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THE EFFECTIVENESS OF FOOD INDUSTRY WASTEWATER TREATMENT BY MEANS OF DIFFERENT KINDS OF CAVITATION GENERATORS

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Abstract. The effectiveness of wastewaters treatment by means of ultrasonic and vibration response cavitation has been investigated. The application of the vibration and cavitation equipment produces the same effects as in case of ultrasonic cavitation, but it is economically reasonable to use vibration response low-frequency cavitators.

Keywords: acoustic cavitation, water purification, reaction kinetics, biological contamination, chemical oxygen demand, cavitators.

1. Introduction

The intensification of the production processes, as well as the solution of the problems connected with power and resources preservation in recent times, have become more important. One of the most effective ways to reach high technological results in processing of liquid heterogeneous systems is an impulse action over the media under processing [1-3]. According to the analysis of the typical technological schemes and corresponding equipment, most of the processes in food industry are energy consuming and require an application of the intensification methods of modern technological processes. The phenomena that accompany cavitation belong to such methods [4, 5]. Cavitation may be created by means of different methods, which include spark discharge, impulse passage of high-voltage current (electro-hydraulic shock), ultrasonic radiation, hydrodynamic pressure loss in the current to the critical point (hydrodynamic cavitation) [6]. Spark discharge and electro hydraulic shock effect are used to process the limited amount of liquid. In case of spark discharge and electro hydraulic shock an integral current rip in the liquid followed by shock wave propagation is observed on the area between the electrodes. Because of electric leakage in the liquid in the flow volume surrounding the discharge channel, there the high-pulse pressures are developed, which generate the local cavitation that in this particular case serves as a complementary factor in the processing of the medium [7, 8]. The energy of the spherical shock wave, which is distributed from the center of the liquid volume to its periphery, is inversely proportional to the squared distance from the area of electrical discharge [9, 10]. It leads to uneven force action over the liquid and in case of increase in the volume of the liquid under the treatment, requires the power improvement and amount of electrical discharges, which lead to increased energy consumption for the processing operation. Besides, the creation of the powerful shock waves throughout the liquid volume requires the strengthening of the working chamber of the unit [11, 12].

The above-indicated defects exclude ultrasonic method, which consists in the application of vibrations of the ultrasonic frequency for the creation of conditions for the development of cavitation nuclei, which are the gas inclusions located in the fluid. The shock waves are generated on the small territory around each cavitation cavern [12]. It provides the uniformity of the force influence over the liquid and the absence of load impact on the wall of the working chamber of the unit. The energy of ultrasonic radiation is located in a big amount of small volume of liquid and allows decreasing the energy consumption for the performance of processing in comparison with the spark discharge and electro hydraulic shock. However, in the course of ultrasonic processing, the cavitation arises on a working surface of the acoustic radiator, excluding its destruction due to erosion. Besides, the passing of ultrasound through the liquid is related to the great losses of energy of the acoustic waves. Some of the indicated problems are solved in the conventional ultrasonic apparatuses [11], where not all the liquid is being processed at once, but only its part that flows through the working area of the apparatus, which allows avoiding great consumption for the ultrasound radiation [12].

The transition to the perspective current processing scheme stipulates the possibility to use the hydrodynamic

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method generating cavitation. In this case, the appearance of cavitation is determined by the decrease of pressure in a flow to the values that correspond to the pressure of the saturated steam of the liquid under treatment. Hereby the cavitation nuclei of different sizes are grasped, which intensifies the development of hydrodynamic cavitation and the process of the liquid treatment in comparison with ultrasonic method. In order to intensify the industrial technologies, the most applicable are all kinds of hydrodynamic cavitation, which allows processing of the big amount of liquid in a flow [11, 12]. Hydrodynamic cavitation may be carried out in the apparatuses of different kinds of construction and by means of different methods. The following kinds of hydrodynamic cavitation are distinguished: static, dynamic, intermittent, centrifugal, nozzle, fricative, current, mandatory, thermal, steam, gas. Apparatuses that are based on the use of the effect of hydrodynamic cavitation are meant for the processing of the liquid heterogeneous systems. The effect of cavitation is significantly influenced by the construction and principles of the apparatus operation. The equipment that the cavitation effects are used in, has the following advantages: increased productiveness of the processes due to high carrying capacity, increased level of the products quality due to high dispersibility of the particles, increased resistance and uniformity of the system, decrease of the unit costs of energy for the processing due to the local concentration of efforts, provision of the universality of application. In this particular case, a gas cavern serves as the energy transformer, which is being introduced and the object of influence [11, 12]. In case of intense broadening, compression or pulsation of caverns under the influence of the external pressure which is periodically changed, the carrying processes are activated both on the micro-level, throughout a separate cavern and on the macro-level, for the whole volume, in consequence of a turbulence transition of the interphase surface. The combined activity of these factors increases the total coefficient of the mass-transfer in a system [11].

According to the classification of the cavitation equipment for the processing of the technological media, four groups of constructions exist.

The equipment where cavitation appears due to a sharp variation of the flow geometry is referred to the first group. Because of local pressure release in the current of a medium, a hydrodynamic cavitation is developed. A change of the flow geometry is reached by selecting a form of the flow chamber of equipment or by placing the bluff bodies in a flow – cavitators. Stimulation of cavitation is made by means of a cavitator, which is turning round. These devices are structurally simple, reliable, convenient and highly productive (up to 100 m^3/h),with broad technological properties [12].

In industry, cavitation devices are effectively used, the most perspective of which is the dynamic type flowing device. Simplicity of the design provides it with significant advantages over others. The processed medium comes to flow cylindrical chamber and enters the placed there cone-shaped cavitator turned towards the flow with the smaller foot. Entering the special spots of the cavitator, the current of the liquid is spinning round and by means of speed increase a cavitation mode of the flow is created, making the cavitator spin round. Behind the cavitator the cavitation caverns are created that move along the circular helix and generate the field of cavitation bubbles, which saturate a stream of a medium throughout the whole volume of the flow chamber of a mixer or homogenizer. In a flow chamber at the output behind the cavitator a conical nozzle is placed, which narrows a liquid flow, increases a flow speed and decreases a hydrostatical pressure. Under such conditions at the outlet of the chamber, a flow with significantly big bubbles is formed. Splashing inside, the cavitation bubbles create the pulsating shock waves, which intensify the mixing process. Moving the cavitator along the flow chamber, they change the length of the cavitation zone [12].

The devices (rotor and flowing type hydrodynamic radiators), where the cavitation is generated by periodical change of the liquid pressure *via* hydrodynamics belong to the second group. These devices are structurally simple, though their productivity does not exceed $30{\cdot}m^3$/h [12].

Cavitation devices of the third group operate with acoustic radiator in the ultrasonic frequency spectrum; they have low productivity (up to 30 m^3/h) and contain an expensive ultrasonic generator [12].

The fourth group includes the devices, which use high voltage discharge in the liquid (electrohydraulic effect), due to the electric breakdown of which the high impulsive pressures generating cavitation appear in the environment zone of discharge channel [11, 12].

2. Experimental

We studied the influence of cavitation on sewage water of the brewery, yeast production (private company “Enzime”), yeast lysates with different initial values of microbial number (MPN) and different types of organic and biological contamination (COD). An ultrasonic generator UZDN-2T was used with the capacity of 40 W (Fig. 1) and low-frequency vibration and resonance cavitator (Fig. 2). The microbial number was defined before and after the processing by means of surface plating at a beef-extract agar. The investigations connected with combustion of admixtures in water of the natural reservoirs was carried out at the temperature of 298 K and pressure of $1{\cdot}10^5$ Pa, selecting the same experiment conditions for running the processes both in the ultrasonic field and with application of the vibrocavitation.

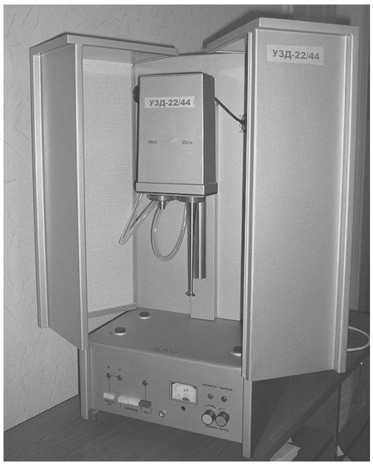


Fig. 1. The image of an ultrasonic generator UZDN-2T for combustion of inclusions of organic matters and disinfection of microorganisms in the ultrasonic field

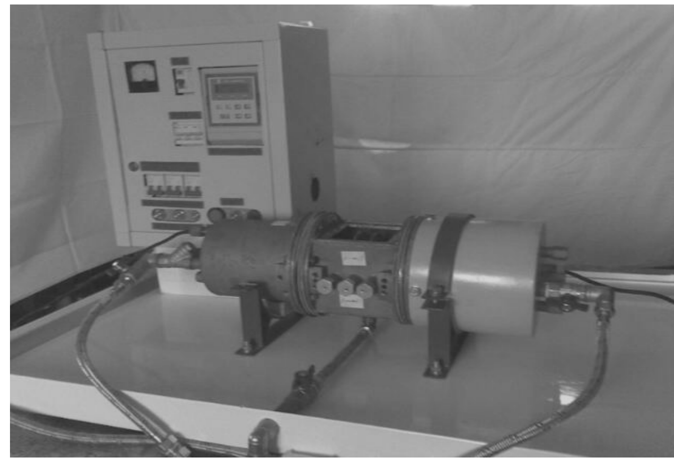


Fig. 2. An image of the low-frequency vibration and resonance cavitator for cavitation processing of water solutions with high content of MPN and COD under the pressure and at the elevated temperature (with partially removed protective elements of a case) [11]

For cavitation processing of water solutions and solutions with toxic and chemically aggressive matters, special constructions of low-frequency vibration cavitators have been developed, able to provide the processing at the increased liquid pressures (up to 3.5–4.0 kg/cm^2) and the temperatures up to 493 K. They are manufactured of stainless steel and their peculiar feature is the absence of elastic corrugated tubes and resonance elasticity of a pendant of the oscillating decks-cavitation stimulators.

In order to prevent overheating of the drive electric magnets when processing the liquids at the elevated temperatures, a cooling system for electrical drives has been provided.

Having determined the optimum performance of the cavitator, the necessary frequency range of the supply variations of the electromagnet drive is established on its remote control. By means of socket pipes, through the regulatory throttles the liquid and gas under processing are delivered to the operating chamber of the cavitator (in case of process requirement) and processing is carried out.

3. Results and Discussion

When treating the contaminated water with ultrasound the reduction rate of chemical oxygen demand of water is significantly higher than its aeration with oxygen. At the same time, the simultaneous processing of water by means of the ultrasound with its aeration by oxygen increases the speed of oxidation process of organic compounds in water. Running the process in accordance with the last methods allows decreasing the amount of chemical consumption of oxygen to the accepted standards for water.

In the course of sonication in the oxygen environment, a significant decrease of the microbial number (Fig. 4) takes place within the first minutes of water processing with ultrasound. In case of long-term water treatment with ultrasound and with simultaneous aeration with oxygen, the degree of water clearing from biological contamination may reach 91 % (Fig. 4). It is much higher than it is required according to the standards for certain types of microorganisms.

A significant decrease of the microbial number is confirmed by the results of microphotographic experiments (Fig. 5). It may be seen from the microphotographs that during the contaminated water processing the amount of the inoculated colonies of microorganisms significantly decreases.

As may be seen from Fig. 6, the decrease of chemical consumption of oxygen is well described by the second-order kinetic equation, moreover, in this particular case, the synergetic effect of oxygen activity and ultrasonic cavitation is also observed. High effectiveness of COD index reduction during the sonication in the oxygen environment is related to the fact that under the cavitation conditions peroxy radicals, peroxides and oxoradicales are created, which take part in radical-chain oxidation of the organic compounds and provide a high rate of the process.

As may be seen from Fig. 7, within two-week storage, the water COD is not actually changed (within the experimental error), and the microbial number starts to grow after the second day of storage and reaches the initial value at the end of the seventh day.

The increase of MPN of water, which initially contains biological contamination and organic component, but which was not subjected to the ultrasonic treatment, comes at once. The post effect of ultrasound activity is the same for the photochemical treatment of water but for the photochemical initiation it is quite lower (up to 2 h).

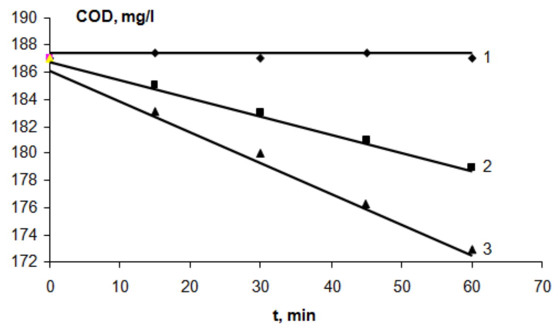


Fig.3. The change of COD of yeast dispersion in time during ultrasonic irradiation under anaerobic condition (1), aerobic condition (2) and at the oxygen bubbling through dispersion (3). Initial concentration of yeast 1.6 g/l

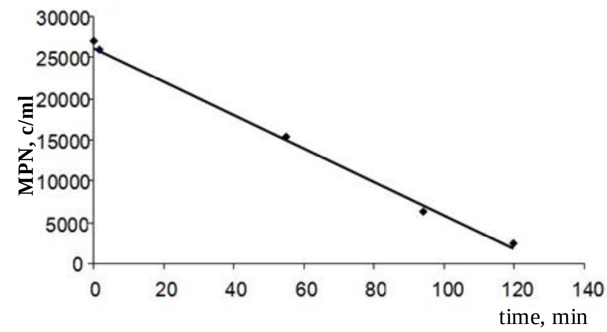


Fig. 4. Change with the time of the microbial number of water after the waste treatment facilities of private company "Enzyme" at the temperature of 298 K, $P = 1{\cdot}10^5$ Pa, [MPN] = 27000 c/ml under treatment with US and oxygen aeration

a) b)

Fig. 5. Microphotographs of water from a contaminated water body before (a) and after (b) ultrasonic treatment; duration 60 min

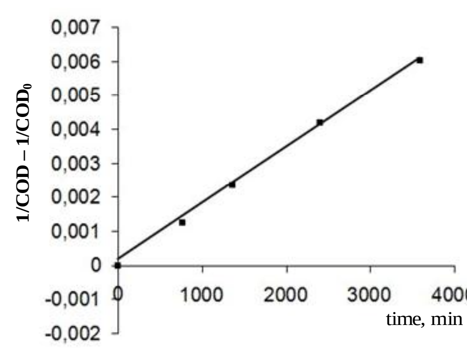


Fig. 6. Dependence of chemical consumption of oxygen of water after the waste treatment facilities of private company "Enzyme" on the duration of ultrasonic treatment in the coordinates of the second- order equation

In Fig. 8 it is shown that the use of vibrocavitation device gives the same effect as in case of US cavitation. The decrease of MPN of sewage waters of the brewery, yeast production, yeast lysates is satisfactory outlined by the first order reaction levels and is only distinguished by the decay constant (Fig. 8, Table).

Our results show the decrease of sewage waters COD in time during ultrasound and vibrocavitation treatment (Fig. 9).

Just in 1 h of processing with the frequency of 50 Hz the level of destruction of yeast living cells reaches 99.8 %, this is a satisfactory index for the technological implementation. However, the handling time depends very heavily on the frequency. In Fig. 10 the dependence of the level of dying away of yeast cells from the oscillation frequency of decks-the stimulators of cavitation is shown and it may be seen that the best effect was reached with the frequency of 37 Hz. This frequency is a resonance frequency, where the maximum result with the minimum energy consumption is reached, required for the stimulation of the cavitation, in other words the oscillation frequency of decks is divisible or equal to the oscillation frequency of the cavitation nuclei. That is why the optimum frequency is 37 Hz.

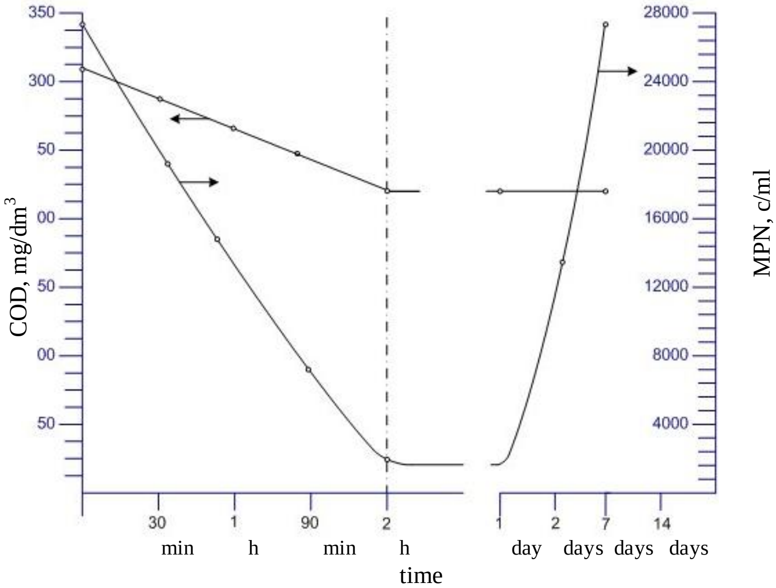
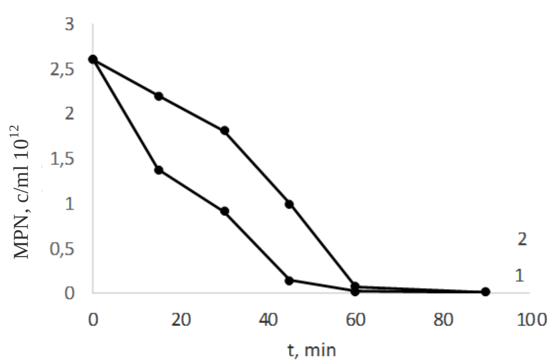
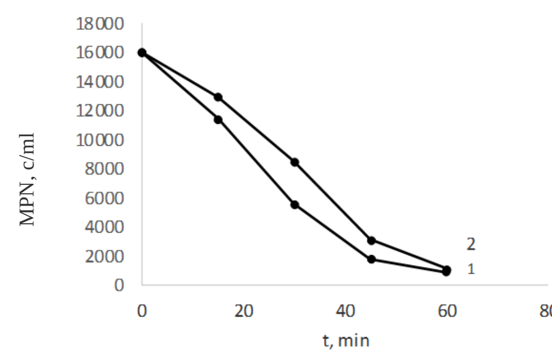


Fig. 7. Dependence of the change of COD and MPN of water after the waste treatment facilities of private company "Enzyme" in case of ultrasonic treatment and its preservation



a)



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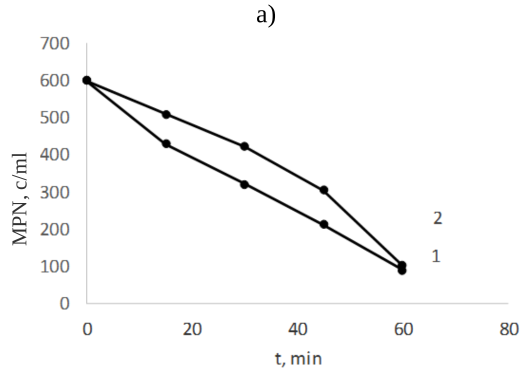

c)

Fig. 8. Kinetic curves of MPN variation of yeast solutions, received from pure culture (a), sewage waters of the yeast plant (b) and brewery (c) using vibrocavitation (1) and ultrasound (2), relative to 100 W of electric power. The temperature is 293 K and the frequency is 37 Hz

Table

Rate constants of destruction of yeast cells in water solution with the use of ultrasonic and vibrocavitation, taken to 100W of electric power. The temperature is 293 K and the frequency is 37 Hz

MPN, c/ml	Vibrocavitation	US cavitation
600	0.0342	0.0343
16000	0.0594	0.0563
$2.6 \cdot 10^{12}$	0.0878	0.0819

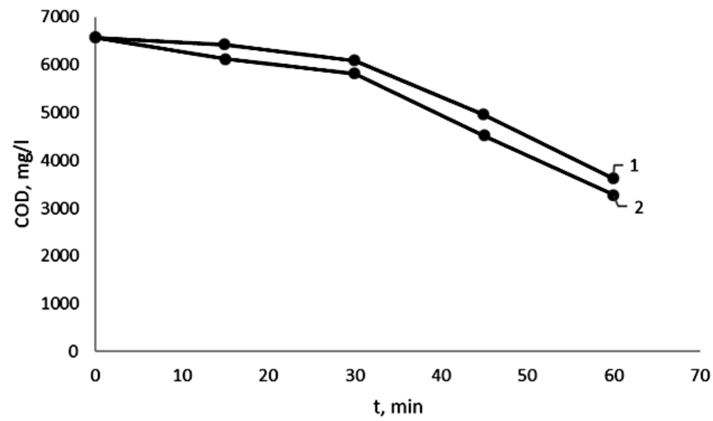

Fig. 9. The change of COD of yeast dispersion in time using vibrocavitation (1) and ultrasound (2), relative to 100 W of electric power. The temperature is 293 K and the frequency is 37 Hz

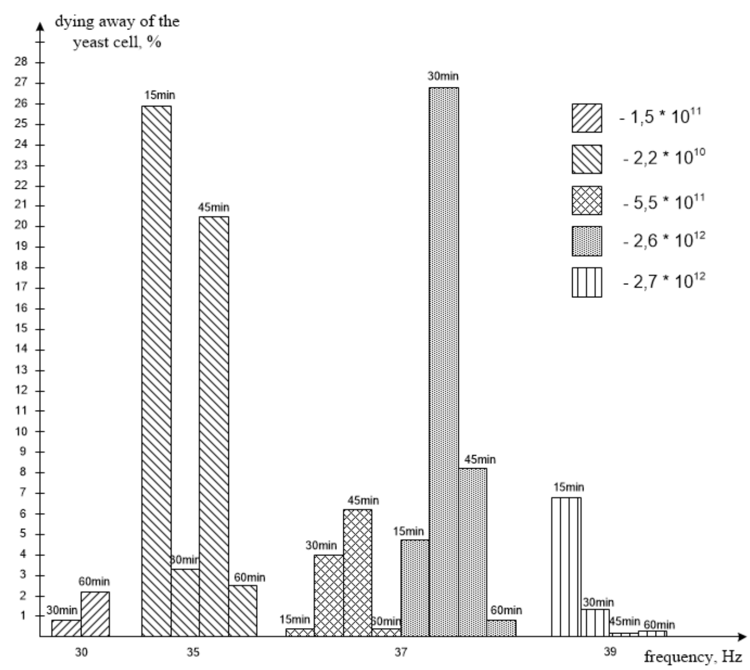

Fig. 10. Dependence of the level of dying away of the yeast cell on the oscillation frequency of decks – the stimulators of cavitation and the initial concentration of the cells of microorganisms

If we analyze the consumption of the electrical power to create the cavitation process, then we see that US generator consumes 1.4 kW and radiates only 100 W, which relates to the loss of energy in the course of transformation of electric power to the magnetic field and latter – into the mechanical oscillation of a magnetostrictor. Vibrocavitator consumes 800 W and also radiates 800 W (the coefficient of efficiency is about 98 %). The increase of the coefficient of efficiency in these cavitators is reached by means of experimental selection of oscillation frequency of deck – the stimulators of cavitation, close to divisible by resonance oscillation frequencies of the cavitation nuclei. It is carried out by means of the device for investigation of oscillation frequencies in the cavitation nuclei liquids, divisible by resonance. That is why it is economically reasonable to use low frequency vibration-resonance cavitators for cavitation stimulation.

4. Conclusions

The efficiency of water purification from chemical and biological impurities under ultrasonic and vibrocavitation conditions has been investigated. It has been demonstrated that the decrease of microbial number of sewage waters both with the use of ultrasonic cavitation, and with the use of vibrocavitator is described by the first order reactions and differs only by decay constants. The efficiency of vibrocavitation processing has been investigated in case of cleaning the sewage waters with different concentrations of biological contamination with different oscillation frequencies of decks – the stimulators of cavitation. The best effect has been reached with the frequency of 37 Hz. It was demonstrated that the use of vibrocavitation device provides the same effect as US cavitation. However, the coefficient of efficiency of the vibrocavitator is about 98 %, that is why it is economically reasonable to use vibration-resonance low-frequency cavitators for stimulation of cavitation.

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ЕФЕКТИВНІСТЬ ОБРОБЛЕННЯ СТІЧНОЇ ВОДИ ПІДПРИЄМСТВ ХАРЧОВОЇ ПРОМИСЛОВОСТІ РІЗНИМИ ТИПАМИ ГЕНЕРАТОРІВ КАВІТАЦІЇ

Анотація. *Досліджено ефективність очищення стічних вод за допомогою ультразвуку та віброкавітації. Застосування віброкавітації дає такий же ефект, як і використання ультразвукової кавітації, але економічно доцільніше використовувати вібраційний низькочастотний кавітатор.*

Ключові слова: *акустична кавітація, очищення води, кінетика реакції, біологічне забруднення, хімічне споживання кисню, кавітатори.*