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Cavitation-Reagent Technology for Water Purification of Pools and Water Parks

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ABSTRACT

The research goal was to develop an improved water purification technology for public reservoirs by adding the vibrocavitation purification before a reagent method with sodium hypochlorite, produced via electrolysis of salt. The main tasks of the research include the determination of vibrocavitation treatment efficiency and the development of a new low-frequency vibration resonance cavitation process for water purification, as well as equipment for this process. The vibroresonance method supporting the intensity of spatial displacements of cavitation exciters was developed on the basis of the theory of cavitation fields in liquids. While using this method, it was possible to establish the boundary conditions for stable support of the cavitation field created by low-frequency vibrations. The developed method is based on the formation of high intensive cavitation fields in liquids by vibratory decks. The advanced technological scheme of water purification for pools and public use reservoirs was proposed, which includes the addition of resonance vibrocavitators to a closed circulation cycle of water purification with the reagent method.

Keywords: pool, water purification, electrolysis, cavitation, vibration, elastic system, oscillation, working chamber.

INTRODUCTION

In recent years, the scientists have paid increasing attention to the technological processes of water treatment and water purification, which are the guarantee of preserving hydrosphere for the descendants and ensuring the health of mankind at present. Unfortunately quite often, the implementation of promising technologies is constrained by the production of significant amounts of wastes that can accumulate and cause secondary pollution of the environment. For example, a significant amount of spent sorbents are formed while using the adsorption purification method (Melnyk et al. 2015, Malyovanyy et al. 2013). The majority of reagent methods are accompanied by the accumulation of reaction products. At best, these substances are used in other industries, for instance, as complex fertilizers of prolonged action (Tulaydan et al. 2017). The biological methods (this technology is typical of municipal waste water purification) produced a large amount of biological sludge, which has already created considerable environmental pollution in Ukraine and in a number of other countries (Malovanyy M. et al. 2016, Malovanyy A. et al.

2014). Therefore, the purification methods that do not form secondary waste are of special interest. These methods include, first of all, the physical methods of purification.

Improving the welfare of the population in the world contributed to the rapid increase in the number of not only entertainment, but also health-improving institutions, focused on the use of water procedures. Apart from traditional swimming pools and showers, a lot of entertainment venues (saunas, therapeutic hydromassage, various water attractions and slides, cosmetic SPA-salons) use large volumes of high purified water. The increased requirements for the quality of water forced to abandon such chemical purification method as chlorination, which was prevalent in the past. Modern water treatment technologies for pools and water parks are oriented on advanced methods using hydrogen peroxide H_2O_2 or ozonation. The physical methods, which are based on the obtaining of purification reagent via electrolysis of sodium chloride aqueous solutions, become increasingly popular. The formed sodium hypochlorite, the effect of which is similar to the chlorine action, efficiently decontaminates and purifies water without creating insoluble wastes that would cause the secondary pollution of the environment. However, high power consumption is a significant disadvantage of this method. In this regard, scientists around the world continue to develop more advanced physical methods of water purification and water treatment (Farooq et al. 2009, Shevchuk et al. 2014) and cavitation is of great interest from this standpoint.

Nowadays, ultrasonic generators and hydrodynamic cavitators are mainly used for the cavitation treatment of liquids and suspensions on their basis. Ultrasonic cavitation treatment is characterized by the high intensity of the cavitation field, but it is extremely low in productivity due to the rapid attenuation of the ultrasonic wave in the fluid medium. The energy consumption of ultrasonic generators is quite high – up to 500 W/dm^3, limiting the use of ultrasound mainly for the laboratory investigations (Koval et al. 2011a, 2011b).

In hydrodynamic cavitators, the cavitation field is generated as a result of the changes in the velocity and geometry of hydraulic flows when they flow around solids or when solids move in liquids with certain speed. The most widely used blade cavitators are based on the formation of a cavitation field as a result of high-speed rotation of multiblade impeller in a liquid. The productivity of the cavitation treatment in such a case is 2÷3 m^3/h. However, the intensity of the formed cavitation field is insignificant, which does not provide qualitative treatment of liquids and limits the use of hydrodynamic cavitators (Vitenko 2009).

Regardless of the field excitation nature, the mechanisms of cavitation that influence the liquid are almost identical. The most illustrative one is observed in the water-based liquids. Numerous, short-time stages of the origin, growth and collapse of cavitation bubbles which occurred under the influence of pressure changes, contribute to the formation of a powerful energy wave, the development of chemical reactions and structure transformations of water molecules. The cavitational field in the water-based liquid generates the H° and $^{\circ}OH^1$ radicals, as well as the primary products of water decomposition, such as hydrogen peroxide, which are highly reactive relative to oxidation reactions. Although the lifetime of these individual radicals is milliseconds only, a large number and the continuous formation of new ones (instead of those that have entered into chemical reactions) promote the intensive development of chemical oxidation reactions with contamination of liquids, for example organic matter. In this case, the energy of microwaves formed during the bubbles collapse, destroying the shells of microorganisms, bacteria and yeast contained in the liquid. This provides the disinfection of the liquid medium from biological contaminants. The organic matter of the destroyed bacteria and the microorganisms under the influence of $^{\circ}OH^1$ radicals is partially converted into H_2O and CO_2, and partially deposited in the accumulators of the processed liquid (Kondratovych et al. 2013, Koval et al. 2012).

Undoubtedly, the influence of cavitation mechanism on the liquids being treated is much more complex and a comprehensive theoretical explanation of it has not been created yet. However, the fact that cavitation has a beneficial effect on liquids, improving their quality and providing them with new positive properties, is unquestionable.

To date, the absence of equipment, capable of combining the required efficiency of treatment with its quality constitutes the limiting factor of wide industrial use of cavitation.

The goal of the research was to develop an improved water purification technology for public reservoirs by adding the vibrocavitation purification before a reagent method with sodium hypochlorite, produced via salt electrolysis. The main tasks of the research include:

- establishing the prospects of vibrocavitation treatment for water purification and water treatment of public reservoirs;
- analysis and prospects of using low-frequency vibrations for cavitation fields excitation in liquids;
- experimental study of origin and stable existence of a cavitation field under the conditions of low-frequency vibrations;
- development of calculation methods and design of resonance vibrocavitators;
- experimental determination of basic technological parameters of vibrocavitation treatment;
- verification of technological possibilities and suitability of vibrocavitation treatment for water purification of pools and public reservoirs.

Fig. 1. Image of the working vibrocavitator model

MATERIALS AND METHODS

A working model of the vibrocavitator was used to establish the prospects of vibrocavitation treatment for water purification and water treatment (Fig. 1). The main elements of the device are 1 dm^3 cylindrical working chamber, a system of feeding blue-green algae and gases, electromagnetic vibration drive with attached oscillating deck equipped with cavitation exciters and a power supply to the vibration drive.

The cavitator is installed on a stationary basis and consists of two vertically located transparent cylindrical tubes connected by a metal ring. The connecting metal ring is equipped with nozzles for supplying the liquid and associated gases, as well as a nozzle for mounting a pressure gauge. An electromagnetic vibration drive is fixed above the cavitator on a stationary platform. It consists of an electromagnet with a field bobbin and an oscillating anchor mounted on the elastic elements. The anchor is attached to the stem, which, with its free end, is inserted into the cavitator.

A fixed deck on the support attached to the bottom of the cavitator is situated below the moving deck. The fixed deck is equipped with cavitation exciters, rotated by its end face to the exciters of the moving deck. Both decks have holes for the flow of liquid.

The electric control network of the electromagnetic drive is equipped with a laboratory autotransformer for adjusting the power of the electromagnet, as well as a wattmeter for recording the power consumed by it.

The water from the Aquapark (a public water park, Lviv, Ukraine) was used as an object of research. A model environment with a high content of urea and uric acid was created, since these substances are available in public swimming pools.

The carbonic acid diamide (urea or carbamide) is a water-soluble organic substance that has two amino groups in its composition. According to its chemical properties urea is decomposed into ammonia and biuret under the influence of high temperatures, namely those above its melting temperature (T = 132.7°C). This means that the removal of this substance from water of public pools is a complex process.

The experiments were carried out at the frequencies of 25, 37, 75, 90 and 110 Hz under nitrogen as the most effective gas medium (Koval et al. 2011a, 2011b) and various ratios of uric acid:water, namely: 1:10, 2:10, 3:10. The values of chemical oxygen demand (COD) were in the range of 656–304 mgO_2/dm^3, depending on the initial concentration of uric acid.

RESULTS AND DISCUSSION

The dependence of COD on the treatment time at the frequency of 37 Hz and different uric acid:water ratios is represented in Figure 2.

Figure 2 shows that the vibrocavitation treatment without gas decreases the COD value only by 56 mg O_2/dm^3. Regarding the combined action of vibrocavitation and nitrogen, the organic substances are actively destroyed already during the first hour of the experiment, regardless of their initial concentration. This process is described by the first-order equation, which is proven by the calculated effective constants of the destruction rate (Shevchuk et al. 2014). For the chosen gas (nitrogen) the effective constants are $1.8 \cdot 10^{-4} s^{-1}$ (curve 2) and $2.02 \cdot 10^{-4} s^{-1}$ (curve 3). The effective constants are in the same range, regardless of the initial concentration of organic compounds. Nitrogen supply at the uric acid:water ratio of 1:10 allows to achieve a five-fold decrease in COD. For comparison, at the uric acid:water ratio of 3:10 the value of COD decreases only twice.

While changing the frequency of vibrational cavitation from 25 to 75 Hz, it was found that at the uric acid:water ratio of 1:10, in the atmosphere of nitrogen, during the first hour of the experiment the effectiveness of organic compounds destruction is 70% and 75%, respectively. At frequency of 37 Hz, the obtained value is 84%. This confirms that high efficiency is achieved at oscillation frequency multiple of resonance one. At the frequencies above 75 Hz, the degree of purification did not exceed 80%.

On the basis of the experimental data presented, it can be argued that the frequency of 37 Hz corresponds to the resonance frequency for the studied system.

The main advantage of low-frequency vibrocavitators, first created by the authors, is a decrease in the energy consumption for excitation by 20÷25% and ensuring the stability of the cavitation field formation. This is achieved by involving the cavitation nuclea present in the liquid, which are microbubbles of the air and gases dissolved in the liquid, various suspended impurities and microparticles.

It was found that the cavitation nuclei resonance can be achieved not only at the frequencies equal to the oscillation ones, but also at the frequencies multiple of resonance ones. In mechanics, this phenomenon is quite common and used for technological purposes, for example, in vibration centrifugal machines for strengthening the parts, in planetary vibroexciters and in other similar devices. The mechanism of this phenomenon is quite simple in its essence and is most clearly illustrated by the example of children's swing. In order to increase the amplitude of swing oscillation there is no need to push it every period of oscillation. It is enough to apply force regularly in such a manner that the direction and vector of

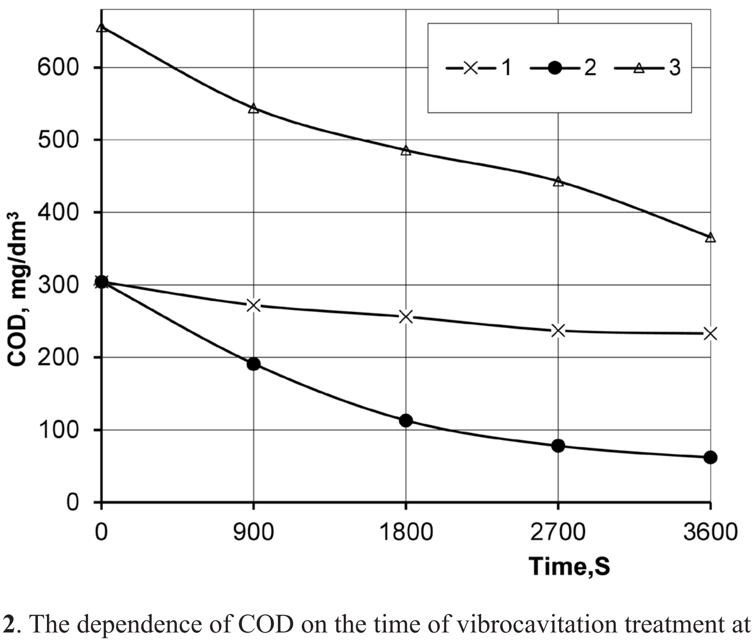


Fig. 2. The dependence of COD on the time of vibrocavitation treatment at the frequency of 37 Hz and different uric acid:water ratios: 1 – vibration without gas, ratio 1:10; 2 – vibration/N_2, ratio 1:10; 3 – vibration/N_2, ratio 3:10.

force coincide with the direction of swing oscillation. In this case, depending on the frequency and magnitude of the external force, the amplitude of swing oscillations can both decrease and increase.

Experimental confirmation of this phenomenon has become a key stage in the creation of a fundamentally new class of cavitation equipment, which we call as low-frequency vibration cavitators of resonance action.

A schematic diagram presenting the ring electromagnetic vibration cavitator of resonance action (Patent 2014, Shevchuk et al., 2011) is shown in Figure 3. In Figure 4 a 3D model is represented with a cross section for better perception of its construction. Figure 5 demonstrates the fragment of the initiator of cavitation – the deck with a nozzle. The liquid through the nozzle is accompanied by the cavities formation. Different (two extreme and average) positions of the oscillation chamber are shown in Figure 6.

The structure of the ring vibration electromagnetic cavitator of resonance action includes the loading (6), the working (9) and the unloading (14) chambers. The working chamber (9) is connected to the loading (6) and the unloading (14) chambers with the possibility of relative

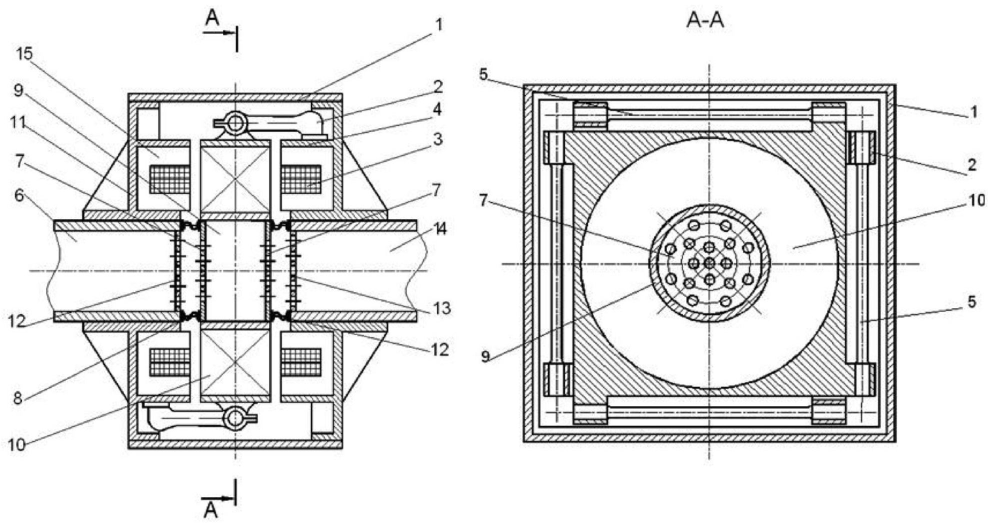


Fig. 3. Principal scheme of a ring vibration electromagnetic cavitator of resonance action.

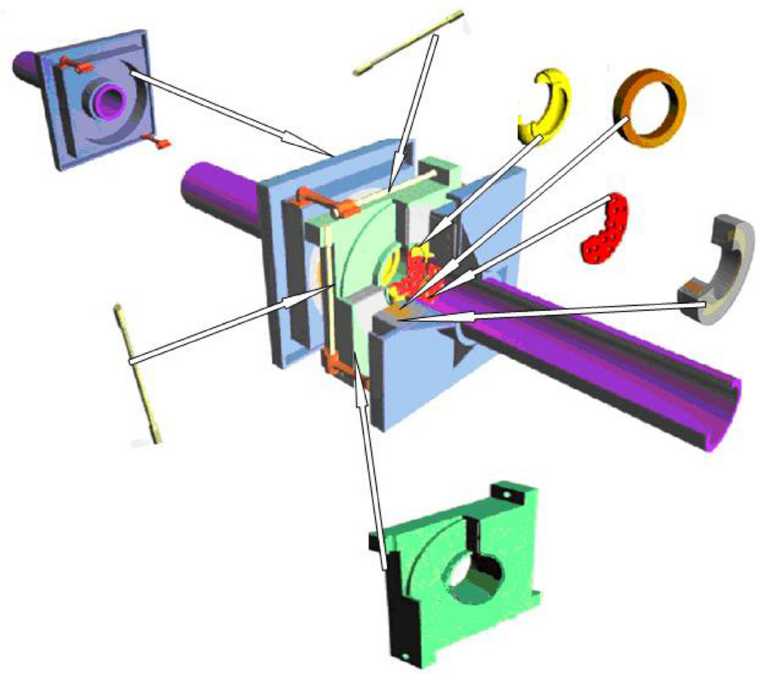


Fig. 4. Three-dimensional model of a vibroresonance electromagnetic cavitator

displacements through the flexible grooves (8 and 12). The ring-shaped anchor (10) made of sheet iron is fixed on the working chamber (9). The chamber and the anchor through the brackets (2) and the cylindrical elastic rods (5) are connected with reactive masses (11), which are fixed on the pipes of loading and unloading chambers. The electromagnet body (4) is attached to each of reactive masses (11) coaxially to the anchor (10). In body (4), the stators (15) with windings (3) are mounted coaxially to the anchor (10). Each of the stators (Fig. 3) form two electromagnets symmetrically arranged relative to the anchor (10). The windings of electromagnets are connected to AC power with phase displacement in such a way that in the first half-period of the sinusoidal alternating voltage the anchor is attracted to one of the extreme electromagnets, and in the second half-period – to another electromagnet.

Coaxially located stators (15) with windings (3) and anchor (10) with the working chamber (9) form a ring electromagnetic vibroexciter with two electromagnets and a common anchor. The exciter and the elastic rods (5) form a two-mass resonance oscillation system. The first oscillating mass is the working chamber (9) filled with the liquid under treatment, anchor (10) attached to it and decks (7); the second one – stators (15) with windings (3) and reactive masses (11) with pipes of the loading (6) and the unloading (14) chambers.

Decks (7) and (13) with holes for the flow of liquid under treatment which are uniformly located throughout their area are rigidly mounted on the anchor and stator. The diameter of holes is equal to the oscillation amplitudes of the working chamber, and the distance between adjacent holes is equal to treble value of amplitude. A couple of decks attached to the anchor and stator is

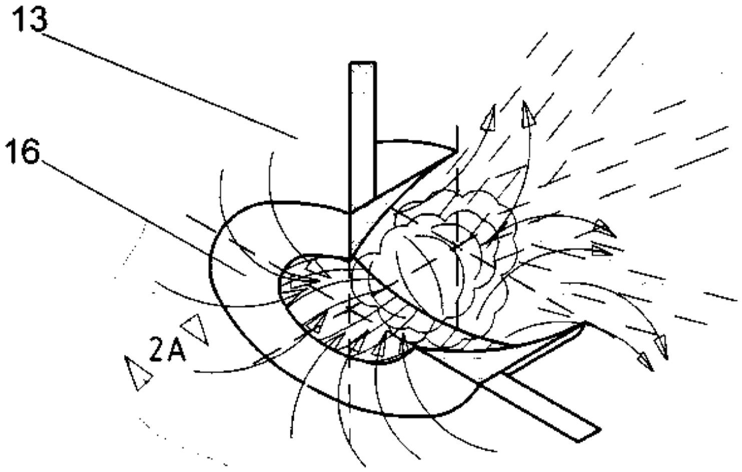
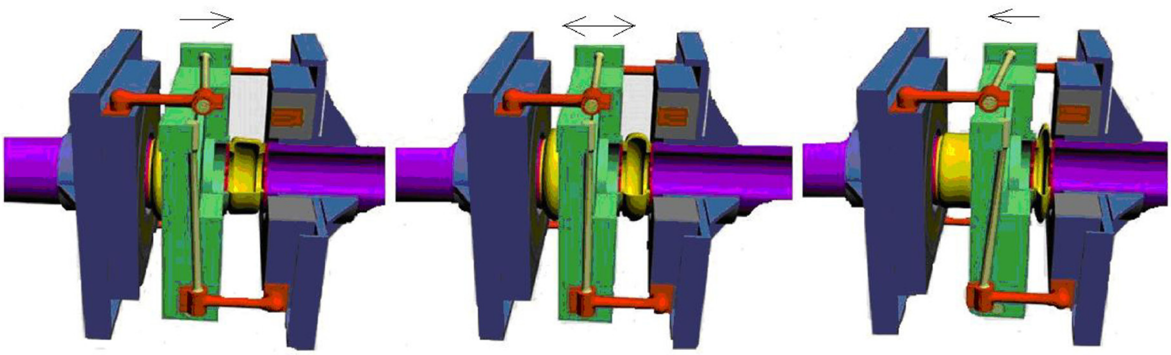


Fig. 5. A fragment of the deck with the nozzle and formation of cavities (numbering of positions is in accordance with Fig. 3)



A b c

Fig. 6. Different positions of the oscillating chamber of the vibrocavitator: a – the extreme left, b – the middle, c – the extreme right.

mounted symmetrically at the inlet and outlet of the working chamber (9). The exciter is equipped with a casing (1) to protect the device from the foreign substances.

In order to intensify the synthesis of cavities, the nozzles (16) with cylindrical external and spherical internal surfaces are pressed over deck holes (Fig. 5). Both the diameter of the cylindrical surface and the radius of the spherical inner surface are equal to double value of amplitude A of the deck oscillation. In the intersection with the end plane of the nozzle (16), the inner spherical surface forms an aperture for flowing liquid, the diameter of which is equal to A. This aperture of the nozzle (16) is oriented toward the opposite direction of the liquid being treated (Fig. 5).

The vibration electromagnetic cavitator is operated as follows: the liquid is fed under a slight pressure or gravity along the pipe of the loading chamber (6) into the working chamber (9). At the same time, voltage is supplied to the windings of the electromagnets with the abovementioned phase displacement. Electromagnets alternately attract the anchor (10) with the chamber (9) filled with liquid, while flexing the elastic cylindrical rods (5). The deflection and elasticity of the cylindrical rods (5) are designed in such a way that they provide resonance oscillation modes of the working chamber (9) and prevent collisions of the anchor (10) and stators (15) with each other (Fig. 3). The alternate attraction of the anchor (10) to the electromagnet (15) is transformed into directional, plane-parallel vibration displacements of the working chamber (9). These oscillations occur with certain amplitudes, with a frequency equal to the double value of voltage supply. Therefore, at the frequency of 50 Hz, the oscillation frequency of the working chamber (9) will be equal to 100 Hz. Apart from the oscillations of the working chamber (9), the flat-parallel movements are intrinsic to the decks (7). As the oscillating decks (7) move to fixed decks (14), the liquid pressure between them increases, and promotes pushing of the liquid through the holes in decks (14) with the velocity equal to that of the decks (7).

At the recommended oscillation amplitude of 1.5–2 mm and frequency of 100 Hz, the velocity, at which the deck crosses the flow of liquid, is 0.95–1.15 m/s. The coaxial arrangement of oscillating and fixed decks, which oscillate towards each other, provides the increased pressure and velocity of the hydraulic flows moving through the holes in the decks. Therefore, the flow loses density and strength. At the same time the cavitational bubbles originate in an avalanche-like manner from cavitation nuclei, which are always present in the liquid; subsequently increase in volume and collapse, forming the cavitational field of high intensity. The uniform location of the holes in decks (7) and (14) provides the uniformity of the cavitation field intensity throughout the cross-sectional area of the working chamber (9), i.e. the uniformity of the liquid treatment.

The velocity of a liquid flow is sufficient for the formation of air cavities from air and gases dissolved in the liquid being treated. When the cavities move along the spherical inner surface of nozzle (16), the pressure inside the cavity, as well as its volume rapidly increase, which results in the occurrence of shock wave impulses in liquid at the nozzle exit (Fig. 5). The effect of such impulses on the cavitation nuclei is accompanied by the instantaneous origin, growth and collapse of cavitation bubbles.

Due to the symmetric arrangement of the decks, the liquid flowing through the working chamber 9 is treated twice. Then the liquid is taken off through the unloading chamber 14 for further use.

The quality of the treated liquids is regulated by the intensity of the cavitation field formed by the cavitator. It depends on the oscillations amplitude A of the decks, frequency of these oscillations and the diameter of holes for the flow of liquid. The oscillation amplitude is regulated by different values of supply current for electromagnet windings. Then, the attraction force of the anchor to the stator electromagnets varies, and this actually specifies the amount of spatial displacements, i.e., the amplitude of the oscillatory displacements of the decks. The oscillation frequency of the decks is regulated by a thyristor circuit for adjusting the voltage supply to the electromagnet windings, the change of which changes the frequency of anchor attraction to the stator electromagnets, i.e. the frequency of spatial displacements of rigidly connected to the anchor exciters of the cavitation. The optimum values of the amplitude and oscillations frequency are chosen experimentally, depending on the physical parameters of the liquids – their density, viscosity, forces of surface tension, etc. The choice of oscillations frequency for decks is of particular attention. They are chosen as a multiple value maximally close to the own frequency of micro-bubbles of the soluble gases and air present in a specific liquid being treated. These microbubbles serve as the cavitation nuclei providing the cavitation treatment in the so-called resonance mode with minimal energy costs.

In order to increase the efficiency of the cavitation treatment, a gas supply system is designed in the working chamber (9) (not shown in the figures). The type of gas supplied to the working chamber depends on the type of liquid. When pool water is treated, it is expedient to use oxygen or cheaper nitrogen. The gas flow rate is chosen depending on the degree of water pollution in the range of (15 ÷ 25) dm^3 per cubic meter of water under treatment. It is necessary to supply gas to the working chamber to compensate the degassing phenomenon, which necessarily accompanies the cavitation processes.

The elasticity of the oscillating systems, the power of electromagnets and structural elements of the drive (shape and dimensions of the electromagnets, cross-section and the number of turns of windings, etc.) are calculated according to the generally accepted methods for the vibration devices with an electromagnetic drive (Lanets 2008).

The devices for vibroresonance cavitation treatment of liquids include two groups of variable parameters which provide the quality of cavitation treatment, in particular a group of design and a group of technological parameters.

The group of design parameters includes:

- oscillation frequency of decks-cavitation exciters, which is regulated by the frequency regulator installed in the control panel, e.g., AFC-120 model;
- the oscillations amplitude of decks-cavitation exciters, which is regulated by the power and constructive parameters (the distance between anchor and stator) of the drive electromagnets and the rigidity of the elastic system (rods 2 and 5) of the deck suspension;
- direction of oscillation of decks-cavitation exciters (along or across the liquid being treated) due to the location of the drive electromagnets.

The main task of changing the design parameters involves altering the velocity and directions of the spatial displacements of decks-cavitation exciters in the liquid flow, which ultimately affects the range of vibroresonance excitation of the cavitation.

In turn, the group of technological parameters includes:

- the pressure and velocity of the liquid in the area, where they are regulated by the flow rates (pump and throttle of the feed line) and quantity of the liquid supplied to the working area;
- type, quantity and pressure of the gas phase or air, which are regulated by the throttling on the gas pipeline;
- the amount of cavitation nuclei available in the liquid under treatment, which is regulated by the quantity of the supplied gas.

The main task of changing the technological parameters is the effect on the energy state of the liquid being treated, as well as on the treatment time.

Thus, the changes in the design and technological parameters effectively affect the liquid ability for excitation and stable existence of cavitation phenomena in it. Hence, they influence the intensity of the cavitation field formed in the liquid, which determines the quality of cavitation treatment in general.

The peculiarity of vibrocavitators, as well as cavitators of any other type, is the need to provide a certain energy effect. The level of energy impact should ensure excitation of the cavitation phenomena which initiate the effective proceeding of specific physical processes and chemical reactions in the environment. From the molecular physics standpoint, the creation of certain prerequisites for the origin and further growth of the cavitation nuclei existing in the liquid is regulated by the dimensionless Reynolds complex *Re* (the so-called Reynolds number). Reynolds number relates the changes in the characteristics of the liquid flows of a certain density and viscosity with the change in velocity and pressure of a liquid. The critical Reynolds number Re_{cr} can be interpreted as the parameter that determines the threshold of cavitation origin in the liquid. In mathematical expression, the Reynolds number *Re* has the following form (Farooq et al. 2009, Silin et al. 2009):

$$\mathrm{Re} = \frac{\rho \cdot \upsilon \cdot L}{\mu} = \frac{\upsilon \cdot L}{\nu}, \tag{1}$$

where: ρ is a liquid density, kg/m^3;
υ is a liquid flow rate, m/s;
μ is a coefficient of dynamic viscosity, Pa/s;

Here: $\nu = \frac{\mu}{\rho}$ is a kinematic viscosity, m^2/s;
L is a linear dimension typical of definite equipment, m.

For the liquids with density and viscosity close to those of water, the value of Re_{cr} is usually slightly higher than the value of (1.5 ÷ 2.0) 10^5, i.e. $Re \geq (1.5 \div 2.0)\ 10^5$ (Vitenko 2009).

Therefore, by specifying the numerical values of the liquid parameters and Re_{cr} in the equation (1), and using the equation (2), one can determine the critical velocity of the oscillatory decks movement, necessary to excite the cavitation

$$V_d^{\,*} = \frac{\mu \cdot \mathrm{Re}_{cr}}{\rho \cdot L_d} = \frac{\nu \cdot \mathrm{Re}_{cr}}{L_d}, \tag{2}$$

where: L_d is the total specific size of the circle length of the oscillatory deck holes, m.

In the case of simultaneous use of several decks which oscillate in the antiphase, the velocity of each can be reduced by the total number of these decks n, i.e.,

$$V_d = \frac{V_{d^*}}{n}. \tag{3}$$

The average velocity of oscillatory movements of any vibration bodies, including decks-cavitation exciters, the so-called vibrovelocity, is limited by the frequency f and the amplitude A of their oscillations. Therefore, specifying, for example, the value A and equating the velocities between themselves $V_k = V_d{}^*$, one can determine the required frequency of oscillations decks, i.e.

$$f = \frac{V_k}{2 \cdot \pi \cdot A} = \frac{\mu \cdot \mathrm{Re}_{cr}}{2 \cdot \pi \cdot A \cdot \rho \cdot L_d} = \frac{\nu \cdot \mathrm{Re}_{cr}}{2 \cdot \pi \cdot A \cdot L_d}, \tag{4}$$

Drive force F_T, due to which the deck oscillates and overcomes the resistance of the fluid, is proportional to the total pressure ΣP_t on the oscillation deck, the total value of the surface area ΣS_0 of the oscillatory deck holes for liquid flow and the inclination β of the vibration decks relative to the direction of the flow, i.e.

$$F_T = \left(\sum P_t\right) \cdot \left(\sum S_0\right) \cdot \sin \beta. \tag{5}$$

In the case of traditional single- and two-mass resonance vibration constructions, the drive force of electromagnetic vibroexiters is calculated by means of the formula:

$$F_T = \frac{M_o \cdot \omega^2 \cdot A_{rel}}{\lambda \cdot z^2}, \tag{6}$$

where: M_o is a specific oscillating mass, which in this case is the total oscillating mass of the working chamber and includes the mass m_a of the electromagnet anchor of the vibration drive, the specific mass m_e of the elastic oscillating system, the mass m_l of the liquid under treatment with definite ρ in the working chamber of the volume V, the mass m_d of oscillating deck with the holes for liquid flow in a sum with fastening elements of sealing corrugations, i.e.

$$\begin{aligned} M_o &= m_a + m_e + m_l + m_d = \\ &= m_a + m_e + \rho \cdot V + m_d; \end{aligned} \tag{7}$$

$\omega = 2 \cdot \pi \cdot f$ is a circular frequency of cavitation exciter oscillations;

f is a oscillation frequency of the electromagnet anchor;

A_{rel} is the relative amplitude of oscillations of the oscillatory system.

Here: $\lambda = \dfrac{1}{\sqrt{\left(1 - z^2\right)^2 + 4 \cdot \gamma^2 \cdot z^2}}$ is the dynamic coefficient in which the value of the resistance parameter γ for a steel elastic system without structural hysteresis γ = 0.004 ... 0.006; for rubber elastic systems γ = 0.1 ... 0.15.

z is a resonance adjustment factor.

Such an important parameter for resonance modes of vibration equipment operation as the size of elastic suspension rods is determined from the following observations. The length of the cylindrical rod of the elastic suspension is specified in accordance with the maximum allowable dimensions of the construction, and the rod diameter d is determined from the following dependence (Lanets 2008)

$$d = 2\ \sqrt[4]{\frac{C_r \cdot l_r^3}{3E \cdot \pi \cdot n \cdot k}}, \tag{8}$$

where: E is the elastic modulus of the rod material;

C_r is the elastic suspension rate, which is determined from the dependence below

$$C_r = M_o \left(\frac{\omega}{z}\right)^2; \tag{9}$$

where: n is a number of the elastic suspension rods;

l_r is a length of the elastic suspension rod;

k = 0.80–0.85 is a restraint coefficient of the elastic suspension rod.

As it was mentioned above, the purification technology using sodium hypochlorite, obtained via electrolysis of salt, is the most effective water treatment method of public swimming pools to date. However, its widespread use is hampered not only by the high value of electrolysis machines, but also by significant energy consumption during their operation. For example, the most commonly used electrolysis unit Sivash URE-1000 consumes up to 10 kW of electricity per hour. Moreover, it is necessary to use at least two plants for high-quality water treatment of the pool with an average size of 3,500–5,000 m^3. Such high energy consumption negatively affects the cost of services for consumers of water procedures.

We have experimentally tested the advanced technological scheme of water treatment, which combines the electrolysis of the salt solution to obtain sodium hypochlorite and the vibrocavitation stage.

The process flowsheet of reagent-cavitation water purification of pools and reservoirs of public use is shown in Figure 7. The circulating closed cycle includes a water filtration unit with coarse and fine filters, electrolysis unit Sivash URE-1000, cavitation unit with several electromagnetic vibrocavitators of resonance action, and a system of gas supply to the working chambers of vibration cavitators.

Daily required volume of water to be treated is approximately 15–20% of its total volume. A cavitation purification unit includes 2 ... 4 vibroresonance cavitators with a single productivity of 3 ... 3.5 m^3/h and power consumption of 1 ... 1.5 kW/h. Nitrogen is used in the amount of 0.15 dm^3 per cubic meter of water under treatment.

Three independent circuits are included in the general system. The first one is intended for the city water or reserve tanks for filling the pool. Beyond the filtration unit, the water is fed into the working chambers of vibrocavitators, where it is purified from organic and biological contaminants. Then it is directed to the storage reservoir, where it is mixed with the sodium hypochlorite obtained in the electrolysis plant. After precipitation, the treated water is supplied to fill the pool.

The second circulating circuit is intended for cyclic disinfection of the pool water. The contaminated water from the pool overflow system is mixed in a reservoir with a solution of sodium hypochlorite, purified and supplied again to the pool by pumps. Purification of this circulating water is carried out periodically, approximately 3–4 times a day, depending on the degree of water contamination and time schedule of the pool.

The third circuit is intended to purify the contaminated pool water before its discharge into the sewage system. In this circuit, the water after filtration and decontamination in vibrocavitators is directed to a storm drain or sewage system.

The proposed double reagent-cavitation purification of water not only improves its structure and the quality of purification, but also reduces the energy consumption by 40÷45%. It is provided by the fact that cavitation treatment effectively disinfects the contaminated water from biological and organic pollutants, including urea, and

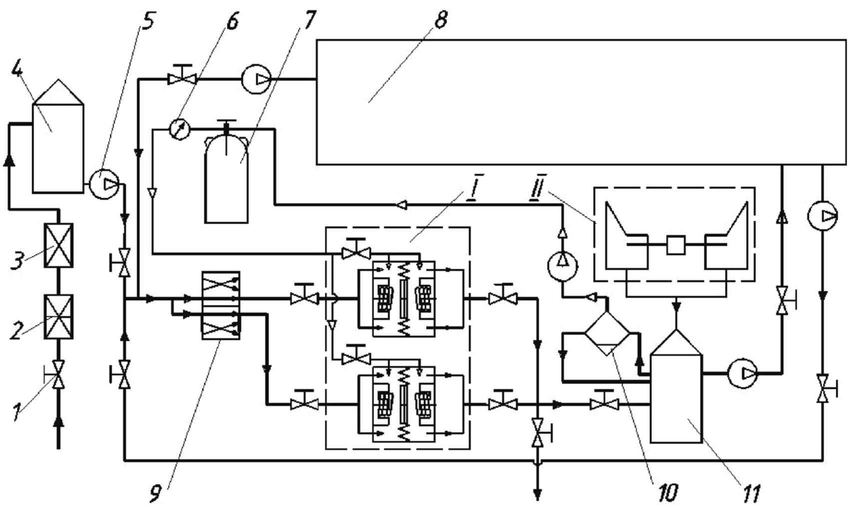


Fig. 7. Process flowsheet of reagent-cavitation water purification of public reservoirs: 1 – regulating valve, 2 – coarse filter, 3 – fine filter, 4 – storage reservoir, 5 – pump, 6 – pressure gauge, 7 – gas cylinder, 8 – pool, 9 – pneumatic gauge switch of water flows, 10 – separator, 11 – storage reservoir for mixing water with sodium hypochlorite, I – block of vibrocavitators, II – block of electrolysis preparation of sodium hypochlorite.

reduces the operational time of energy-consuming electrolysis plants in half.

The vibroresonance cavitation treatment of natural reservoirs water, which is used for growing fry, for drinking and preparing fodder in livestock-breeding or for irrigation of agricultural plants was proven to be quite effective. The explanation is that the cavitation treatment of water not only purifies it from the biological and organic pollutants, but also improves it via transformation from the cluster structure into a monomolecular state peculiar to spring water. It is well-known that water in a monomolecular state is better absorbed not only by plants, but also by living organisms, beneficially affecting the digestion organs, and the circulatory system.

CONCLUSIONS

1. The prospects of vibrocavitation treatment for water purification and water treatment of public reservoirs were proven. While changing the initial values of the frequencies of vibrational cavitation in the range of 25–75 Hz in the nitrogen atmosphere, during the first hour of the experiment the effectiveness of organic compounds destruction (uric acid:water = 1:10) was 70% and 75%, respectively; at 37 Hz this value was 84%.
2. A new method of low-frequency vibrations for cavitation fields excitation in water-based fluids and equipment for its implementation was created. The peculiarity of the process is the energy effect of the cavitation exciters on the liquid flows at the oscillation frequencies multiple of the proper oscillation frequencies of the cavitation nuclei suspended in the liquid under treatment.
3. The conditions for cavitation processes excitation by low-frequency vibrations were determined and theoretically substantiated. The dependences for calculating the velocities of the spatial displacements of the cavitation exciters in the liquid, the frequencies of their oscillations, as well as the basic parameters of the vibrocavitators drive were determined.
4. In comparison with ultrasonic cavitators, in which point magnitostriction agents of cavitation are mainly used, vibration cavitators provide a uniform distribution of the cavitation field intensity across the cross-section of the working chamber, and, consequently, the uniformity of the liquid treatment.
5. Compared to hydrodynamic cavitators, vibroresonance cavitators provide a 25–30% increase in the cavitation field intensity, and, accordingly, proportional increase in the productivity of cavitation treatment.
6. The experiments regarding the technological capabilities of vibroresonance cavitation treatment confirmed its high efficiency for water purification of natural reservoirs and public pools.

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