Annals of Agrarian Science

Journal homepage: http://journals.org.ge/index.php

Drinking Water Treatment Technology for Microbial Contamination by Means of Cavitation Method

Nikoloz Enuqidze*, Tsitsino Kurtskhalia, Zaira Simonia, Nana Sakvarelidze, Nodar Ckeidze

G.Tsulukidze Mining Institute, 7, Mindeli Str., Tbilisi, 0186, Georgia

Received: 29 October 2019; accepted: 25 January 2020

A B S T R A C T

The aim of the work is to undertake systemic research of the treatment process of drinking water contaminated with microorganisms by means of cavitation method; development of technology and creation of experimental treatment system that will significantly reduce the cost and ensure high quality of treatment process. A jet micro-cavitator with the capacity of 5-10 l/h has been developed to conduct laboratory research. The selection of design of the cavitator was based on the following: low consumption of sample liquids, pressure range 1-5 bar, simple and flexible design. The novelty of the created activator is due to the fact that, as of today, activator with such a low capacity does not exist. On the basis of the research, cavitation and filtration were identified as two main nodes of the treatment system. Cavitation technology for treatment of the microbially contaminated drinking water has been developed and optimal technological parameters have been defined for the treatment. Target experimental technological system has been created. Water obtained in the system meets the requirements of drinking water technological regulation by its organoleptic, physical and chemical as well as microbiological parameters. The proposed system, in future may become a new technical installation for treatment of drinking water sharply reducing the costs of appropriate devices and simplifying their application and ensuring high level of safety.

Keywords: Water, Microorganisms, Cavitation, Filtration, Technology, Experimental System.

*Corresponding author: Nikoloz Enuqidze: E-mail address: enuqniko@gmail.com

Introduction

Quality of drinking water, its chemical and microbial safety, is among the main topics for ensuring human health. As of today, despite the existence of many treatment systems that apply various methods for removal of microbial contamination, the costliness and difficulty of maintenance of those systems restrict their widespread.

Ozonation, chlorination and ultraviolet (UV) radiation constitute the main conventional methods of water disinfection [1]. These three methods have strong disinfection effect on both bacteria and viruses. Application of chemical methods (ozonation, chlorination) result in byproducts that deteriorate water quality. In case of UV application required intensity of radiation should be defined (according to set regulations) and strongly followed to avoid photoreactivation (reparation), of microbes induced by incorrect dozes. Hence, application of the method requires high qualification of personnel.

Development of new technologies of water treatment and consequent technological systems ensuring reduced cost and simplified maintenance as well as required level of safety is very important.

Research Methods and Objects

The aim of the proposed work is to study treatment process of drinking water contaminated with microorganisms by application of cavitation method, develop technology by considering achieved results and create consequent technological system that would significantly reduce the costs and ensure high qulity of the treatment.

Hydrodynamic cavitation belongs to non-con-

ventional technologies of removal of microbial contaminants from water. Generally, cavitation is the breakdown of liquid continuity caused by sharp decrease of local pressure in comparison with the saturated vapor pressure of liquid. In the liquid- free zones bubbles containing mixture of liquid vapor and gases dissolved in liquid are formed. In the process of formation of bubbles minimal pressure varies in the range of 100-2500 kPa. Different types of inserts, such as microbubbles, solid microparticles, including microorganisms stimulate formation of bubbles. In the areas of low pressure bubbles grow, merge and form cavities. When pressure increases bubbles compress, deform, decompose or collapse. The process is accompanied with sharp increase of local temperature and pressure generation of cumulative microflows, synthesis of strong oxidizers (O, H_2O_2) that causes lysis of microorganisms in the liquid [2].

Cavitation can be generated by different mechanisms e.g. light photons of high intensity (laser), strong electric discharge, high frequency acoustic waves (ultrasound cavitation). Hydrodynamic cavitation takes place when rapid passage of water through pipes of various cross section is being applied. In case of pipes with small cross section the rate of flow increases, and the pressure decreases that induces breakdown of liquid phase and formation of bibles. When the liquid passes through the pipes with large cross section the flow rate of liquid decreases, pressure increases causing compression, deformation, fragmentation or collapse of bubbles. Cavitation actively progresses predominantly in vortex flows of liquids.

Influence of ultrasound cavitation of microorganisms is well studied [3,4], while data on effects of hydrodynamic cavitation on bacteria are rather limited [5].

When selecting hydrodynamic cavitators the following fact was considered: ranges of frequencies and intensities applied during production of emulsions coincide with that of ultrasounds being lethal for microorganisms.

Formation of emulsions in hydrodynamic emulgent-cavitator has been well studied. Since parameters (frequencies, ultrasound, power on 1cm^3, length of exposure) of influence of cavitation are close for microorganisms and emulsioning processes, for assessment of effects of cavitation on microorganisms characteristics of dispersion agents of various types can be applied (Table 1).

Table 1. *Characteristics of Various Types of Cavitation Dispersion Agents*

Types of dispersion agents	Capacity l/minute	Diameter of particles (μ)	Power kW	Specific power kW/m^3
Valvular	5000	0.8-2.5	37	7.4
Ultrasound	30	1.6	1.4	13.3
Jet	1000	1-1.25	4.4	4.4
Vortex on the basis of valvular A1-ОГ2М	5000	0.77-1.05	19	3.8
Hydrodynamic rotor-vortex Я5-ОЭА	300	1-2.5	0.15-0.175	0.5-0.6
Hydrodynamic rotor-vortex Я5-ОММ	3500-4000	1-2.5	2.1	0.5-0.6
Hydrodynamic rotor-vortex Я5-ОММ	6000-7000	-	2.5	0.4

As the table demonstrates rotor-vortex cavitators are more energy efficient in comparison to other types of cavitators [6]. Hydrodynamic cavitator consists of two main parts: cavitator itself and medium-pressure pump (0.4-1 MPa). Assemblage of hydrodynamic cavitator is simple and cheap. Main cost is related to pump. Cost of installations with the capacity of 30-40t/h is 4800- 100000 USD. Relative cost of the installation applied for cavitation treatment of 1tone liquid is within the range of 1600-2500 USD while the cost of the ultrasound installation with the capacity of 1m3 is in between 14000-22000 USD [7].

When comparing costs for treatment of water of certain volumes by various applicable methods cavitation method appearss to be the cheapest one. Expenditures are as follows: for cavitation 162 $, ultrasound treatment 261 $, chlorination 482 $ and ozonation 1600 $. [8]

The emphasis is made on hydrodynamic cavitation due to cheapness of its generation that results in cheapness of consequent device.

The study objects are drinking waters contaminated with microorganisms due to technogenic processes. Microorganisms - E.coli, St.faeculis, Ps. Aeruginosa and Typhimurium that according to ISO present indicators of contamination were used. Analysis were performed in line with the following ISO methods - ISO 9308–1:214; ISO 9899–2:00; ISO 16266–06 and ISO 19250–10.

Spectrophotometer DR-2800 LPV manufactured by „HACH LANGE" and Turbidimeter HI 93703 C and combined device HI 98204 – pH/ ORP/ EC/ T of "HANNA instruments" were used for determination of phisical and chemical parameters of water.

For laboratory research, the jet micro-cavitator (Fig. 1.) with capacity of 5-10 l/h was created, the selection of the design of which was based on the following considerations: Low consumption of sample liquids; Pressure range 1-5 bar; Simple and easily modified design.

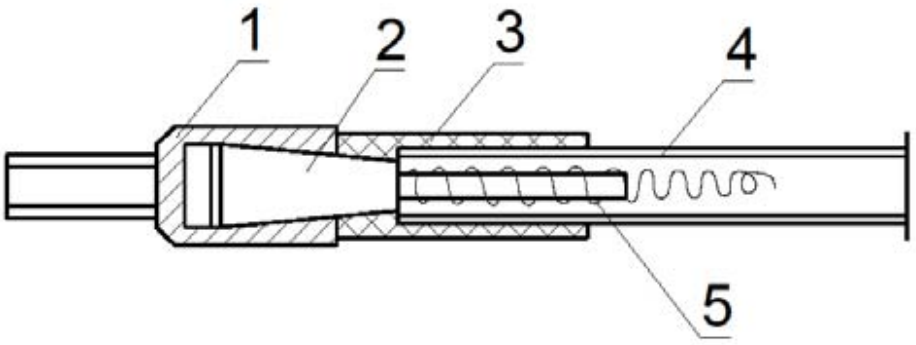

Fig. 1. *General scheme of jet micro-cavitator*

1. connector Luer-Lock; 2. injection needle (liquid accelerator); 3. tightener; 4. cavitation pipe; 5. hydraulic resistance (spiral).

It should be considered that production and operation of jet-cavitator is simpler and cheaper in comparison to other types of cavitators. In the given cavitator for acceleration of liquid stainless steel pipes (injection needles) with diameters of 0,1–0,55mm and length of 2-4 cm and for hydraulic resistance combination of spirals and nodes were used. The novelty of the proposed jet micro-cavitator derives from the fact that as of today low capacity micro-cavitator applicable for the continuous systemic laboratory research of cavitation processes does not exist [9–12]

Discussion and Analysis of the Results

To carry out experiments, cavitation test-bench (Fig. 2.) consisting of jet micro-cavitator produced by the authors was assembled.

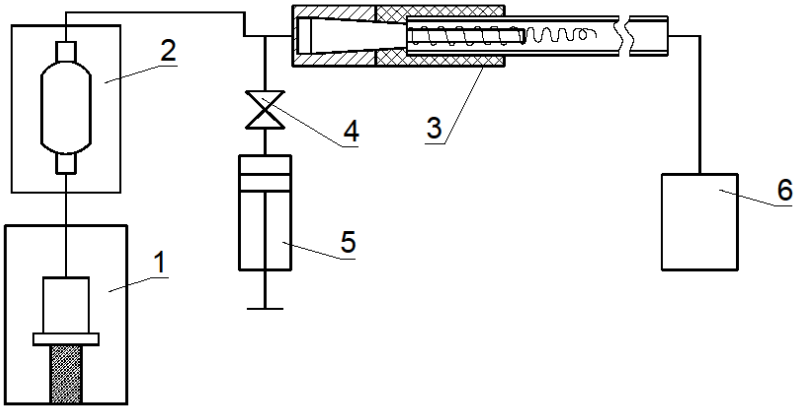

Fig. 2. *Hydrodinamic cheme of cavitation test-bench*

1. vessel for sample water; 2. pump-dozer with reversing valve and filter; 3. jet micro-cavitator; 4. Stopcock; 5. syringe for filling the hydraulic system; 6. vessel for cavitated water.

Experiments were conducted for the treatment of drinking water with microbial contamination. The data listed in the tables (Table 2.) are mean values of the parallel tests.

To avoid incomplete oxidation of microorganisms (due to insufficiency of oxygen – 1 l water contains 8 mg oxygen) in the process of cavitation some of the drinking water samples were pretreated with hydrogen peroxide (H_2O_2).

Table 2. *Microbiological Analysis of Cavitated Water*

#	Drinking water contaminated with microorganisms	Quantity of Microorganisms, CFU*/100 ml				
		Initial	Samples after cavitation			
			1	2	3	4
1	E.coli	900	Not present	Not present	Not present	Not present
2	Ps.aeruginosa	800	–,,–	–,,–	–,,–	–,,–
3	St.faecalis	7900	–,,–	–,,–	–,,–	–,,–
4	Typhimurium	850	–,,–	–,,–	–,,–	–,,–

* – Colony Forming Unit

For each microorganism four samples were prepared (table 2). First two samples (sample 1, sample 2) of each microorganism were not pretreated with hydrogen peroxide other two (sample , sample 4) were pretreated. For the first and third samples duration of cavitation was 5-10 minutes and for the second and fourth samples cavitation took place in the process of single passage. The same sequence was applied for all four samples. Cavitation process war conducted at pressure of 4-5 bar. According to results none of the cavitated samples contained live microorganisms. Hence, it can be concluded that in the conditions of given concentrations of microorganisms water can be purified without its pretreatment with hydrogen peroxide and the duration of cavitation does not exceed 5 minutes. The same results were obtained in the process of single passage of the solution.

The research was continued in the conditions of single passage of water through cavitator.

Subsequent experiments were carried out on samples treated with hydrogen peroxide to avoid incomplete oxidation in the conditions of different concentrations of contaminating microorganisms. To define optimal value of one of the main technological parameter-pressure, experiments on water samples contaminated with E. coli and Ps. Aeruginosa were carried out. Experiments were conducted on two different concentrations of each microorganism. Pressure was altered between 1-5 bar. Sample number indicates the pressure(bar) during the cavitation process (Table 3).

Table 3. *The Results of Cavitation of Water Contaminated with Microorganisms (in the conditions of single passage)*

Pressure during cavitation process	Quantity of microorganisms, CFU*/100 ml							
	E.coli				Ps. Aeruginosa			
	Initial	Cavitated	Initial	Cavitated	Initial	Cavitated	Initial	Cavitated
1	170	340	780	156	210	Not present	660	Not present
2	–,,–	185	–,,–	45	–,,–	–,,–	–,,–	–,,–
3	–,,–	Not present	–,,–	1	–,,–	–,,–	–,,–	–,,–
4	–,,–	–,,–	–,,–	Not present	–,,–	–,,–	–,,–	–,,–
5	–,,–	–,,–	–,,–	–,,–	–,,–	–,,–	–,,–	–,,–

* – Colony Forming Unit

At relatively higher pressure (4-5 bar) complete lysis of microorganisms takes place. When applied low pressure (1,2 bar) in case of E.coli increase of quantity of microorganisms is observed that is possibly associated with destruction of microbial organic components during cavitation and production of further deformation products representing food for the microorganisms and inducing their growth [1].

According to the obtained results it can be concluded that by means of proposed design of the jet cavitator high degree of lysis of microorganisms can be attained in the conditions of regulating pressure in the process of single passage of water.

By-products of cavitation - products of complete and partial oxidation of microorganisms and their lysis-destruction were analyzed. The results of the analysis enable selection of methods for removal of those substances.

Literature review shows [13-16] that main content of microbial cell is water (80-85%). Dry component presents 15-25% out of which 50-80% is proteins of various types. N, C, O, H are organogen of dry residue. In the presence of oxygen those elements transform into gaseous state and evaporate. Due to incomplete oxidation of amino acids that are building blocks of all proteins, cavitated drinking water may contain inorganic compounds containing nitrogen - NO_2^- , NO_3^- , NH_4^+. The turbidity of cavitated drinking water may also be ascribed to content of products of microorganisms' destruction (Table 4).

Table 4. *Characteristics of Cavitated Water*

Samples	Pressure, bar	Microorganisms														
		E.coli					Ps. Aeruginosa					St.faecalis				
		COD* mg O_2/l	Turbidity FTU**	NO_2^-,	NO_3^-,	NH_4^+,	COD*	Turbidity	NO_2^-,	NO_3^-,	NH_4^+,	COD* mg O_2/l	Turbidity FTU**	NO_2^-,	NO_3^-,	NH_4^+,
Water contaminated with microorganisms		13,0	0,6	0	0,1	0	14,0	1,03	0	0	0	12,0	1,0	0	0	0
Cavitated water contaminated with microorganisms	1	1,56	1,42	,,	0,2	,,	1,95	2,11	,,	0,20	,,	1,56	2,01	,,	,,	,,
	2	1,50	2,09	,,	0,2	,,	1,95	2,16	,,	0,20	,,	1,48	1,50	,,	,,	,,
	3	1,36	0,88	,,	0,2	,,	1,85	1,48	,,	0,20	,,	1,30	2,16	,,	,,	,,
	4	1,36	0,99	,,	0,2	,,	1,50	2,59	,,	0,25	,,	1,30	2,40	,,	,,	,,
	5	1,30	0,99	,,	0,2	,,	1,50	2,00	,,	0,25	,,	1,30	2,40	,,	,,	,,

* Chemical Oxygen Demand

** FTU Unit of Turbidity, defined according to Formazin

Experiments were carried out on the pressure between 1-5 bar. The obtained results reveal that in the conditions of cavitation the complete destruction of microorganisms takes

Experiments were carried out on the pressure between 1-5 bar. The obtained results reveal that in the conditions of cavitation the complete destruction of microorganisms takes place mainly due to their complete oxidation (sharp reduction of chemical oxygen demand). The tendency of increasing turbidity of cavitated water demonstrates that destruction of relatively small amount of microorganisms is linked with their fragmentation, splitting.

Low turbidity may be caused by small sizes of products of microorganisms' splitting. Applied method (turbidimetry) is based on the characteristics of particles to scatter transmitted light. The intensity of scattering effect depends on the size of particles.

Filtration method was applied for the removal of microorganisms' destruction splitting by-products. Tests were made on comparative filtration system (Fig.3).

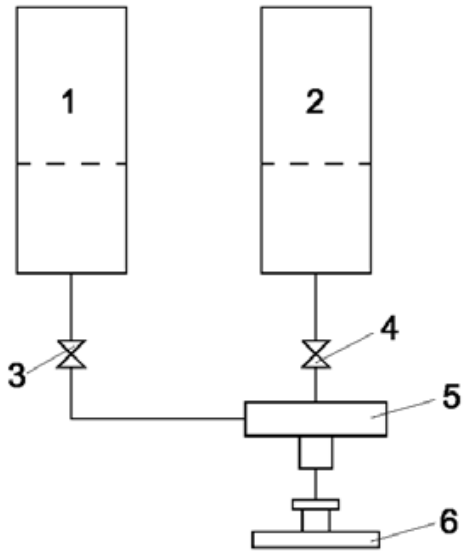

Fig. 3. *Hydrodynamic Shceme of Filtration Test-Bench*

1. blank reservoir; 2. sample reservoir; 3, 4. stopcock; 5. Trifurcate; 6. syringe filter

Syringe filters of 0,45 micron with 25 mm diameter were used as filters (6). Assessment of contamination level sensitive to filter is done on the test-bench: by means of connector filter (6) is fixed to the trifurcate (5), stopcock is opened (3) and the blank (saline) is injected into the filter. Height of hydraulic head is 65 cm. The flow rate of liquid in the filter is measured by timer(ml/sec.). Stopcock is closed (3) and opened (4)-sample is injected into the filter and the flow rate of the sample passing through the filter is measured (Table 5.).

Table 5. *Data of Filtration Processes*

Object of Study	Volume of filtrate, ml	Filtration time, sec	Flow rate of liquid, ml/sec.	Filtrate turbidity FTU		
				Microorganisms		
				E.coli	Ps. Aeruginosa	St.faecalis
Saline	10	70	0,14	0	0	0
	20	150	0,13	,,	,,	,,
Water contaminated with microorganisms	10	100	0,10	1,27	3,01	1,30
	20	260	0,07	,,	,,	,,
Cavitated water contaminated with microorganisms	10	120	0,08	0,70	0,72	0,68
	20	290	0,06	,,	,,	,,

* FTU Unit of Turbidity, defined according to Formazin

Waters with different levels of contamination (drinking water contaminated with microorganisms and its cavitate) and saline (pharmacological preparation) were filtered, the filtration rate of which was considered as relative standard. The flow rate (ml/sec) of cavitated (at various levels) water contaminated with microorganisms was measured in the conditions of obtaining equal volume of filtrate. The results (table 5.) confirm formation of small particles in the process of cavitation. The particles slightly affect increase of filter resistance.

As the result of performed experiments cavitation and filtration were identified as constituent nodes of the target system (experimental system of treatment of drinking water contaminated with microorganisms). A new experimental system was created (Fig. 4).

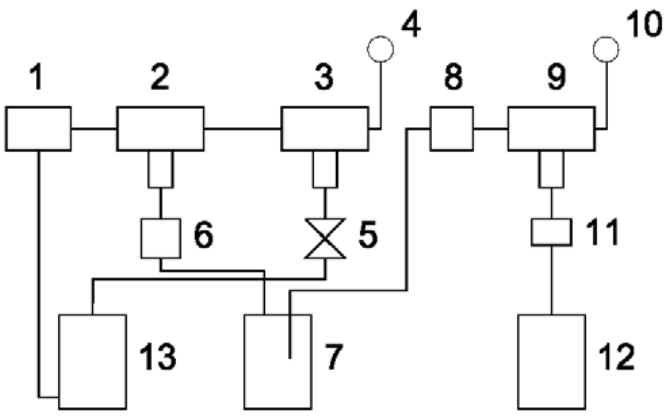

Fig. 4. *Hydrodynamic Shceme of ExperimentalSystem for Water Treatmentn*

1. pump-dozer BL-10; 2,3. trifurcate; 4. Manometer; 5. pressure regulator; 6. Cavitator; 7. reservoir for cavitated water; 8. pump-dozer BL-5; 9. trifurcate; 10. manometer; 11. 0,45 μm membrane filter; 12. reservoir for filtered water; 13. reservoir for raw water.

Sample water from reservoir (13) is pumped (1) to cavitator (6). In the system pressure is regulated with bypass stopcock (5) by controlling manometer (4). Liquid from the cavitator accumulates in the reservoir (7) from where it is pumped to the 0,45 μm membrane filter (11) by pump-dozer(8). Passing the membrane filter the liquid accumulates in the reservoir (12).

Synchronisation of the capacities of the cavitator and the filter is performed by regulating capacity of pump-dozer.

Table 6. *The Results of Treatment of Water with Microbial Contamination Conducted on the Experimental System*

#	Sample	Quantity of Microorganisms CUI/100მლ		Physical and Chemical Parameters					
				E.coli			Ps. Aeruginosa		
		E.coli	Ps. Aeruginosa	pH	COD* mg O_2/L	Turbidity FTU**	pH	COD* mg O_2/L	Turbidity FTU**
1	Water contaminated with microorganisms	700	800	8,12	13,00	1,07	8,13	14,00	1,70
2	Cavitated water contaminated with microorganisms	Not present	Not present	8,15	1,56	1,27	7,20	1,95	3,01
3	Filtrate of Cavitated water contaminated with microorganisms	Not present	Not present	8,17	1,50	0,70	8,50	1,90	0,72

* Chemical Oxygen Demand

** FTU Unit of Turbidity, defined according to Formazin

Water obtained in the experimental system, according to its chemical (pH, COD), organoleptic (turbidity) and microbiological parameters (table 6) meets the demands of Technical Regulation of Drinking Water.

Conclusion

Based on the obtained results of the systemic researches experimental system for treatment of microbially contaminated drinking water was created. The system consists of the two main nodes-cavitation and filtration. The capacity 5-10 l/h of the microcavitator created within the frameworks of the project has been applied. Water obtained in the system meets the requirements of drinking water technological regulation by its organoleptic, physical and chemical as well as microbiological parameters.

The proposed experimental system, in future may become a basis for a new technical installation for treatment of drinking water sharply reducing the costs of appropriate devices, simplifying their application and ensuring required level of safety.

Acknowledgements

The article is written on the results of the project implemented by financial support of the Shota Rustaveli National Scientific Foundation (Project 217818 "Study of Treatment Process of Water Contaminated with Microorganisms)

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