the cavitation effect changes the structure of the liquid and lowers the surface tension, and over time, the achieved state of water is preserved for up to five days. The obtained results of changes in indicators over time make it possible to state that the cavitation effect changes the structure of the liquid and lowers the surface tension coefficient, and over time the achieved state of water is preserved for up to five days.

Next, an experimental study of the simultaneous effect of cavitation and a permanent magnetic field on river water indicators: TDS, pH, ORP was conducted. The research results are presented in the form of graphs in Figure 6. The simultaneous use of cavitation and a magnetic field for water treatment increases the hydrogen pH index to 9.0 units, which is more than when cavitation is applied only. This indicates a greater number of breaks in hydrogen bonds between water molecules and a decrease in the surface tension coefficient. ORP makes it possible to estimate the

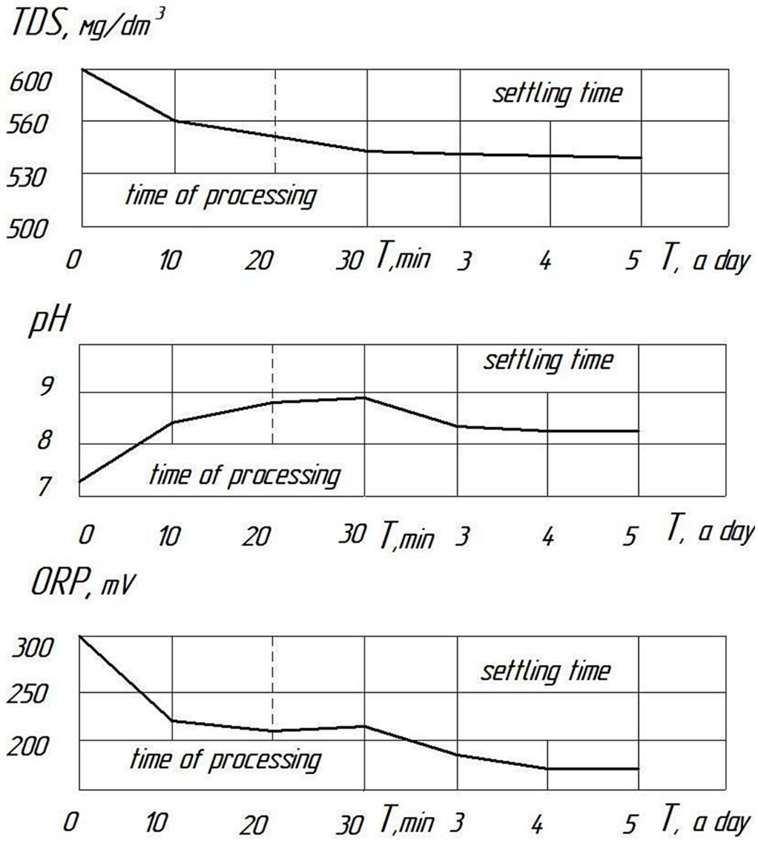

Figure 6. Changes in river water parameters over time during simultaneous cavitation and magnetic field treatment and settling time (vibration parameters: frequency of oscillations f = 14 Hz and amplitude of oscillations A = 2 mm); TDS – total level of mineralization; pH – hydrogen indicator; ORP – redox potential; T – time

oxygen demand for fermentation of biological remains in water. The smaller it is, the lower the need for oxygen in the water. The ORP indicator decreases during the treatment period, but then increases during the first hour of settling and then decreases over time. This behavior can be explained by the removal of the effect of the magnetic field after the treatment at the beginning of the deposition. The TDS indicator gives an estimate of the presence of impurities in water. Its decrease indicates a decrease in dissolved Ca, Fe radicals that have reacted with oxygen, and an improvement in the water composition.

To confirm the obtained results, a study was conducted to study the effect of cavitation and cavitation-magnetic treatment of water on the change in its structural state by the crystal-optical method [32]. Figure 7 shows a photograph of the crystalline region of the precipitate of a drop of raw tap water. The crystal types of raw water sediment show its cluster structure with a high surface tension coefficient. Figure 8 shows a photograph of a section of crystalline water sediment treated by cavitation and a magnetic field. The appearance of sediment crystals indicates the structure of water with a low coefficient of surface tension, which confirms the violation of hydrogen bonds.

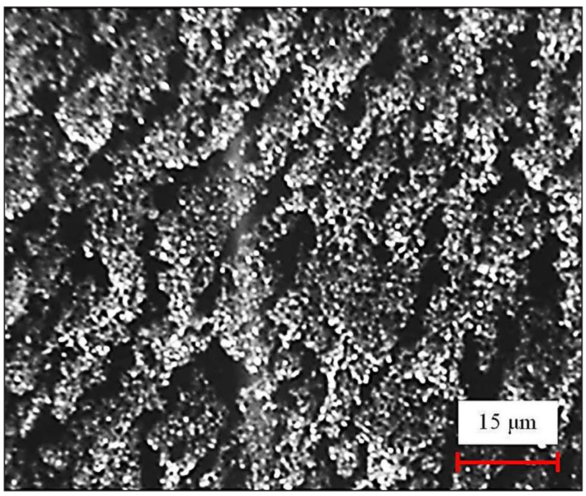

Figure 7. Section of a drop of tap water deposited by untreated cavitation and a magnetic field

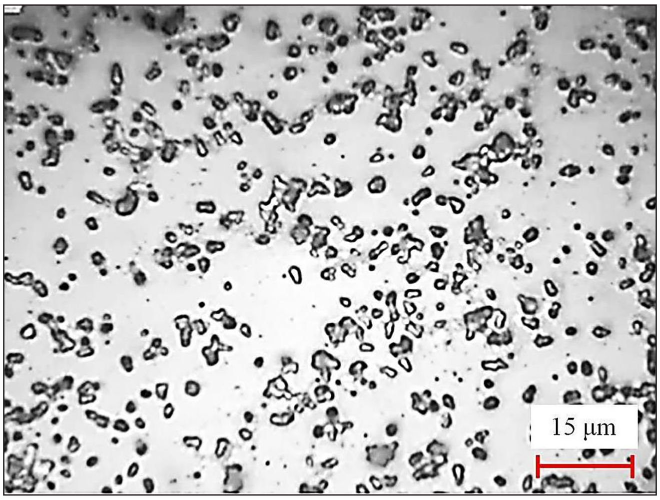

Figure 8. The sediment area of a drop of tap water treated by cavitation and a magnetic field after 20 minutes of treatment: magnification (1 cm = 15 μm**)**

A uniform distribution and balanced shape of sediment crystals is observed. This is due to a low coefficient of surface tension, the breaking of hydrogen bonds, and the structuring of water. From the conducted studies, it was established that the obtained state of activated water is preserved for up to three days, after which the indicators stabilize: pH, ORP, but at a level significantly higher for pH and lower for ORP than the initial level. This allows us to assert that the properties of water have improved. During settling of the treated water, a precipitate of water-insoluble carbonates is observed, which floats up (Fig. 9) and a precipitate of oxidized iron colloid, which accumulates at the bottom of the container (Fig. 10).

A method and design of a vibrating machine for changing the properties of water and cleaning is proposed [33], which is implemented as follows: water is poured into the container of the vibrating machine. The drive of the machine is turned on and the water begins to reciprocate from the pulsation chamber through non-magnetic nozzle into the container. Thanks to its reciprocating movement, and in the pulsation chamber and the nozzle, appropriate reactions take place. At certain oscillation frequencies, a cavitation cavity appears in the nozzle and the pulsation chamber, in which the process of splitting water molecules into active radicals takes place. At the same time, during the reciprocating movement of water through a non-magnetic nozzle, which is covered by permanent magnets (Fig. 11), an additional influence of a variable magnetic field in the direction of the water is exerted,

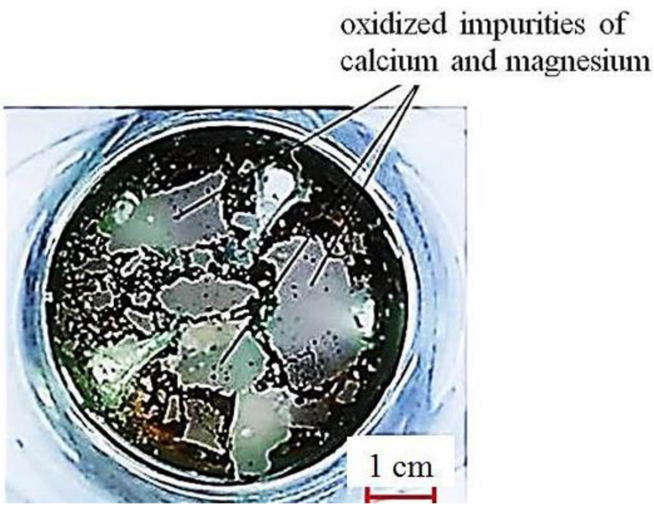

Figure 9. Sediment of water-insoluble carbonates that surfaced during settling of treated water

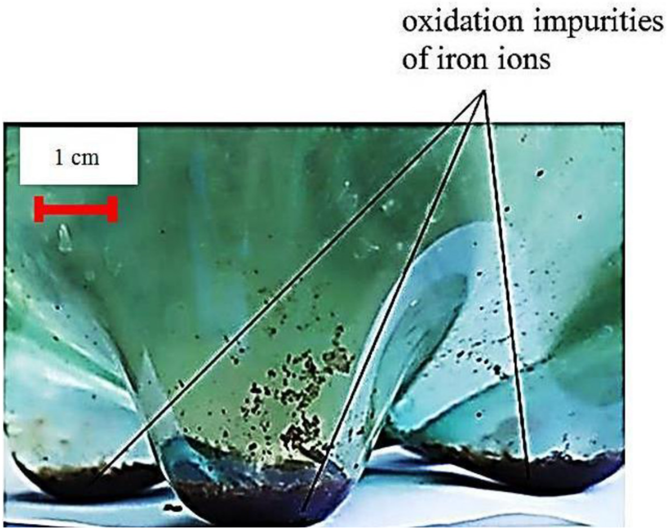

Figure 10. The precipitate of colloid of oxidized iron during settling of water

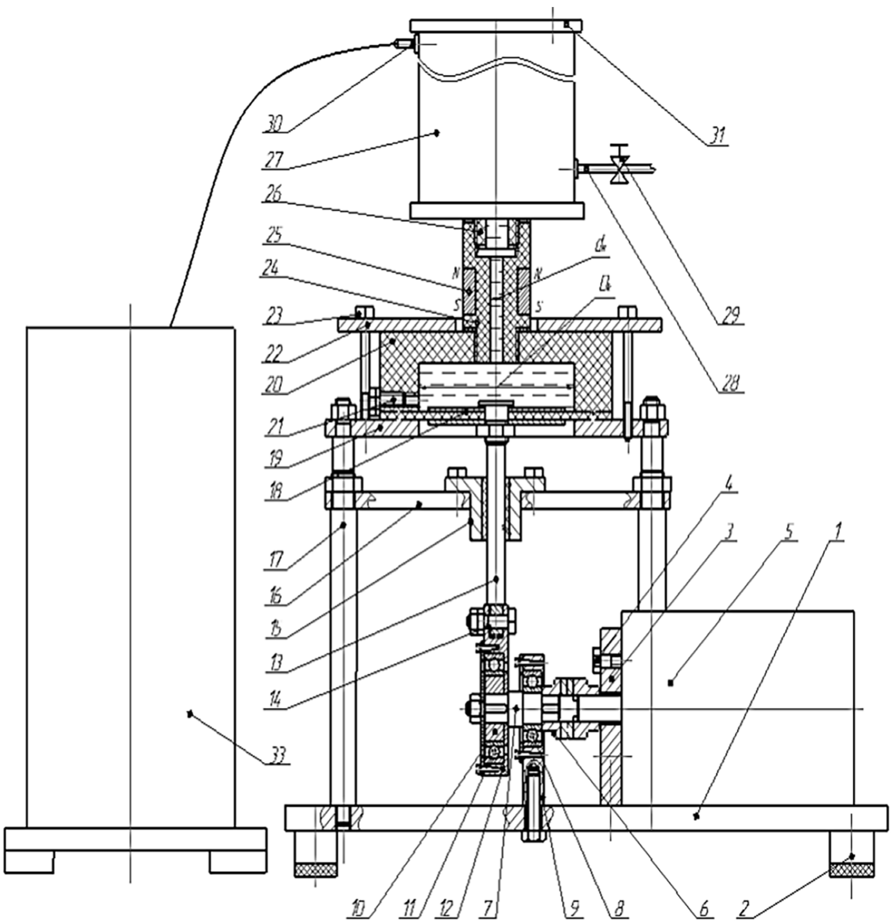

Figure 11. Schematic diagram of a vibrating machine for implementing a method of changing water properties and cleaning: 1 – base; 2 – vibration supports; 3 – body; 4 – bolts; 5 – electric motor; 6 – clutch; 7 – eccentric drive shaft; 8 – body; 9 – bearing; 10 – eccentric; 11 – bearing; 12 – body; 13 - rod; 14 – axis; 5 – sleeve; 16 – plate; 17 – stable; 18 – elastic membrane with disks; 19 – plate; 20 – pulsation chamber; 21 – fitting; 23 – bolt; 24 – nozzle; 25 – permanent magnets; 26 – fitting; 27 – capacity; 28 – fitting for water supply; 29 – water supply control valve; 30 – water outlet fitting; 31 – cover; 32 – hole; 33 – a tank for collecting treated water

which strengthens the breaking of hydrogen bonds in water molecules and their splitting in the cavitation cavity into active radicals After processing, the water is poured into a container.

The schematic diagram of the vibration machine for implementing the method is presented in the drawing of Figure 11 and Figure 12. The vibrating machine includes: base 1 on vibration supports 2, on which is located the housing 3, to which the electric motor 5 is attached with bolts 4, the shaft of which is connected by a coupling 6 to the shaft of the eccentric drive 7 installed in the housing 8 in the bearing 9. The eccentric 10 is installed on the shaft 7 in bearing 11 and housing 12. Housing 12 is connected to rod 13 by axis 14.

The rod 13 enters the guide sleeve 15 located on the plate 16, which is mounted on the racks 17. An elastic membrane with discs 18 is installed on the upper end of the rod 14 and is located on the plate 19, which is mounted on the racks 17.

On the elastic membrane with discs 18, a pulsation chamber 20 is installed with a fitting 21 for draining water in the event of a general stoppage of the process, and it is fixed with a disc 22 with the help of bolts 23. A nozzle 24 is screwed into the pulsation chamber 20, the outer walls of which cover permanent magnets 25 and a fitting is screwed into it 26, which connects the container 27 with the nozzle 24. In the container 27, there is a fitting for water supply 28 with a water supply control valve 29 and a fitting for water removal 30, and it is closed with a cover 31 with an opening 32. The fitting 30 is connected with a hose to the tank 33 for collecting treated water. In fig. 12 shows a cross-sectional diagram of the container 27, which shows the location of the partition 34 at an angle of 75° to the wall of the container with holes 35.

The vibration machine works as follows. The water to be treated fills the pulsation chamber 20 and the container 27 through the fitting 28 thanks to the open tap 29, which is then closed. The drive of the machine is turned on and thanks to the vertical oscillations of the rod 13 and the membrane with discs 18 in the pulsation chamber 20, a decrease or increase in water pressure occurs alternately relative to atmospheric pressure, while a cavitation cavity appears in the nozzle 24 and in the pulsation synthesis chamber 20. Cavitation bubbles filled with gases enter the pulsation chamber 20 from the nozzle 24 when the rod 13 moves down and grow in size, and when the rod 13 moves up, compression and increased pressure

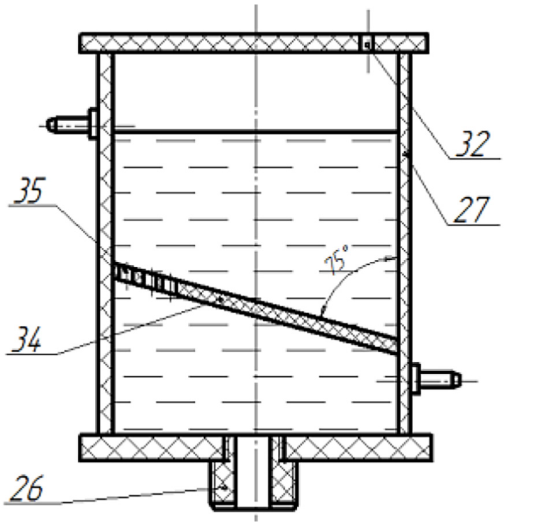

Figure 12. Cross-sectional diagram of the capacity of the vibrating machine for the implementation of the method of changing the properties of water and cleaning; 27 – capacity; 34 – a partition located at an angle of 75° to the container wall; 35 – openings (author's development)

in the water occur and the cavitation bubbles burst, splitting water molecules into active radicals. The liquid, which has received a cavitation-magnetic effect, in the form of a jet from the nozzle 24, enters the container 27.

To prevent splashing and separation of the treated water from the untreated one, the container 27 is separated by a partition 33, located at an angle of 750 to the wall of the container with holes 34. During the reciprocating movement of the liquid during retraction and ejecting the liquid through the nozzle 24, the additional effect of the variable magnetic field from the permanent magnets 25 is carried out by the splitting of water molecules into radicals. Thus, the volume of liquid in the container 27 undergoes cyclic multiple hydrocavitation treatment, and the jet of liquid from the nozzle 24 stirs the water in the container 27, disturbs the surface of the water in the container 27 and creates conditions for air capture through the hole 32 in the cover 31.

After 15–20 minutes of cyclic hydrocavitation treatment of the first volume of water through the water inlet fitting 28 with the help of a tap 29, raw water is constantly supplied, with a slight leak, while the vibration drive of the machine is operating, and the treated water flows through the water outlet fitting 30 by gravity into the tank 33 until it is filled. After filling the tank 33, the vibrating machine is turned off and the tank 33

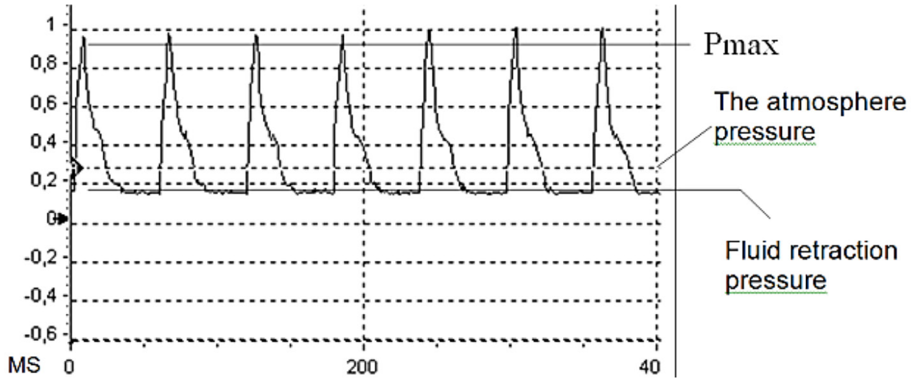

Figure 13. Screenshot view of the oscillogram of the maximum pressure in the pulsation chamber

is replaced with an empty one. When the process of operation of the vibrating machine is stopped altogether, the water is drained from the container 27 and the pulsation chamber of the synthesis 20 with the help of the fitting 21. The operating parameters of the vibrating machine drive were determined based on the maximum pressure in the pulsation chamber. For this purpose, the MPM489 pressure sensor is provided, which is connected to a USB oscilloscope BM8020 connected to a personal computer via a USB port and serviced by the "DiSco" software product. Figure 13 shows a screenshot of the oscillogram of the change in the maximum pressure in the pulsation chamber of the vibrating machine during the oscillation cycle at a certain oscillation frequency.

As a result of the conducted research, the rational frequency limits of the operation of the vibration drive of the machine were established at which the maximum pressure in the pulsation chamber will be obtained, and which lie in the range from 18 to 23 Hz with an amplitude of oscillations of 0.002 m and the ratio of its design parameters of the membrane diameter of 0.1 m to the diameter of the hole in the nozzle from 0.008 to 0.01 m.

CONCLUSIONS

After conducting a number of studies on changes in the properties of water and its structural state, it was established that hydrocavitation with the simultaneous influence of a magnetic field has the greatest impact. From the conducted studies, it was established that the obtained state of the treated water is preserved for up to three days, after which the indicators stabilize: pH, ORP, but at a level significantly higher for pH and lower for ORP than the initial level. This allows us to assert that the properties of water have improved. The total concentration of dissolved salts decreases from 400 to 300 units, which also indicates an improvement in water quality. The rational frequency limits of the vibration drive of the machine are in the range from 18 to 23 Hz with an amplitude of oscillations of 0.002 m, and the ratio of its design parameters is determined: with a piston diameter of 0.1 m, it is recommended to use a diameter of the hole in the piston from 0.006 to 0.008 m. The conducted research and the proposed design of the vibrating machine showed the prospects of using the cavitation-magnetic method of changing the properties of water and cleaning in the creation of vibrating machines and devices for individual use.

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