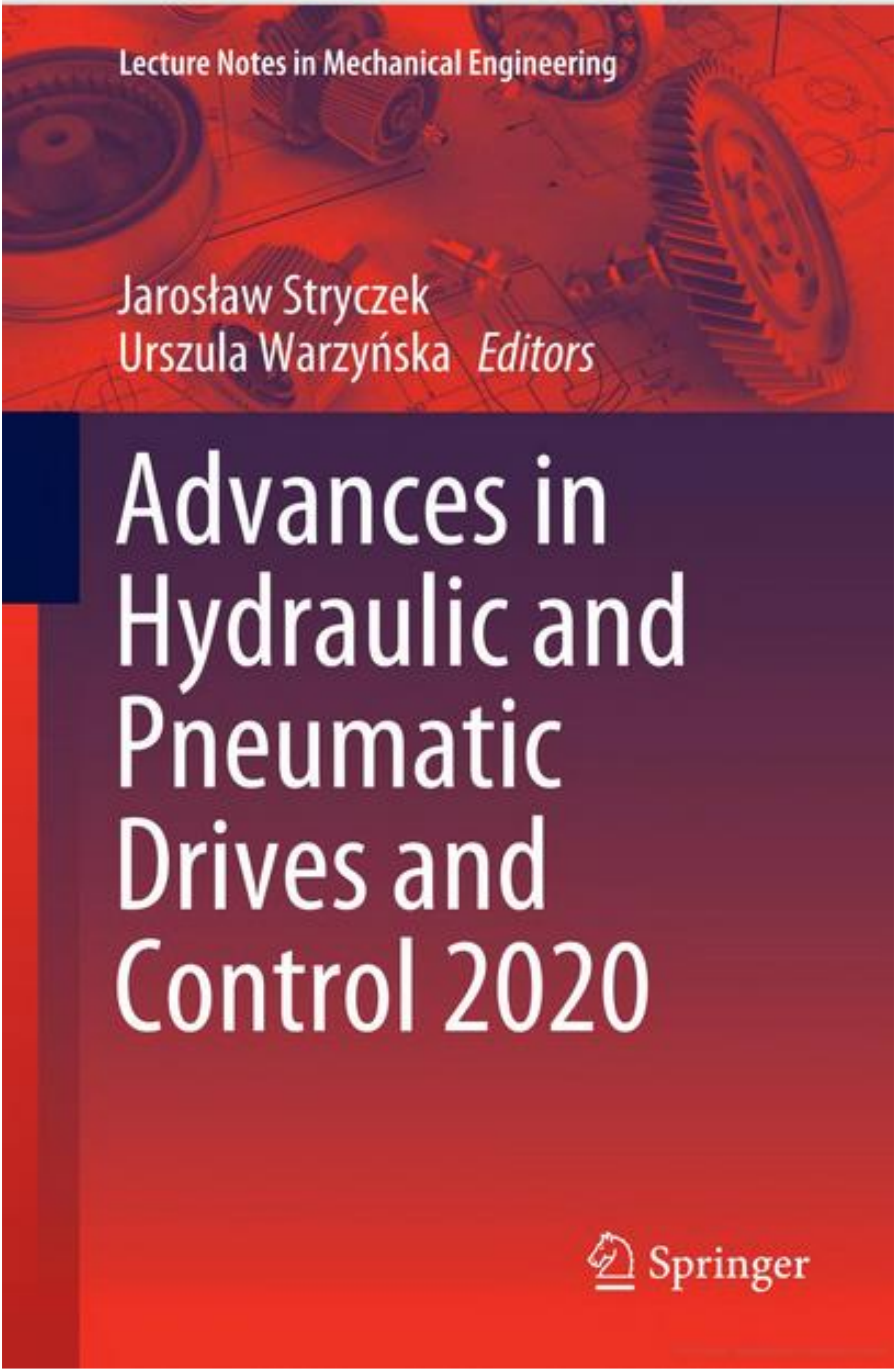
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Contents

Материал, защищенный авторским пр

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Mobile Equipment for Ultrasonic Cavitation Inactivation of Microorganisms in the Liquid Environment

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Abstract. The article is devoted to the study of the possibilities of ultrasonic cavitation inactivation of microorganisms. The possibilities of constructing mobile processing equipment for implementing the technology of ultrasonic cavitation inactivation of harmful and dangerous microorganisms for human health are considered. Two possible ways of increasing the intensity of ultrasonic exposure to biological objects were presented due to the concentration of ultrasonic energy and cavitation treatment in a thin layer on the radiation surface. The results of microbiological analysis as well as recommendations to increase the efficiency of cavitation inactivation of microorganisms had given.

Keywords: Ultrasonic cavitation · Inactivation of microorganisms · The intensity of ultrasonic vibrations · Mobile cavitation equipment

1 Introduction

In industrial processes using liquid environment, it is often necessary to decontaminate working fluids, i.e. to inactivate harmful for human health microorganisms.

Known methods of disinfection of liquid environment can be divided into four main groups, which differ by mechanism of microorganisms' inactivation [1, 2]:

- chemical methods associated with the use of strong oxidants reagents. Chlorine, chlorine dioxide, sodium hypochlorite, ozone, iodine, bromine, hydrogen peroxide, manganese-acid potassium are used as oxidizing agents [3, 4];
- thermal methods realized via liquids' boiling or freezing [5, 6];
- water saturation methods using ions of noble and non-ferrous metals with bactericidal effect - silver, copper, etc. [7, 8];

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– physical methods, i.e. ultraviolet radiation, ultrasound, radiation [9, 10].

Each of these methods is characterized by mechanism of inactivation of microorganisms, has its advantages and disadvantages.

In many respects, ultrasonic cavitation method of inactivation is preferred, relating to non-reagent inactivation methods [11–14]. The mechanism of its operation is:

– the damaging effect of the cumulative jet stream formed by the collapse of the cavitation bubble in the immediate vicinity of the microorganism;
– local increase of temperature and pressure in case of cavitation bubble collapse resulting in thermal and mechanical destruction of microorganisms;
– a drop in pressure over the microorganism's length in a standing ultrasonic wave, resulting in a breakdown of the structure of the microorganism;
– intensification of chemical oxidation processes in the cavitation environment, leading to acceleration of the process of inactivation of microorganisms by the formation of chemically active free radicals.

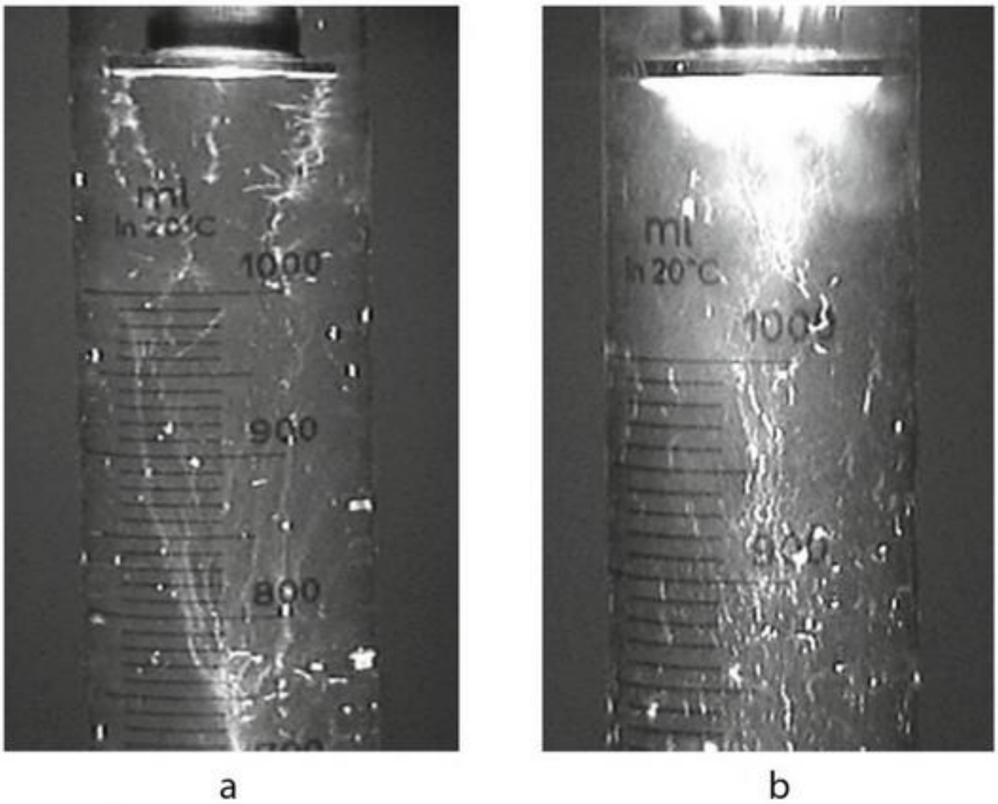

Fig. 1. Effect of formation of shielding cavitation layer on the emitting surface of ultrasonic transducer when ultrasound intensity increases from 18 W/cm^2 (a) to 28 W/cm^2 (b).

This method can be applied at any degree of liquid transparency. It is environmentally safe and is least capable of adversely affecting the human body, as it does not require the use of chemical agents.

The purpose of the proposed article is to analyse problems encountered in the creation of ultrasonic cavitation equipment for disinfecting liquid media and to test its effectiveness.

An important point in the implementation of the technology of ultrasonic cavitation inactivation of microorganisms is the intensity of ultrasonic oscillations, which are introduced into liquid. Low intensity (less than 2 W/cm^2) stimulates intensive reproduction and development of microorganisms [11, 12]. In order to achieve high efficiency of the process of inactivation of microorganisms by the method of ultrasonic cavitation treatment it is necessary to provide the level of intensity of ultrasound above 20–30 W/cm^2. At the same time, the width of the spectrum destroyed in the liquid of microorganisms depends significantly on the intensity of the ultrasonic oscillations. Therefore, the developers of ultrasound cavitation technological equipment for disinfecting fluids aim to ensure the maximum intensity of ultrasonic fluctuations. The problem is that ultrasonic fluctuations with low intensity only (Fig. 1a) can be introduced into the liquid with high efficiency [15]. When the intensity of ultrasonic oscillations increases on the radiating surface of the ultrasonic converter, a two-phase cavitation layer is formed (Fig. 1b), which absorbs and dissipates ultrasonic energy, resulting in the efficiency of the introduction of ultrasonic oscillations into the liquid decreases. When creating stationary industrial flow cavitation plants, this problem is solving due to using of the focusing features of the radiating surface [16–18]. The use of a tubular radiating surface, which is activated on the radial mode of the vibration, allows introducing the low-intensity ultrasound fluctuations effectively into the liquid and then focusing them on the longitudinal axis of the vibrator (Fig. 2). As a result, the intensity of about 120 W/cm^2 can be reach and a wide range of microorganisms can be inactivate.

2 Ultrasonic Cavitation Equipment

During the designing of the mobile and home ultrasound cavitation equipment, it is very difficult to use the considered tubular cavitator, triggered on the radial mode of fluctuations, due to mass-size characteristics. In this case, liquid quarter wave transformers of oscillating pressure (Fig. 2) are often used to increase sound pressure [19, 20].

In Fig. 3 was presented a scheme of construction of a step-type hydraulic transformer of vibrational pressure using a semi-wave ultrasonic piezoelectric transducer consisting of sequentially composed and reinforced radiating lining 5, piezoceramic elements 7 and damping lining 6. The diameter of the radiating surface 9 and the diameter of the larger transformer stage are selected significantly less than half the wavelength. This ensures the piston nature of the vibrations of the transmitter surface and a flat acoustic wave in the inner volume of the cavitation chamber. The ultrasonic transducer is fixed at the nodal point of deformation wave 11, which is set along its length. Due to tightness of the ultrasonic transducer mounting in the pressure transformer housing there is a closed air cavity 8, which does not allow the treated liquid to wet the nodal point of the transducer and reduce the efficiency of ultrasonic energy input into the liquid through

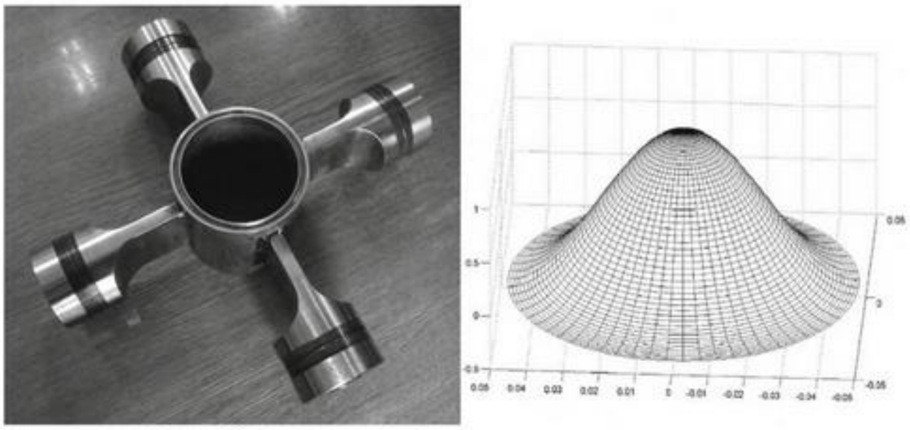

Fig. 2. Ultrasonic flow cavitator with tubular radiating surface and distribution of sound pressure over its cross-section in case of excitation of radial mode of vibration.

the radiating surface. The enlarged area of the radiating surface 9 makes it possible to adjust the load on the piezoelectric transducer and to inject ultrasonic vibrations into the liquid with sufficiently low intensity. This is prevent the formation of cavitation layer 9 on the radiating surface and ensures that ultrasonic vibrations are dispersing into the liquid bulk with maximum efficiency. Since the chambers 1 and 2 of the oscillating pressure transformer have a length divisible by an odd number of quarters of the length of the standing ultrasonic wave in the liquid at the resonant frequency of the piezoelectric transducer, and the stage transition of a larger diameter of the pressure transformer to a smaller diameter stage is organized in the plane of the nodal point of the pressure wave 12, then along the length of the transformer oscillatory pressure is installed standing deformation wave, and in the nodal planes standing deformation wave in the stage of small diameter level of sound pressure increases in proportion to the ratio of areas of the transformer stages. As a result, in a step of a smaller transformer diameter the level of ultrasound intensity sufficient for inactivation of a wide range of dangerous microorganisms for human health will be provided.

In Fig. 4 were shown the scheme of ultrasonic mobile cavitation equipment, which provides cavitation treatment of liquid in thin layer. Ultrasonic wave with high ultrasound intensity is specially demonstrated on the scheme. For this aim using the oscillating speed transformer 3 high amplitude of oscillations of radiating disk 4 at the output end of transformer 3 is provided. Figure 1b shows, that in this case, most of the ultrasonic energy will be absorbed in the cavitation layer with developed cavitation formed on the radiating surface. It is in this layer the most intensive treatment of the liquid with the aim of inactivation of microorganisms will occur. Therefore, the scheme under consideration provides for the organization of narrow gaps 5 and 6 between the radiating disk surface and housing 1, through which all the treated liquid was proceed. In addition, the casing made of non-magnetic material has an output channel of resonant length, in which a standing deformation wave 8 is set, at the nodal points of which there are intensive cavitation zones, providing additional cavitation treatment of the liquid. The output channel of the body 1 is covered with powerful permanent magnets 7, which ensure the structuring of fluid after destructive intensive cavitation treatment and due to alternating

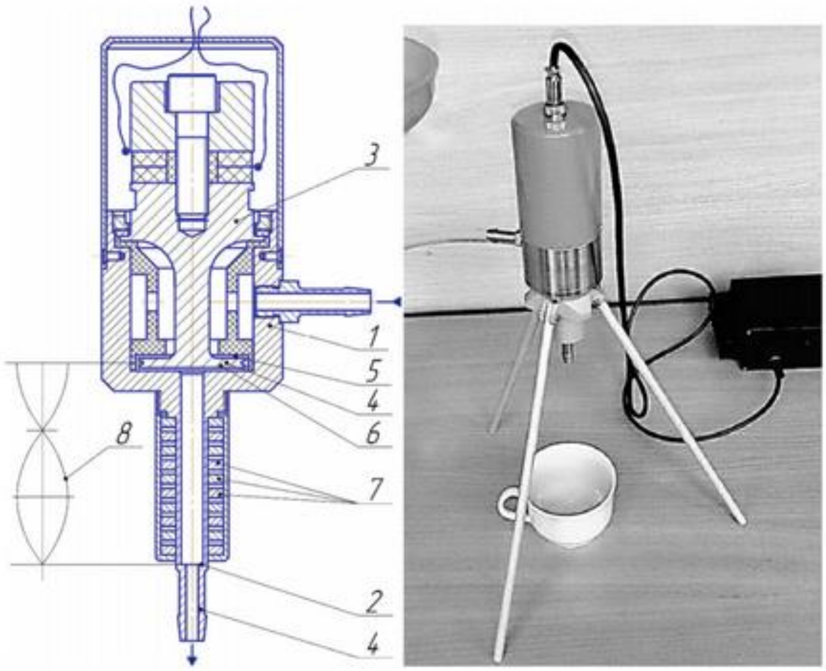

Fig. 4. Scheme and appearance of mobile ultrasonic cavitation equipment with thin layer processing. (1 - case made of non-magnetic material with input and output connectors and resonant output channel; 2 - reflective end of output channel; 3 - piezoelectric ultrasonic radiator with transformer of vibrational speed; 4 - radiating disk of transformer of vibrational speed; 5 and 6 - slot gaps for a flow of processed liquid; 7 - block of permanent magnets; 8 - standing deformation wave in the output channel. (Intensity of ultrasonic field 60… 80 W/cm^2; productivity - 2 l/min; power consumption - 40 W).

magnetic field ensure the removal of heavy metal ions from the liquid, which also adversely affect the human body. Structured water already has healing properties because it has increased permeability through the cell membranes.

3 Microbiological Studies

Microbiological studies were carried out to evaluate the efficiency of water treatment in thin layer in ultrasonic cavitation equipment presented in Fig. 4.

Microorganisms of different species with different structure of the cell walls were selected for the research: gram-negative Escherichia coli, Pseudomonas aeruginosa (non-pathogenic), sulfate-reducing corrosive-relevant bacteria Desulfovibrio sp., Desulfovibrio desulfuricans, Desulfovibrio vulgaris; gram-positive - Bacillus subtilis, Staphylococcus aureus; microscopic fungi Saccharomyces cerevisae. Studies with microorganism's cultures were carried out in the laboratories of the D.K. Zabolotny Institute of Microbiology and Virology NAS of Ukraine.

Sterile tap water with introduction of bacteria in initial titers 106-108 cells/ml was used as a working liquid. The volume of working liquid was 200 ml. After each cycle of liquid spilling through the ultrasonic cavitator 1 ml of sample was taken for analysis and treatment with cavitation. There is shown results for data approximation for the following microorganisms *S. aureus; E. coli; S. cerevisae, D. desulfuricans* (Fig. 5 a, b, c, d).

5 Conclusions

The problems that arise during the introducing the ultrasonic vibrations with increased intensity into a liquid were elucidated. Two methods of increasing the intensity of ultrasonic vibrations to sufficient level for inactivation of the microorganisms in water are considered.

The results of microbiological studies confirm the operability of ultrasonic cavitation equipment. However, they shown that for achieving the almost complete inactivation of microorganisms it is necessary to provide number of cycles manually or automatically due to micro pump a treated liquid for a set of the required number of treatment cycles.

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