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Physical Chemistry

Creation of Micro-Cavitator and Determination of its Bactericidal Effect

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

*Physical and Chemical Analysis of Water and Technologies Group, L.E.P.L. G.Tsulukidze Mining Institute, Tbilisi, Georgia

(Presented by Academy Member Vladimer Tsitsishvili)

ABSTRACT. Highly efficient jet micro-cavitator with the capacity of 5-10l/h was created. The complete destruction/lysis of microorganisms in waters in the conditions of low expenditure of sample liquids and within the pressure range 1-5 bar was achieved by application of the cavitator. It should be considered that for industrial purposes manufacturing and maintenance of the jet caviator is simpler and cheaper in comparison with the other types of cavitators. Bactericidal effect of the microcavitator on drinking water contaminated with bacteria is 100%. Micro-cavitator designed by us consists of only five elements: connector, liquid accelerator, operational or cavitation pipe and hydrodynamic resistance. Connector connects cavitator with hydrodynamic system, liquid accelerator (medical injection needle) is fixed to the connector. By means of tightener – silicon pipe the needle is fixed on cavitation pipe that encloses hydrodynamic resistance. Changing of injection needle or hydrodynamic resistance of both is enough for alteration of hydrodynamic parameters of cavitator. Flow is accelerated in the confusor of injection needle and in the accelerator of cavitator (injection needle) the flow with high velocity (ω≈10m/s) is formed that induces rapid decrease of pressure in both, accelerator and inlet of operation chamber. In the vicinity of the outlet of accelerator at the inlet of operation chamber two-phase (gas-liquid) flow with ultrasound velocity is formed that brakes when passes through the operation chamber. In that moment gas and liquid vapor bubbles collapse that results in release of local high energy in the form of high temperature, strong microflows and shock waves. Local physical and chemical parameters are also altered. Joint influence of those factors results in the significant weakening of microbial membrane and its farther lysis. The created cavitator will significantly increase the area of the practical application of the cavitation method. *© 2019 Bull. Georg. Natl. Acad. Sci.*

Key words: cavitation, microorganisms, bactericidal effect, micro-cavitator

The performed study is aimed at creation of micro-cavitator with the capacity of up to 5÷10 l/h intended for laboratory investigations. The design of the cavitator is to be selected based on its main purpose – complete destruction/lysis of microorganisms presented in water.

Productivity of the cavitator for laboratory research is usually higher than 100 l/h [1-4].

Hydrodynamic cavitation processes are widely applied today in chemical and pharmaceutical technologies to intensify extractive processes, increase rate of chemical reactions and obtain various types of ultra dispersive emulsions. Such emulsions are mostly used in thermal power plants. Cavitation is also used in food production for disinfection of various liquids (milk, juices, bottled water etc).

Though hydrodynamic cavitation is widely applied in technological process, further optimization of process in that direction requires intensification of laboratory studies. For that purpose, creation of cavitation system that guarantees easy alteration of technological parameters of the system in wide range and is available for a researcher is regarded reasonable.

Hydrodynamic cavitation, as in case of other physical methods (thermal processing, ultrafiltration and ultrasound irradiation) of disinfection of liquids, represents no reagent disinfection method.

The impact of cavitation on microorganisms is determined by the rapid increase of pressure and temperature in air and water vapour bubbles formed as a result of cavitation. The latter causes thermolysis of water, changes physical and chemical characteristics of water, in particular: conductivity, pH, oxidation-reduction potential [4] and significantly alters structure of the cell wall, and in the presence of certain substances (oxidizers) or multiple repeating causes its complete destruction.

Vortex micro-cavitator was applied by us to define rates of chemical reactions, in particular, rates of oxidation of hydrogen sulphide and decomposition of bicarbonates. In this regard, vortex cavitator is highly effective, though not sufficiently clear that the same effect can be achieved in case of lysis of bacteria. To induce lysis of bacteria creation and testing of different types of vortex cavitotrs may become necessary. Analysis of various designs of cavitators demonstrate that in comparison with other designs of cavitators the production of jet micro-cavitators of various modifications is the simplest option. The issue of simplicity in designing and operating the jet cavitators in the production environment is also to be considered.

Micro-cavitator designed by us is simple to manufacture. It consists of only five elements (Fig. 1): connector, liquid accelerator, operational or cavitation pipe and hydrodynamic resistance. Connector connects cavitator with hydrodynamic system (Fig.2), liquid accelerator (medical injection needle) is fixed into the connector, needle by means of tightener – silicon pipe, is fixed on cavitation pipe that encloses hydrodynamic resistance. Changing of injection needle or hydrodynamic resistance of both is enough for alteration of hydrodynamic parameters of cavitator.

The general scheme of jet cavitator is presented in Fig.1.

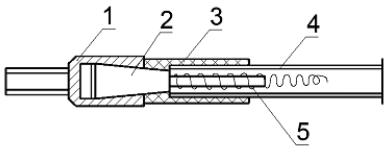

Fig 1. Jet micro-cavitator.
Connector Luer Lock; 2.Injection needle (Accelerator of liquid); 3. Tightening silicon pipe with thick wall; 4. Cavitation pipe; 5. Hydrodynamic resistance (spiral).

Flow is accelerated in confusor of injection needle, in the accelerator of cavitator (injection needle) flow with high velocity (ω≈10m/s) is formed that induces rapid decrease of pressure in both, accelerator and inlet of operation chamber. In the vicinity of outlet of accelerator at the inlet of operation chamber two-phase (gas-liquid) flow with ultrasound velocity is formed that brakes when passes through the operation chamber. In that moment gas and liquid vapor bubbles collapse that results in release of local high energy in the form of high temperature, strong microflows and shock waves. Local physical and chemical

parameters are also altered. Joint influence of those factors results in the significant weakening of microbial membrane and its further lysis. Lysis of microbial cell can be accelerated in the presence of disinfectants (ozone, hydrogen peroxide etc). This was one of the very directions of our study.

In the hydrodynamic system conditions of generation of cavitation are defined by the formula of cavitation number [5]:

$$æ=(P_1-P_2)/\rho\omega^2, \quad (1)$$

where

P_1 – is the pressure (Pa) at the inlet of accelerator;

P_2 – is the saturated vapor pressure (Pa) of water on the process temperature;

ρ – is the density of the liquid;

ω – is liquid flow velocity (m/s).

On the low temperatures in particular T≈ 20^0C, P_2 is low and satisfies the condition: $P_1>>P_2$.

Since membrane turbo-dozers with the capacity of 5 l/h and 10 l/h and maximum pressure (4÷7 bar) were at our disposal the pressure at the inlet of accelerator of jet cavitator could have been up to 4÷7 bar.

The flow velocity for jet cavitator is calculated with the formula:

$$\omega = \frac{V}{f}, \quad (2)$$

where:

V is volumetric flow rate (m^3/s);

f is area pipe section (m^2).

For circular cross-section pipes volumetric flow rate is calculated with the formula [6]:

$$V = \frac{G}{\rho} = \frac{\pi\left(p_1 - p_2\right)D^4}{128\mu L}, \quad (3)$$

Where:

V is volumetric flow rate (m^3/s);

G mass flow rate (kg/s);

p_1 is the pressure (Pa) at the inlet of cavitator;

P_2 is the pressure (Pa) at cavitation cavern;

D – pipe diameter (m);

ρ – is the density of the liquid (water) 1000 kg/$m^{3;}$

π=3.14;

μ – liquid dynamic viscosity (Pa.c);

L – pipe length (m);

As a rule, $P_1>> P_2$.;

Since the pumps at our disposal perform at pulse mode and the formula (2) and (3) are calcualted for constant flows, usage of those formula are only meaningful to evaluate diameter (D) of accelerator of liquid of micro-cavitator .

For rough calculation of D let'us assume that V= 3.6 l/h =$10^{-6}m^3$/h; P= 10^5 Pa .

Calculated diameter will be D=0.88*10^{-3}m in accordance with formula (3). Area of section of corresponding cylindrical pipe will be f=2.08*$10^{-6}m^2$ and the flow rate calculated in accordance with formula (2) ω=1.65m/s.

Diameter of accelerator calculated for the same volumetric flow and pressure P=4*10^5 Pa is D=0.25*10^{-3}m and the flow rate equals to ω=21m/s.

From those calculation it is evident that in case of our pumps the diameter of flow accelerator should be within 1mm. Medical injection needles can be used as pipes of such size.

Those injection needles are available and can be used for jet micro-cavitators of various designs.

To perfume tests by cavitation test-bench has been assembled. Hydraulic scheme of jet micro-cavitator is presented in Fig. 2.

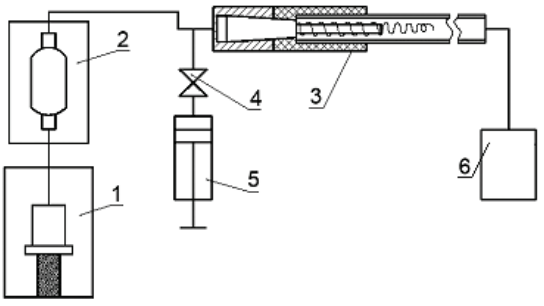

Fig.2. Hydraulic scheme of jet micro-cavitator test-bench: 1. Sample jar; 2. Pump-dozer with reverse valve and filter; 3. Jet micro-cavitator; 4. Tap; 5. Syringe to fill the hydraulic system; 6. Vessel for cavitated liquid.

Table 1. Initial values of physical chemical parameters of water Conduction -2,68·10^{-4} Sm/m, pH-8,2, Temperature ^{0}C - 20,3^0

Accelerator /injection needle	Pressure Bar	Flow rate m/s	Physical and Chemical Characteristics		
			Conduction Sm/m	Temperature ^{0}C	pH
G 25 D=0.26mm L=25mm	2	14.3	$2.9\cdot10^{-4}$	20.8	8.4
	3	18.8	$3.08\cdot10^{-4}$	21.5	8.45
	4	20.7	$3.1\cdot10^{-4}$	21.3	8.5
	5	21.4	$3.21\cdot10^{-4}$	21.7	8.6
G 25 D=0.26mm L=45mm	2	10.0	$2.84\cdot10^{-4}$	21.2	8.4
	3	13.4	$2.92\cdot10^{-4}$	21.2	8.43
	4	15.0	$3.09\cdot10^{-4}$	21.8	8.4
	5	16.8	$3.17\cdot10^{-4}$	22.3	8.45

Usage of pump-dozers, medical injection needles and luer-lock connector significantly simplify both design of micro-cavitator and hydraulic scheme of test-bench. Several jet cavitators with accelerator of liquid having various diameters and with different hydrodynamic resistance have been tested on the test-bench.

Water from the Tbilisi Sea was used as a sample. The tests were made on the following microorganisms: total coliforms with the method ISO 9308-1:2014; E.coli-ISO 9308-1:2014; St.faesalis-ISO 9899-2:00; Ps. Aeruginoza-ISO 16266-06; S.typhimurium – ISO 19250-10.

Microbiological analyses were performed in the Scientific Research Firm "GAMMA".

Experiments were performed in the conditions of single passing of sample through cavitator.

Primarily correlation of water physical and chemical parameters and cavitation intensity was studied. Changes in physical chemical characteristics of drinking water is presented in Table 1.

Table 2. lists characteristics of injection needles used as accelerators in the experiments and visual evaluation of cavitation process. Table 3. Describes influence of vortex flow generated as the result of using various accelerators and hydrodynamic resistances.

Table 2. Visual evaluation of cavitation in the conditions of carious accelerators

№	Accelerator Syringe	Pressure Bar	Capacity ml/min	Mean Rate of Flow m/s	Hydrodynamic Barriers	Cavitation Visual Evaluation
	G 21 D=0.535mm L=40mm	1	83.3	7.02	Spiral + Nodes	Vortex, Air bubbles
	G 25 D=0.26mm L=25mm	3-4	45.5	14	Two Nodes	Vortex at the 2/3 of the pipe. Air bubbles
	G27 D=0.21mm L=25mm	6	33.3	17	Three Nodes	Vortex on the entire length of the pipe. High intensity of bubbles
	G 30 D=0.15mm L=16 mm	6	18	10	Spiral	Low intensity vortex

Table 3. Influence of vortex flow on microorganisms

Sample Name	Total coliforms 100 ml	E.coli 100 ml	St.faesalis 100 ml	Ps.Aeruginoza 100 ml	S.typhimurium 100 ml
Sample 1 Control	1200 CFU	1100 CFU	4 CFU	800 CFU	Free
Sample 2 G 21-1	5 CFU	5 CFU	2 CFU	700 CFU	Free
Sample 3 G21-2	Free	Free	Free	Free	Free
Sample 4 G 25-1	15 CFU	2 CFU	Free	30 CFU	Free
Sample 5 G25-2	Free	Free	Free	Free	Free
Sample 6 G27-1	Free	Free	Free	Greenish clumps	Free
Sample 7 G27-2	Free	Free	Free	Free	Free
Sample 8 G30-1	Many yellowish colonies	Many yellowish colonies	Free	Many greenish clumps	Free

G 21-1 denotes cavitation without presence of oxidizers; G 21-2 denotes that cavitation took place in the presence of oxidizer (H_2O_2), CFU – Colony-Forming Unit.

Marking is analogical for all samples. Concentration of oxidant in the solution is 0.6%.

As a result of analysis of Table 2 and Table 3 injection needle G25 was selected as the accelerator of liquid for further experiments. The choice was made due to:

1. Good bactericidal effect;
2. Relatively low pressure (3-4bar), that further becomes the basis for creating cost-effective cavitation system. The lower the pressure the cheaper the cavitation pump. The pump is the most expensive part of the cavitator;
3. Satisfactory capacity (for laboratory studies).

Combination of spirals and nodes were selected as hydrodynamic barriers.

Results presented in Table 3 demonstrate that in case of single passing of the sample through micro-cavitator the bactericidal effect of cavitator without presence of oxidizers is 70-99% and in case of treatment with oxidizer the complete lysis of microorganisms takes place.

It is worth mentioning that according to literature [4,7] such level of lysis of microorganism and changes of physical and chemical parameters is obtained in case of multiple passing of liquid through the cavitator.

As a result of the performed studies the micro-cavitator with high bactericidal effect and the capacity of 5÷10 l/h was created. The use of the cavitator will enable conduction of systemic laboratory investigations that will significantly increase area of application of cavitation process in practice.

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ფიზიკური ქიმია

მიკროკავიტატორის შექმნა და მისი ბაქტერიოციდული ეფექტის განსაზღვრა

ნ. ენუქიძე*, ნ. საყვარელიძე*, ც. კურცხალია*, ზ. სიმონია*

*წყლის ფიზიკურ-ქიმიური ანალიზისა და ტექნოლოგიების ჯგუფი; სსიპ გრ. წულუკიძის სამთო ინსტიტუტი, თბილისი, საქართველო

(წარმოდგენილია აკადემიის წევრის ვ. ციციშვილის მიერ)

შეიქმნა ჭავლური მაღალეფექტური მიკროკავიტატორი წარმადობით 5–10ლ/სთ. აღნიშნული კავიტატორით მოხდა წყალში არსებული მიკროორგანიზმების სრული განადგურება, ანუ ლიზისი, რაც მიიღწევა შემდეგი პირობების გათვალისწინებით: საცდელი სითხეების დაბალი ხარჯი, წნევების დიაპაზონი 1–5 ბარი, მარტივი და ადვილად მოდიფიცირებადი კონსტრუქცია. გასათვალისწინებელია, რომ საწარმოო პირობებში ჭავლური მიკროკავიტატორის დამზადება და ექსპლუატაცია უფრო მარტივია და იაფი, ვიდრე სხვა ტიპის კავიტატორების. შექმნილი მიკროკავიტატორის ბაქტერიოციდული ეფექტი ბიოლოგიურად დაბინძურებული სასმელი წყლის მიმართ პრაქტიკულად არის 100%. ჩვენ მიერ კონსტრუირებული მიკროკავიტატორი ხუთ ელემენტს შეიცავს: კონექტორს, სითხის ამაჩქარებელს, მუშა, ანუ, საკავიტაციო მილს და ჰიდროდინამიკურ წინაღობას. კონექტორი აკავშირებს კავიტატორს ჰიდროდინამიკურ სისტემასთან, სითხის ამაჩქარებელი (სამედიცინო საინექციო ნემსი) მაგრდება კონექტორში. ნემსი, გამამჭიდროებლის – სილიკონის მილის საშუალებით, მაგრდება საკავიტაციო მილში, რომელშიც განთავსებულია ჰიდროდინამიკური წინაღობა. კავიტატორის ტექნოლოგიური პარამეტრების შესაცვლელად საკმარისია საინექციო ნემსის ან ჰიდროდინამიკური წინაღობის ან ორივე ელემენტის ერთად შეცვლა. საინექციო ნემსის კონფუზორში ხდება ნაკადის აჩქარება, ხოლო საინექციო ნემსში (კავიტატორის ამაჩქარებელში) ხდება მაღალი სიჩქარის ($\omega \approx 10$მ/წამში) ნაკადის ფორმირება, რაც უზრუნველყოფს ნაკადში წნევის მკვეთრ ვარდნას როგორც ამაჩქარებელში, ასევე მუშა კამერის შესასვლელში. ამაჩქარებლის გამოსავალთან ახლოს მუშა კამერის შესავალში წარმოიქმნება ორფაზიანი (აირი-სითხე) ზებგერითი სიჩქარის მქონე ნაკადი, რომელიც მუშა კამერაში გავლისას მუხრუჭდება, რა დროსაც ადგილი აქვს აირისა და წყლის ორთქლის ბუშტულების კოლაფსს, რის შედეგადაც ლოკალურად დიდი ენერგია გამოიყოფა მაღალი ტემპერატურის, მძლავრი მიკრონაკადების და დარტყმითი ტალღების სახით. იცვლება აგრეთვე წყლის ლოკალური ფიზიკურ-ქიმიური პარამეტრებიც. ამ ფაქტორების ერთობლივი ზემოქმედებით ხდება მიკროორგანიზმების გარსის მკვეთრი შესუსტება და შემდგომ ლიზისი. მიკრობული უჯრედის ლიზისი შეიძლება მნიშვნელოვნად დააჩქაროს დეზინფექტანტების (ოზონი, წყალბადის ზეჟანგი და სხვა) არსებობამ წყალში. შექმნილი მიკროკავიტატორის არსებობა მნიშვნელოვნად გაზრდის კავიტაციის მეთოდის პრაქტიკული გამოყენების არეალს.

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