

Lecture Notes in Mechanical Engineering

Jarosław Stryczek  
Urszula Warzyńska *Editors*

# Advances in Hydraulic and Pneumatic Drives and Control 2020

 Springer

*Editors*

Jarosław Stryczek  
Wrocław University of Science and  
Technology, Faculty of Mechanical  
Engineering  
Wrocław, Poland

Urszula Warzyńska  
Wrocław University of Science and  
Technology, Faculty of Mechanical  
Engineering  
Wrocław, Poland

ISSN 2195-4356 ISSN 2195-4364 (electronic)  
Lecture Notes in Mechanical Engineering  
ISBN 978-3-030-59508-1 ISBN 978-3-030-59509-8 (eBook)  
<https://doi.org/10.1007/978-3-030-59509-8>

© The Editor(s) (if applicable) and The Author(s), under exclusive license  
to Springer Nature Switzerland AG 2021

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG  
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

---

# Contents

## Hydraulic Components

|   |     |
|---|-----|
| <b>Research on Flow Forces in the USAB10 Control Valve Using a CFD Method</b> . . . . .   | 3   |
| Grzegorz Filo and Edward Lisowski   |     |
| <b>Design, Modeling and Simulation of Gearing for Improving Gerotor Pump Performance</b> . . . . .                                | 15  |
| Lozica Ivanović   |     |
| <b>Volumetric and Torque Efficiency of Pumps During Start-up in Low Ambient Temperatures</b> . . . . .                            | 28  |
| Ryszard Jasiński  |     |
| <b>Flow Analysis of a 2URED6C Cartridge Valve</b> . . . . .   | 40  |
| Edward Lisowski, Janusz Rajda, Grzegorz Filo, and Paweł Lempa   |     |
| <b>Strength Calculation Methodology for Circumferential Backlash Compensation with Integrated Lips</b> . . . . .                  | 50  |
| Piotr Osiński   |     |
| <b>Optimizing the Break-in Process of High-Pressure Gear Pumps</b> . . . . .  | 65  |
| Piotr Osiński, Paweł Bury, and Rafał Cieśllicki   |     |
| <b>Influence of Gaps' Geometry Change on Leakage Flow in Axial Piston Pumps</b> . . . . .   | 76  |
| Piotr Patrosz   |     |
| <b>Design of Asymmetric Gerotor Pumps</b> . . . . .   | 90  |
| Andrew J. Robison and Andrea Vacca  |     |
| <b>An Approximate, Closed Form Solution of Sealing Gap Induced Lateral Forces for Imperfect Sealing Land Geometries</b> . . . . . | 102 |
| Rudolf Scheidl, Markus Resch, Matthias Scherrer, and Philipp Zagar  |     |

|  |     |
|--|-----|
| <b>The Influence of Water and Mineral Oil on Pressure Losses in Hydraulic Motor</b> .....                                | 112 |
| Paweł Sliwinski and Piotr Patrosz  |     |
| <b>CFD Simulations and Tests of a Prototype Flow Control Valve</b> .....   | 123 |
| Marta Zaleska-Patrosz, Piotr Patrosz, and Paweł Śliwiński  |     |
| <b>Experimental Research of an Axial Piston Pump with Displaced Swash Plate Axis of Rotation</b> .....                   | 135 |
| Paweł Załuski  |     |
| <b>Hydraulic Systems</b>   |     |
| <b>Intelligent Real-Time Control System for Forging Process Control</b> .....  | 149 |
| Ryszard Dindorf, Jakub Takosoglu, and Piotr Wos  |     |
| <b>Digital Pumping System with Electromechanical Repartition</b> .....   | 159 |
| Petru Drumea, Catalin Dumitrescu, Valentin Barbu, Dan Opruta, and Daniel Banyai  |     |
| <b>Control of the Test Rig with Hydraulic Integrated Actuator for Spring Stiffness Measurement</b> .....                 | 169 |
| Petr Noskiewič, Ahmed Al Zaid, and Yadhu Swaroop Chandra Mohan   |     |
| <b>Hydrostatic Actuator Drive Control with Pump Leakage Compensation</b> .....   | 179 |
| Łukasz Stawiński, Andrzej Kosucki, and Adrian Morawiec   |     |
| <b>Design Rules for Fuzzy Logic Controllers for Pneumatic Systems</b> .....  | 192 |
| Jakub Takosoglu, Ryszard Dindorf, and Piotr Wos  |     |
| <b>Simulation of Transient Flow in Micro-hydraulic Pipe System</b> .....   | 205 |
| Kamil Urbanowicz, Michał Stosiak, Krzysztof Towarnicki, Huan-Feng Duan, and Anton Bergant                                |     |
| <b>The Electro-Hydraulic Lifting and Leveling System for the Bricklaying Robot</b> .....                                 | 216 |
| Piotr Wos, Ryszard Dindorf, and Jakub Takosoglu  |     |
| <b>Operating Problems of Lubrication of Friction Nodes in Mining Machines Working in an Aggressive Environment</b> ..... | 228 |
| Grzegorz Wszelaczyński, Dymitry Capanidis, Maciej Paszkowski, and Tadeusz Leśniewski                                     |     |
| <b>Cavitation, Dynamics, Noise and Vibration</b>   |     |
| <b>Reduction of Noise Emission of Hydraulic Power Units</b> .....  | 241 |
| Wiesław Fiebig and Piotr Rosikowski  |     |

|  |            |
|--|------------|
| <b>Assessment of the Effectiveness of Passive and Active Methods<br/>in Noise Suppression in Machines and Equipment<br/>with the Hydrostatic Drive . . . . .</b>             | <b>252</b> |
| Wacław Kollek, Piotr Osiński, and Kacper Leszczyński   |            |
| <b>Technology of Ultrasonic Cavitation Cleaning of Elastic Surfaces . . . . .</b>  | <b>264</b> |
| Katerina Luhovska, Andrey Movchanuk, Volodymyr Feshich,<br>and Alina Shulha  |            |
| <b>Mobile Equipment for Ultrasonic Cavitation Inactivation<br/>of Microorganisms in the Liquid Environment . . . . .</b>   | <b>272</b> |
| Oleksandr Luhovskyi, Irina Bernyk, Ihor Gryshko, Darina Abdulina,<br>and Andrii Zilinskyi  |            |
| <b>Ultrasonic Cavitation Equipment with a Liquid<br/>Pressure Transformer . . . . .</b>  | <b>282</b> |
| Andrey Movchanyuk, Oleksandr Luhovskyi, Volodymyr Fesich,<br>Iryna Sushko, and Nataliia Lashchevska  |            |
| <b>Research of the Influence of Hydraulic Orifice Material on the<br/>Hydrodynamic Cavitation Processes Accompanied by Luminescence . . .</b>                                | <b>293</b> |
| Ihor Nochnichenko, Oleksandr Luhovskyi, Dmytro Kostiuk,<br>and Jakhno Oleg   |            |
| <b>Comparative Studies of the Dynamic Response of Hydraulic Cylinders<br/>with Different Hydraulic Supply Systems Design . . . . .</b>                                       | <b>301</b> |
| Tomasz Siwulski  |            |
| <br>   |            |
| <b>Analysis of the Impact of Vibrations on the Microhydraulic Pressure<br/>Relief Valve Taking into Account the Interval Classification<br/>of Induction Trees . . . . .</b> | <b>311</b> |
| Michał Stosiak, Krzysztof Towarnicki, Marian A. Partyka,<br>and Adam Deptuła   |            |
| <b>Experimental Research into the Influence of Operational Parameters<br/>on the Characteristics of Pressure Pulsation Dampers . . . . .</b>                                 | <b>323</b> |
| Urszula Warzyńska  |            |
| <b>Influence of Pressure Inside a Hydraulic Line on Its Natural<br/>Frequencies and Mode Shapes . . . . .</b>  | <b>333</b> |
| Jakub Wróbel and Jędrzej Blaut   |            |
| <b>Study of the Structural Materials Cavitation Strength in Ultrasonic<br/>Technological Equipment . . . . .</b>   | <b>344</b> |
| Andrii Zilinskyi, Oleksandr Luhovskyi, Ihor Gryshko, and Vasyl Kovalev   |            |

|   |     |
|---|-----|
| <b>New Materials and Special Solutions in Fluid Power Technology</b>  |     |
| <b>Volumetric Efficiency of a Hydraulic Pump with Plastic Gears Working with Tap Water</b> .....                          | 355 |
| Michał Banaś  |     |
| <b>Torque Transmitted by Multi-plate Wet Clutches in Relation to Number of Friction Plates and Their Dimensions</b> ..... | 367 |
| Marcin Bąk, Piotr Patrosz, and Paweł Śliwiński  |     |
| <b>The Configuration of Circulating Unsteady Flows in the Spacecraft Spherical Tank</b> .....                             | 377 |
| Vasyl Kovalev   |     |
| <b>Functional Verification and Performance Studies of the Gerotor Pump Made of Plastics</b> .....                         | 386 |
| Justyna Krawczyk  |     |
| <b>Numerical and Experimental Analysis of the Base of a Composite Hydraulic Cylinder Made of PET</b> .....                | 396 |
| Marek Lubecki, Michał Stosiak, and Małgorzata Gazińska  |     |
| <b>Design Improvement of Multi-disc Wet Hydraulic Brake</b> .....   | 406 |
| Milos Matejic   |     |
| <b>Measurements of the Hydraulic Fluids Compressibility</b> .....   | 416 |
| Leszek Osiecki  |     |
| <b>Modern Materials and Surface Modification Methods Used in the Manufacture of Hydraulic Actuators</b> .....             | 427 |
| Justyna Skowrońska, Jakub Zaczyński, Andrzej Kosucki, and Łukasz Stawiński  |     |
| <b>Plastics a New Trend in Design of Fluid Power Elements and Systems</b> .....   | 440 |
| Jarosław Stryczek   |     |
| <b>Author Index</b> .....   | 453 |



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

Oleksandr Luhovskyi<sup>1</sup> , Irina Bernyk<sup>2</sup> , Ihor Gryshko<sup>1</sup> , Darina Abdulina<sup>3</sup> ,  
and Andrii Zilinskyi<sup>1</sup> 

<sup>1</sup> “Igor Sikorsky Kyiv Polytechnic Institute”, National Technical University of Ukraine,  
Prosp. Peremohy 37, Kiev 03056, Ukraine

{atoll-sonic, griwko}@ukr.net, zilinski.andrew@gmail.com

<sup>2</sup> Vinnitsa National Agrarian University, Sonyachna St. 3, Vinnitsa 21000, Ukraine  
iryna\_bernyk@i.ua

<sup>3</sup> D.K. Zabolotny Institute of Microbiology and Virology of the NASU, 154 Acad. Zabolotny St.  
03143, Kiev, Ukraine  
adara@ukr.net

**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];

© The Editor(s) (if applicable) and The Author(s), under exclusive license  
to Springer Nature Switzerland AG 2021

J. Stryczek and U. Warzyńska (Eds.): NSHP 2020, LNME, pp. 272–281, 2021.

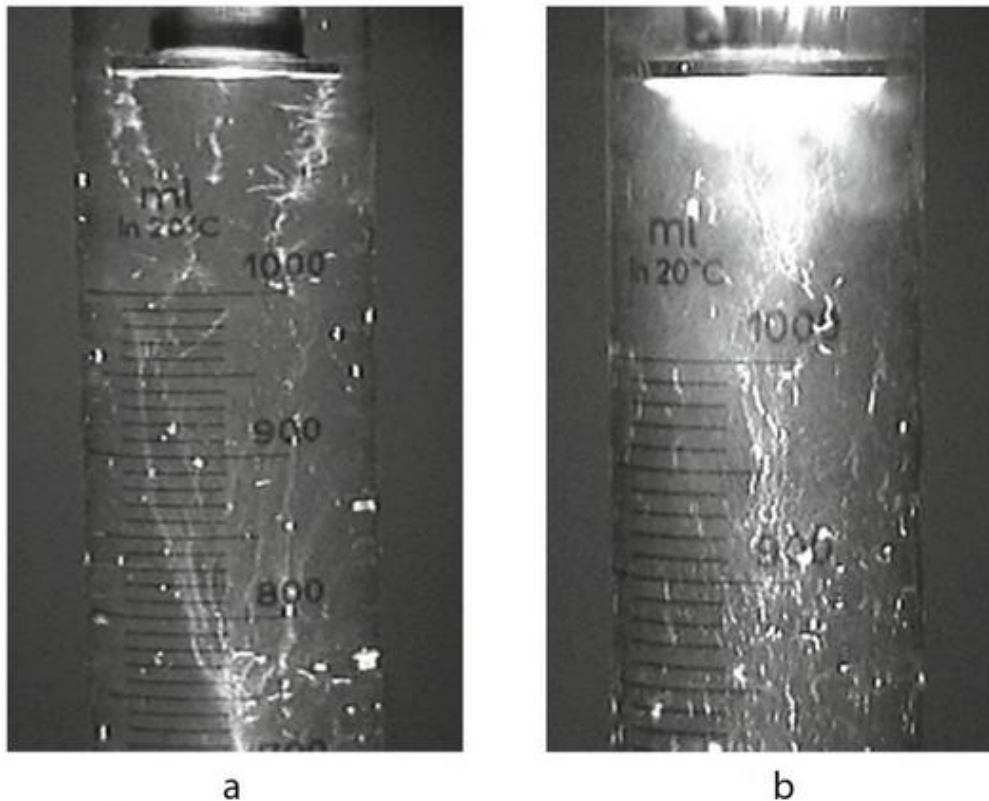
[https://doi.org/10.1007/978-3-030-59509-8\\_24](https://doi.org/10.1007/978-3-030-59509-8_24)

- 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  $18 \text{ W/cm}^2$  (a) to  $28 \text{ W/cm}^2$  (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.

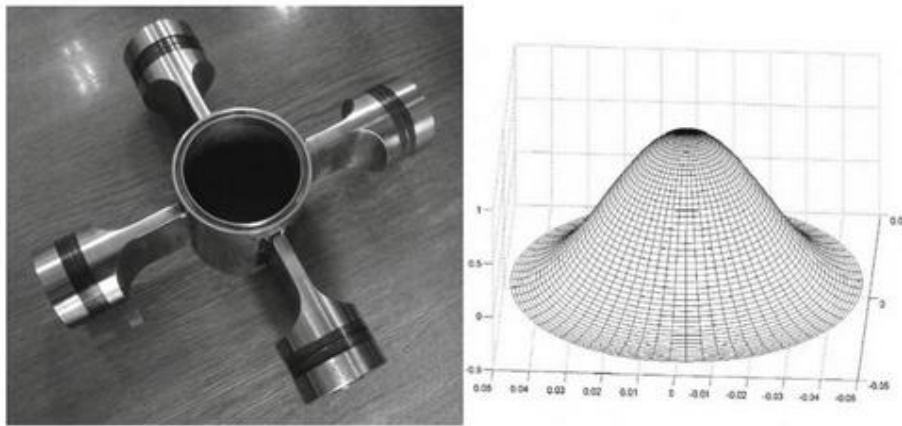
The purpose of the proposed article is to analyse problems encountered in the creation of ultrasonic cavitation equipment for disinfecting liquid media and to test its effectiveness.

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  $2 \text{ W/cm}^2$ ) 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  $20\text{--}30 \text{ W/cm}^2$ . 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  $120 \text{ W/cm}^2$  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].

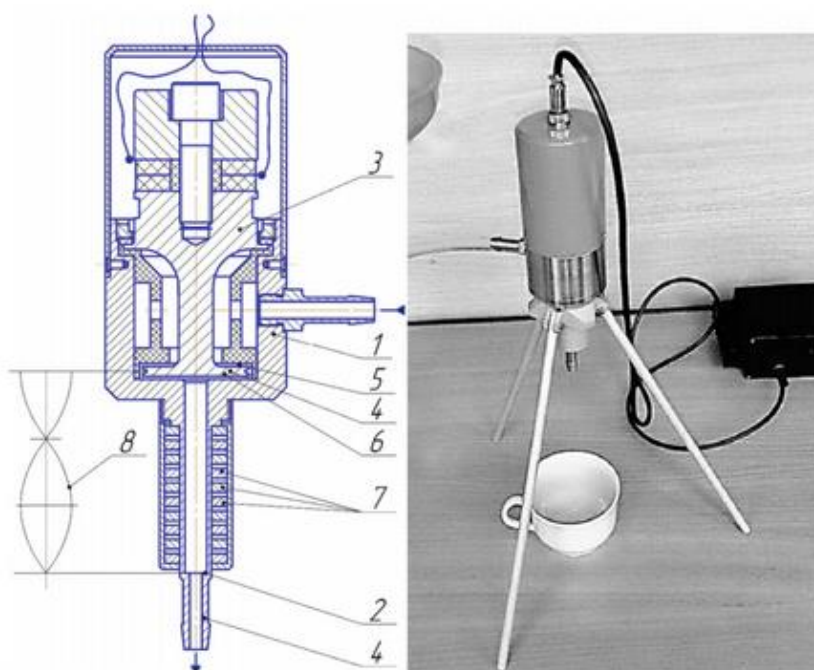
In Fig. 3 was presented a scheme of construction of a step-type hydraulic transformer of vibrational pressure using a semi-wave ultrasonic piezoelectric transducer consisting of sequentially composed and reinforced radiating lining 5, piezoceramic elements 7 and damping lining 6. The diameter of the 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<sup>2</sup>; 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 cerevisiae*. 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 10<sup>6</sup>-10<sup>8</sup> 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. cerevisiae*, *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.

## References

1. Luhovskyi, O.F., Movchanuk, A.V., Gryshko, I.A.: Estimation of the water disinfection methods. Bull. Natl. Tech. Univ. Ukraine "Kiev Polytech. Inst." Mach.-Build. Ser. Rev. **52**, 103–111 (2008). (in Russian)
2. Luhovskyi, O.F., Gryshko, I.A., Bernyk, I.M.: Enhancing the efficiency of ultrasonic wastewater disinfection technology. J. Water Chem. Technol. **40**(2), 95–101 (2018). Allerton Press, Inc., ISSN 1063-455X
3. Rachmanin, Y.A., Zholdakova, Z.I., Poliakova, E.E., Kiryanova, L.F., Myasnikov, I.N., Tulskaia, E.A., Artemova, T.Z., Ivanova, L.V., Dmitrieva, R.A., Doskina, T.V.: Joint application of the active chlorine and coagulants for the purification and disinfection of the drinking water. Hyg. Sanitation (1), 449–458 (2004). (In Russian)
4. Pasi, L.L., Karu, Ya.Ya., Melder, H.A., Repin, B.N.: Handbook of Natural and Waste Water Treatment, pp. 36–39. Medicine, Moscow (1994). (in Russian)
5. Kolesov, A.M., Glagolev, L.S.: Thermal method of the waste water disinfection. Hyg. Sanitation (3) (1978). (in Russian)
6. Sashchenko, V.V.: Improvement of chemical and biological parameters of drinking water by the method of programmed freezing. Doctor of Science: 27.00.03. VUO MANEB, Alchevsk (2009). (in Russian)
7. Zolotukhina, E.V., Spiridonov, B.A., Fedianin, V.I., et al.: Water disinfection with nanocomposites on the basis of the aluminum oxide porous and silver compounds. Sorpt. Chromatogr. Processes **10**(1), 78–85 (2010). (in Russian)
8. Shmuter, G.M., Izotova, P.V., Maslenko, A.L., Furman, A.A., Sobolevskaya, T.T.: Hygienic estimation of the electrochemical method of the water disinfection with silver. Hyg. Sanitation (12), 10–11 (1986). (in Russian)
9. Kostiuhenko, S.V.: Ultraviolet irradiation - a modern method of the water disinfection. Water Supply Sanitary Eng. (12), 21–23 (2005). (in Russian), Ch. 1
10. Bernyk, I.M., Luhovskyi, O.F.: Using of physical fields for hydrolysis of protopectin of plant material. Vibr. Technol. Tech. **3**(52), 92–100 (2008). (in Ukrainian). VBAU, Vinnytsia
11. Elpiner, I.E.: Ultrasound. Physical-Chemical and Biological Action. Fizmatiz, Moscow (1963). (in Russian)
12. Feng, H., Barbosa-Cánovas, G.V., Weiss, J. (eds.): Ultrasound Technologies for Food and Bioprocessing. Food Engineering Series. Springer, Heidelberg (2011)

13. Antoniak, P., Stryczek, J., Banas, M., Grynko, I., Zilinskyi, A., Kovalov, V.: Visualization research on the influence of an ultrasonic degassing on the operation of a hydraulic gear pump. In: MATEC Web of Conferences 211, VETOMAC XIV (2018). <https://doi.org/10.1051/mateconf/201821103005>
14. Luhovskyi, A.F., Gryshko, I.A., Zilinskyi, A.I., Patsola, B.V.: The impact of static pressure on the intensity of ultrasonic cavitation in aqueous media. *J. Water Chem. Technol.* **40**(3), 143–150 (2018). <https://doi.org/10.3103/S1063455X18030050>
15. Luhovskyi, O.F., Gryshko, I.A.: Problems of creation of the technological equipment for ultrasonic cavitation water disinfection. *Promislova gidravlika i pneumatics* **4**(26), 3–6 (2009). (in Russian), Vinnitsa
16. Luhovskyi, O.F., Chukhraev, N.V., Chukhraev, K.V.V.: Ultrasonic cavitation in the modern technologies (2007). (in Russian), K.: MIC “Kyiv. Un-t”
17. Luhovskyi, O.F., Gryshko, I.A., Krivosheev, V.S.: Ultrasonic flow cavitation installation for the technological processes efficiency increase. *Visnik NTUU “KPI”. Mashinobuduvannya, Visnik NTUU “KPI”, vol. 63, pp. 230–232 (2011).* (in Russian), Kyiv
18. Luhovskyi, O.F., Gryshko, I.A., Movchanuk, A.V.: Investigation of the ultrasonic tube cavitation operation in the radial vibration mode. *Visnik NTUU “KPI”. Mashinobuduvannya, Rev.* **59**, 285–287 (2010). (in Russian), Kyiv
19. Luhovskyi, O.F., Movchanuk, A.V., Zilinskyi, A.I., Gryshko, I.A.: Calculation methods of the rational sizes of the one-dimensional ultrasonic cavitators. *Visnik NTUU “KPI”. Mashinobuduvannya, Rev.* **71**, 33–38 (2014). (in Russian), Kyiv
20. Luhovskyi, O.F., Movchanuk, A.V., Luhovskyi, O.O.: Patent UA № 100470; 25.12.2012, Bulletin № 24; Ultrasonic devices for the liquid processing (in Ukrainian)
21. Gromozova, E.N., Voychuk S.I.: Influence of radiofrequency EMF on the yeast *Sacharomyces Cerevisiae* as model eukaryotic system. In: *Biophotonics and Coherent Systems in Biology*, pp. 167–175. Springer, Boston (2007). [https://doi.org/10.1007/978-0-387-28417-0\\_13/](https://doi.org/10.1007/978-0-387-28417-0_13/)
22. Iutinskaya, G.A., Purish, L.M., Abdulina, D.R.: *Corrosive microbial communities of technogenic ecotopes*. M.: LAP Lambert Academic Publishing (2014)
23. Netrusov, A.I., Egorova, M.A., Zakharchuk, L.M. et al.: *Workshop on Microbiology: Textbook. Allowance for Students*. M.: Publishing Center “Academy” (2005)