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Investigation of cavitation and vibration processes in the technology of treatment of the contaminated liquids

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Abstract. This article considers the problems of treatment of contaminated liquids. Scientific works of home and foreign authors were analysed and according to this analysis it was made the conclusion. Experimental studies of the process of treatment of the contaminated liquids, in which the cavitation process in the technology of treatment of the contaminated media were investigated, as well as the process of treatment of the contaminated media in a vibration and centrifugal unit . As a result of the research, it was discovered that the cavitation method can be effectively used to treat water from heavy mechanical impurities, which makes it possible to carry out further filtration in fine filters. A vibration-rotary unit, developed in Belgorod State Technological University n.a. V G Shukhov, (Russia) at the Department of Technological Complexes, Machines and Mechanisms, was taken as a technical object, where experimental investigation of treatment of the contaminated liquids was carried out. It was also carried out the research of the stepwise process of treatment of the contaminated liquids in the developed unit. On the basis of these results the authors propose to use a stepwise method of treatment of liquid media: cavitation effect - for the preliminary phase of treatment and vibration -rotary effect – for the final stage of treatment.

Keywords. liquid, contaminated liquids, vibration and centrifugal unit, rotational speed, filtration chamber, cavitation, vibration, sieve, amplitude of oscillations, treatment.

1. The relevance of treatment of contaminated liquid media

The problem of industrial wastewater treatment and water treatment for technical and household purposes is becoming more and more important. The complexity of treatment is connected with an extraordinary diversity of impurities in the effluent, the amount and composition of which is constantly changing due to the appearance of new industries and changes in the existing technology [1].

The rapid growth of cities, the active development of industry and agriculture - all these factors make the situation of pollution of rivers and lakes with untreated plums more and more complicated every year [2]. Most of the effluents of enterprises fall directly into the reservoirs, which leads to a gradual deterioration of the ecological situation. The principle of wastewater treatment is a complex, multi-stage process [3]. The level of purity of liquids used in manufacturing [4], clinical practice [5], agriculture [6], the service sector and in everyday life [7], as well as the degree of subsequent regeneration of valuable components and disposal of harmful impurities determine the industrial potential, the ecological situation, and the standard of living of the population in general [8].

A new direction in the treatment of industrial wastewater is the creation of non-waste technologies. To a greater extent, it can be achieved by returning the treated water back to manufacturing. Taking into account the growing cost of water consumed, the creation of closed production cycles is becoming increasingly important. In particular cases, enterprises manage to switch over to completely waste-free technology. And sometimes enterprises can profit from the sale of waste, if they are pretreated and meet the necessary standards [9].

About 50% of the river water is exposed to man-made impact every year, including the result of the discharge of 425 • 109 m3 of wastewater. The main causes of pollution of water bodies are ineffective technologies for water treatment, as well as the system of regeneration of used water [10]. Due to these reasons, the requirements of SanR&S 2.1.4.1175-02, which determine the physical - chemical and microbiological indicators of water, are violated [11].

Liquid environment is not only a valuable resource that is used daily by man, but also is the main resource for many industrial enterprises. It includes water, engine oils, technical fluids, and others [12]. Water at enterprises is used for technological needs, for example, for cooling and washing equipment. Usually water is used in a cold and hot state, as well as in the form of steam. Moreover, water has got an economic potential. First, it is purchased for a certain price, and secondly, it is paid for when it is discharged into the environment.

The used water is not the water that the company acquired, it is the water with specific characteristics and properties. This is a complex cocktail of a mixture of various contaminants. Such water cannot be simply dumped back into the river or into the well; it must be cleaned [13]. If the company does not treat it up after using, liquid waste will adversely affect the livelihoods of cities and towns, and the consequences for the environment will be most disastrous. Dirty water getting into the reservoirs will disrupt the ecosystem for many kilometers around [14].

Every enterprise that uses liquid media must be equipped with sewage treatment plants, but such facilities are not cheap: both their installation and operation. Therefore, there is a need to develop and upgrade the equipment that will provide the necessary quality of liquid media treatment, in accordance with the established standards [15].

Water quality is more dependent on the concentration of pollutants and compounds in it. If the concentration of pollutants is exceeded, it has a detrimental effect not only on humans, but also on the biological situation in the region. In this regard, it is necessary to exercise strict control over the treatment of water from harmful substances, as well as to ensure the maximum permissible concentration of MAC of wastewater [16].

It order to solve the problems successfully it is necessary to have a methodology that generalizes a complex of theoretical, research, and technological issues of the development and application of complex systems for the liquid media treatment [17].

The purpose of this work is to study the influence of the processes of preliminary (cavitation) and final (vibration-rotary) treatment on the contaminated liquids.

2. Experimental investigation of the process of treatment of the contaminated liquids

Our analysis of home and foreign literature [16–22] suggests that the problems of treatment of the contaminated liquid media, which are not always subjected to treatment at the industrial enterprises, have not been fully studied so far. In this regard, the most important task is working out measures and constructive decision in order to reduce the negative impact of the contaminated liquids on the environment. Earlier, some experimental studies of the technical means and methods of regenerating of the contaminated liquids [19] were carried out, as well as the development and study of the technical agents for cleaning engine oils [20]. It has been established that vibration-centrifugal treatment of the contaminated liquids allows to speed up the filtration process, as well as to improve its quality.

2.1. Study of the cavitation process in the technology of treatment of the contaminated liquids

Figure 1 shows an experimental plant using the cavitation process. Technical characteristics of the plant: the volume of the treatment chamber V = 200 ml; rated voltage U = 12 V; power consumption

$N_{el.en}$ = 5 W; consumed current I = 2,4 A; nominal frequency of rotation of the motor shaft with blades $n_{el.en}$ = 2500 ÷ 3000 rev / min.

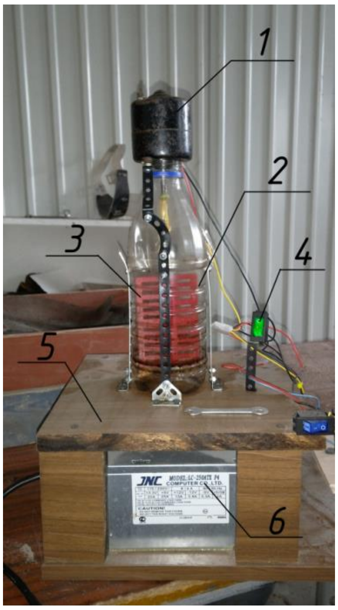


Figure 1. Experimental plant for treatment of the liquids: 1 – electrical engine; 2 – filtration cell; 3 – blades; 4 – switch ; 5 – bed; 6 – power unit

In each experiment, it was used 200 ml of the liquid with 30, 25 and 15% contamination of the total volume. Engine oil, soil, slag and other impurities were the contaminants. Figure 2 shows the contaminated liquid.

30% 25% 15%

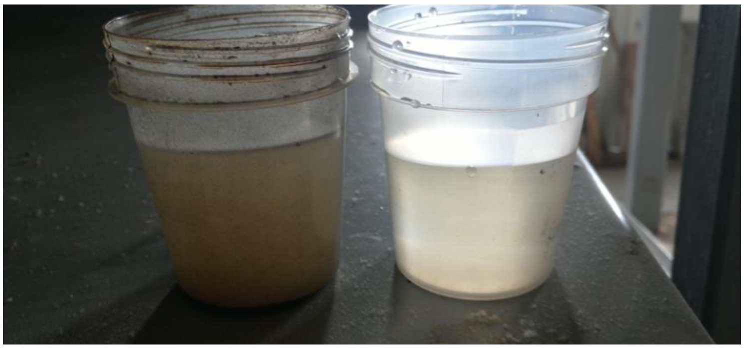
Figure 2. Contaminated liquid.

A number of experiments with treatment of the contaminated liquid in a cavitation chamber in which special blades were carried out.

According to the results of the experimental investigation, it was discovered that the cavitation effect in the liquid being treated was created owing to the cavitation blades - it occurred a break of discontinuity in the liquid with the formation of cavitation micro bubbles filled with a mixture of contaminants, the effect of "cold boiling". As the blades rotated, the microbubbles collapsed and separated heavy and light impurities in the liquid. Experimental studies were conducted using an experimental plant at the frequency of rotation of the shaft of the electrical engine: 2500 ÷ 3000 rpm the operation time varied within 10-12 minutes.

When conducting experimental studies, it was discovered that by the fourth minute a gradual separation of light and heavy contaminants began to occur. By the seventh minute, there was a pronounced separation, and by the eleventh - twelfth minute, heavy contaminants precipitated. With 30% liquid contamination, heavy substances precipitated within some 12 minutes. At 25% contamination of the liquid, it took 11.5 minutes to be clean, and at 15%, heavy contaminants precipitated within 10.2 minutes.

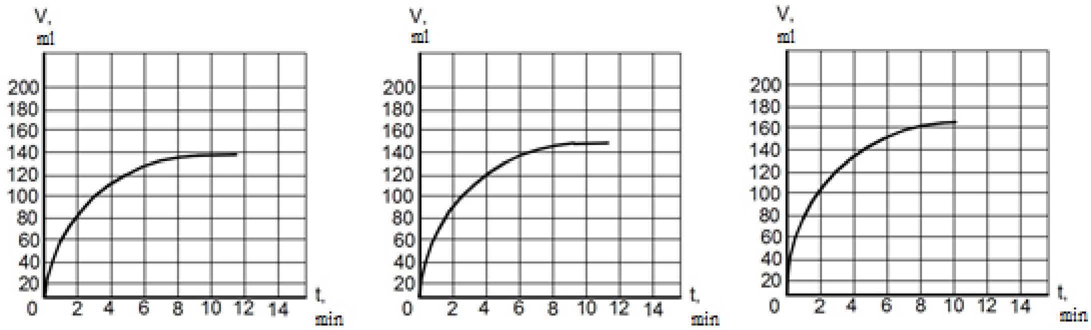
After switching of the plant the liquid settled for 10 minutes. As a result of the treatment, due to the use of the cavitation method, the contaminated liquid was clarified and purified from heavy impurities. At 30% contamination in the liquid being filtered there were 5 ÷ 7% of impurities, at 25% - 4 ÷ 6% on average, and at 15% - about 3 ÷ 5%. Figure 3 shows contaminated and treated liquids.



a b

Figure 3. The state of the liquids: a – before treatment; b – after treatment.

According to the results of the experimental studies of the cavitation method, it was constructed graphical dependences of the volume of the liquid being cleaned (*V*, ml.) on time (*t*, min.) with various amounts of contaminants. Figure 4 shows these graphical dependencies.



30% 25% 15%

Figure 4. Dependences of the volume of the liquid being cleaned (*V*, ml.) on time (*t*, min.) with various amounts of contaminants.

As a result of the research, it was discovered that the cavitation method can be effectively used to treat water from heavy mechanical impurities, which makes it possible to carry out further filtration in fine filters.

2.2. Study of the process of treatment of the contaminated liquid media in a vibratory centrifugal unit

A vibration-centrifugal unit [21] developed in the Belgorod State Technological University named after V G Shukhov (Russia) by the staff of the department of technological complexes, machines and mechanisms [22], which has a number of technological advantages: can be used as a technical object for the realization of the established regularities:

- it provides the possibility of varying the number of parameters (frequency of vibratory and centrifugal effects, the period of staying of the medium being cleaned in the unit, the value of the hydrodynamic effect, etc.);
- it allows you to change the nature of external influences (the value and duration of inertial effects, the sequence of operations, etc.) and the cyclical nature of the liquid to be cleaned;
- it provides the possibility to implement both internal and external recycling of the streams being treated in the unit;
- it creates the conditions for interference of additional positively influencing factors: temperature, ultrasound exposure, the introduction of chemical reagents, etc. on the filtering process;
- it has a simple design, not complex degree of installation and dismantling of the unit itself, its components, etc.
- it allows to realize the operational multifunctionality of the developed unit: to combine physical and mechanical, physical and chemical processes, to organize the implementation of staged technological processes, etc. [23].

At the first stage the analysis of filtering elements for water treatment was carried out, which showed that the most effective filtering elements are activated carbon and sand [24].

They assembled the filtration chambers where some gauze, activated carbon and sand were used. The particle size of the activated carbon was 1–2 mm. The particle size of sand is 0.5 ÷ 0.25 mm. The thickness of the filtering coal layer o - 40 mm, sand - 20 mm [25].

The filtration chamber was installed on an experimental plant of a vibrating and centrifugal unit, which is shown in Figure 5.

Technical characteristics of the experimental plant: the rotational speed of the eccentric shaft - 10 ÷ 330 rpm; vibration amplitude - 40 mm; the volume of the filtration chamber is 200 ml.

Figure 5. An experimental plant of a vibration and centrifugal unit with a filtration chamber vertically installed.

Experimental research used water that was contaminated with slag, engine oil and soil. In each experiment, 500 ml of the liquid was filtered. In a series of experiments the liquid was contaminated at 10, 20, and 30% of the total liquid volume [26].

It was carried out a series of experimental studies of filtration of the contaminated liquids in an experimental plant of a vibration- centrifugal unit at different frequencies of rotation of the eccentric shaft on which the filtration chamber was fixed. The rotational speed of the eccentric shaft was determined by the speed sensor. A series of the experiments at 10, 20 and 30% contamination showed that 500 ml of the liquid at a frequency of rotation of the eccentric shaft 110 ÷ 140 rpm. is treated from dirt for 21.5 minutes on average. After treatment of the initial 500 ml some 470 ÷ 480 ml of the liquid treated left. The remaining impurities in the filtered liquid averaged 2–5%. With the frequency of rotation of the eccentric shaft 220 ÷ 240 rpm, the filtration time was reduced to an average of 13 minutes. Only some 485 ml of the liquid treated left and the amount of the contaminants averaged 5 ÷ 8%. When the rotational speed of the eccentric shaft was increased to 300 ÷ 320 rpm, the filtration time averaged 10 minutes. Average 480 ÷ 490 ml of the liquid treated left and the amount of the contaminants increased to 8 ÷ 15% on average.

Experimental studies have shown that the amount of contaminants increases with increasing rotation frequency of the eccentric shaft. Therefore, to ensure the highest degree of purification, it was decided to carry out a series of experiments with several filtration chambers connected in series (Figure 6).

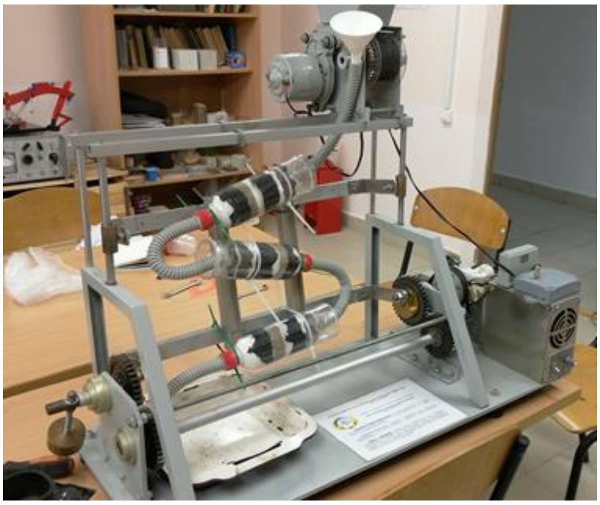


Figure 6. An experimental vibration and centrifugal plant for treatment of liquids.

To improve the filtration conditions of the liquids, it was decided to install each filtration chamber at a certain angle [27]. The first chamber was installed at an angle of 13 ÷ 14º, the second - 8 ÷ 10º, and the third chamber, in view of the need to increase treatment time, was installed horizontally.

Each experiment was carried out with a different frequency of rotation of the eccentric shaft. In the first experiment, 500 ml of the contaminated liquid was filtered in 25.5 minutes on average, at an oscillation frequency of n = 110 ÷ 140 rpm. While 440 ml of the filtrate left. In the second experiment, 500 ml of the contaminated liquid was filtered within 14.5 minutes at n = 220 ÷ 240 rpm. Average 460 ml of the water treated left. In the third experiment, 500 ml of the liquid was filtered within 11 minutes, at n = 300 ÷ 320 rpm. Average 475 ml of the water treated left, but at the same time, the amount of contaminants increased by 8 ÷ 10% on average.

While carrying out a series of experimental studies, about 6% of the total amount of contaminants was observed in the liquid being treated, of which there were only minor mechanical impurities and slag. There was no oil in the liquid. The contamination at the subsequent stages of the experimental studies decreased to approximately 2–4%.

As a result of the experimental studies, it was discovered that to implement the process of filtering contaminated liquids in a vibration and centrifugal unit, several filtration chambers should be sequentially installed at tilt angles of 0 ÷ 14º (with decreasing tilt angles of chambers with their sequential installation) and eccentric shaft rotation speed n = 220 ÷ 240 rpm This allows to speed up the filtration time to 14.5 minutes and reduce the amount of pollutants in the liquid being treated to 2 ÷ 4%.

2.3. Investigation of the stepwise process of treatment of the contaminated liquids

When conducting experimental analysis, a cavitation impact chamber was used, which provided preliminary treatment of the liquid from the coarse contaminants.

In a series of experimental investigation it was used 200 ml. of the liquid contaminated by 20% of the total volume. Slag, engine oil and other inclusions were contaminants in the liquids [28].

A series of experiments showed that the liquid is treated from large impurities in 11.5 minutes on average. After the cavitation process, the liquid precipitated for 10 minutes. As a result of the treatment, the liquid was clarified and cleaned from heavy impurities.

The next step was the filtration of the liquid at the experimental plant of the vibration and centrifugal unit.

Sand and activated carbon were the filter elements in the chambers. The thickness of the filter layer was 80mm [29].

A series of the experimental investigation were conducted at different frequencies of rotation of the eccentric shaft of the unit. In the first series of the experimental investigation, the liquid, cleared from large impurities, was moved into the unit, where it was cleaned from small impurities. The average treatment time was 25.5 minutes, with a shaft rotational speed of n = 110 ÷ 140 rpm. In the second series of experimental investigation, the fluid was cleaned for 14.5 minutes on average at a rotational frequency of n = 220 ÷ 240 shaft revolutions per minute. In the third series of experiments, the fluid was cleaned for 11 minutes on average at a shaft rotation frequency n = 300 ÷ 320 rpm.

According to the results of experimental investigation, the graphic dependences of the volume of the filtered liquid (*V*, ml.) on the filtration time (*t*, min.) were constructed. Figure 7 presents these dependencies.

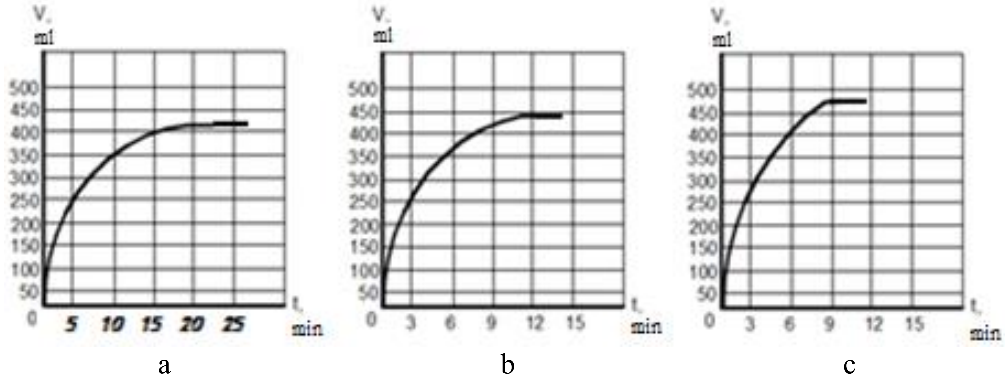


Figure 7. Dependences of the volume of the filtered liquid (*V*, ml.) on the filtration time (*t*, min): a – *n* = 110÷140 rpm; b – *n* = 220÷240 rpm; c – *n* =3 00-320 rpm.

Figure 8 shows the liquid after the preliminary (cavitation) and final (vibration and centrifugal) treatment on the experimental plant of the vibration and centrifugal unit.

As a result of the research made it was discovered that due to the use of the cavitation method, the liquid is effectively treated from the mechanical impurities. This makes it possible to carry out further treatment in a vibration and centrifugal unit, in which the liquid is filtered from the remaining impurities. The time spent on the preliminary (cavitation) treatment was 21.5 minutes. The final treatment time in a vibration and centrifugal unit at *n* = 110 ÷ 140 rpm was 25 minutes, the remaining contaminants were 2 ÷ 4%., when *n* = 220 ÷ 240 rpm - 14.5 minutes. The contaminants were about 2 ÷ 4%. when *n* = 300-320 rpm - 11 minutes. The contaminants were - 8 ÷ 10%.

Figure 8. The liquid after some stages of treatment:
a – n = 300÷320 rpm, b – n = 110÷240 rpm.

Thus, our experimental investigation in treatment of the contaminated liquids in a vibration and centrifugal unit with the provision of a preliminary cavitation effect on the medium being treated showed that the best indicators are achieved when using several treatment stages - preliminary (cavitation) and final (vibration and centrifugal one).

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