SONOMICROBIOLOGY OF RAW WATER AT THE TREATEMENT BY AIR-JET GENERATORS

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Abstract: The paper presents the sonic treatment effect on the microbiological indicators of the raw water, namely total germ number, Streptococci number, total coli forms and fecal coli forms. Also, the paper comprises the sonic installation which includes the vertical reactor and the air-jet ultrasound generator. The results allow the development of a new raw water treatment technology that will eliminate the actually two-stage treatment - filtration and chlorination, for the drinking water plants.

Keywords: microbiology, water, treatment, sonic system, air-jet generator, reactor

1. INTRODUCTION

Currently, drinking water plants for raw water treatment is achieved chemically. At bacteriological level the chlorination process [1, 2] is used and, in order to kill bacteria, a dose of 3-5 mg/l chlorine is needed to ensure a residual chlorine of 0.4 mg/l in a 30 minutes treatment period. A new technology in this area is the use of ultrasound in treatment processes.

Thus, at the frequency of 20 kHz occurs the fragmentation and reduction of microbial colonies larger than 50 microns [3] that are more difficult to destroy by chemical methods. In the specialized literature, there are encouraging results in the use of ultrasound treatment, but only in combination with electrolytic treatment, as well as with the classical method of chlorination.

The previous experiences in ultrasound treatment of water were performed in laboratory conditions [4-9] with ultrasonic generators. The activation time for one liter of water was of 5-10 seconds, sufficient to reduce the number of bacteria. Instead, in our work, using the air-jet ultrasound generator for the Danube water treatment was recorded the destruction of bacteria only by sonic action [5] within an industrial experimental installation.

2. THE EXPERIMENTAL INSTALLATION WITH SONIC REACTOR FOR RAW WATER FLOW TREATMENT

2.1. The sonic installation

The sonic installation for raw water treatment is an experimental equipment for drinking water plants. It contains the first treatment phase of raw water for drinking, which is clarification, and the second phase, which is disinfection. The sonic reactor is supplied with aluminum sulfate solution through a system on which are installed a control valve and a meter for coagulant dose monitoring. Bubbling (aeration) performs a mixture of raw water and coagulant. Decanted water is impounded by collecting eight stacks.

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The research of sonic treatment (ultrasound and simultaneous aeration) of raw water from a surface source assumes certain technical requirements for controlling and monitoring the technological process, which are provided in the experimental facility, built on the platform of Water Treatment Plant from Braila City, Romania.

The experimental plant comprises different systems: I – the sonic reactor; II- the second raw water supply, III – the air supply system of the sonic generator, IV- the sewage system suspension decanted , V-clarified water collection system (Fig 1).

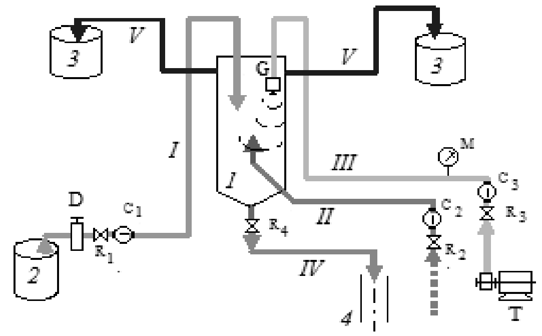

Fig. 1. The sonic installation for raw water treatment:
1- sonic reactor; 2- coagulant tank; 3- decanted water tank; 4- sewerage; g- sonic generator; d- coagulant dozer; r1- coagulant flow control valve; c1- coagulant monitoring meter; r2- raw water regulating valve; c2- raw water monitoring meter; t- turbocharger; c_3- air monitoring meter; r3- air pressure regulating valve; m- manometer; r4- sludge discharge control valve.

The raw water from the plant system is pumped in the sonic reactor 1, the raw water flow is monitored by the valve R2 and by water controlling C2. The Aluminum sulfate solution from tank 2, reaches in the system through dozer D, and the flow of aluminium sulphate solution that comes into the sonic reactor is monitored by valve R_1 and the controlling C_1.

The sonic generator working air produced by the turbocharger T, discharge pressure of 0.05 MPa and the maximum flow rate of 220 m³ / h, is set by regulator R_3 and monitored by manometer M. Sonic generator G, positioned inside the settler, ensure water clarification by simultaneously produces aeration and acoustic waves.

2.2. The sonic reactor

The raw water from the Danube enters into the mixing chamber (Figure 2) through the supply pipe 5. In the mixing chamber occurs the mixture of raw water and coagulant, and in the reaction chamber the mixture is separated into water and floaters, which then settles in the clarifier.

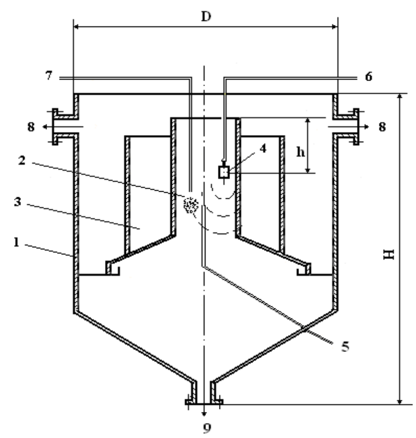

Fig. 2. The Sonic reactor:
1- reactor wall; 2- mixing chamber; 3- reaction chamber; 4- sonic air-jet generator; 5- raw water pipeline; 6- air duct work of the generator; 7- coagulant pipeline; 8- decanted water tank; 9-collector sludge disposal; D,H- reactor diameter and height; h- generator's working depth.

The air-jet sonic generator, powered with air under pressure through the pipe 6, is introduced through the mixing chamber, which produces bubbling and sonic waves. There the water flow arrives by pipeline 5 and the coagulant (the aluminium sulphate solution) through pipeline 7. The suspension is deposited on the bottom (cone) during a certain settling time and is discharged through the sludge outlet spout 9. The experimental sonic reactor has the following overall rate: D = 1.6 m, H = 2.56 m.

2.3. The air-jet ultrasound generators

The air-jet ultrasound generators used in this installation are shown in Figure 3 and Figure 4. The first one is the ultrasound whirlwind generator, rectangular shaped and contains two resonators with whirlwind. The design casing is milled with a fork inside a rectangular channel which is located one and two identical resonators housing (Figure 3).

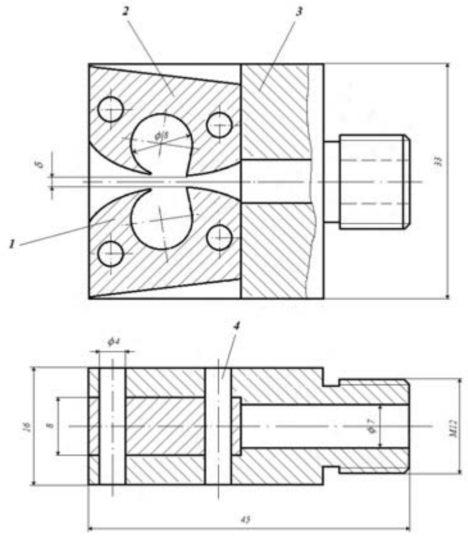

Fig. 3. The ultrasound whirlwind generator with two frequencies:
1- housing; 2- top resonator; 3- lower resonator; D=8 mm- cylindrical chamber diameter; d=7 mm - channel diameter input; h =8 mm- nozzle length; δ =1,2 mm - slot generator control.

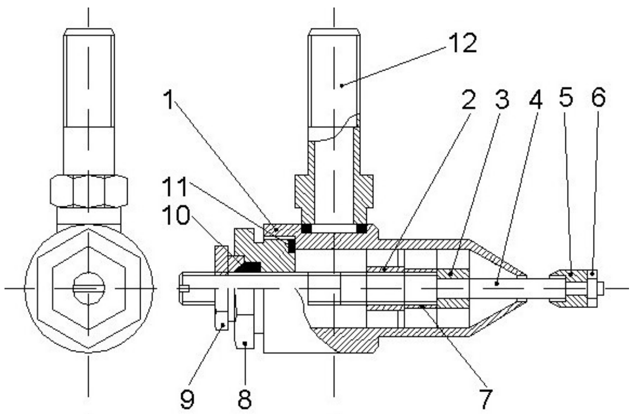

Fig. 4. The air-jet ultrasound stem generator:
1-air nozzle; 2,3-cross support; 4-stem; 5-resonator; 6-screw nut; 7-sleeve; 8-cover; 9-locking nut; 10-gasket; 11-ring; 12-fitting.

The ultrasound whirlwind generator has two working frequencies (sound-ultrasound): the sound frequency of 10.76 kHz and the ultrasound frequency of 21.520 kHz. The acoustic emission of the sound intensity level for the sound frequency is of 109.88 dB, and that for ultrasound frequency is of 108.09 dB. The overall sound intensity level produced by the generator is 112.32 dB [5].

The air-jet stem generator (Fig. 4) emits ultrasound waves with frequencies of 27.2 kHz. The overall sound intensity produced by this generator is of 131.0 dB [6].

3. RESULTS AND DISCUSSION

The research of sonic technology was made in a continuous and discontinuous operation regime. The microbiological indicators determined to assess the quality of water were total germ, Streptococci number, total coli forms and fecal coli forms.

Methodology in experimental research work was:
- establishing the working dates for installation, where water flow is constant (raw water flow rate of 0.9144 m^3/h, speed raw water ascension 0.145 mm/s);
- setting the flow dose of coagulant agent solution (aluminium sulphate $Al_2(SO_4)_3$) in terms of 40-60 g/m^3;
- setting an intermittent work cycle of sonic generator (actual generator operation period of 60 minutes, alternated with periods break for the 5, 10, 15 or 20 minutes).

3.1. The continuous sonic treating regime

The graphic below (Figure 5) show the total germ and Streptococci evolution depending on the water volume flow at the continuous treatment by sonic generator.

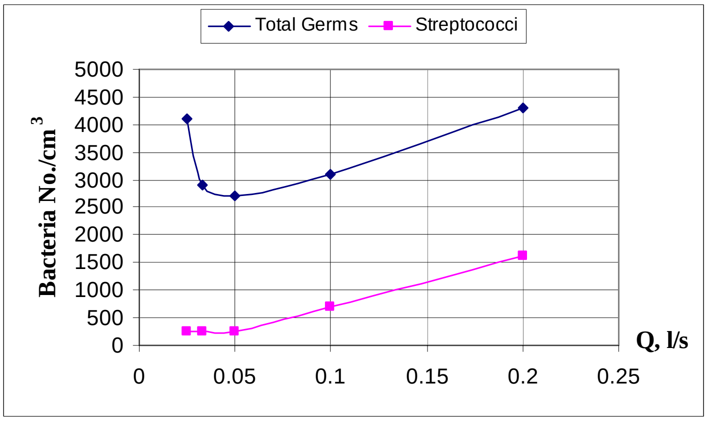

Fig. 5. Total germ and Streptococci depending on the water volume flow (Sound Intensity Level 131 dB, Frequency 27.2 kHz).

The total germ number is minimal at the flow of 0.05 l/s, then increases once with the flow. The minimal values for Streptococci are obtained at lower flow then the one of 0.05 l/s, after that their number is increasing, which confirms the acoustic intensity is not sufficient for higher flow rate.

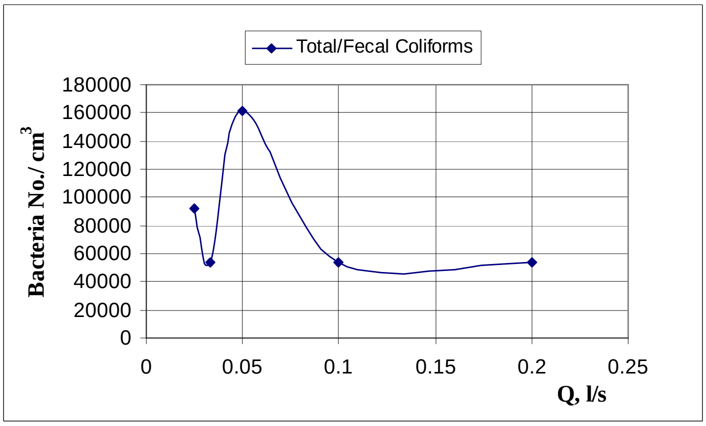

Fig. 6. Total Coliforms and Fecal Coliforms depending on the water volume flow (Sound Intensity Level 131 dB, Frequency 27.2 kHz).

In the Figure 6 is observed the minimum value in two areas corresponding to a low water flow (0.033l/s) and to a higher flow rate (0.1-0.15 l/s). The microbiological values are collected in Table 1.

Table 1. The experimental microbiological data for continuous sonic water treating regime.

Water flow rate, l/s	Total germs number/ml	Total Coliforms number/100ml	Fecal Coliforms number/100ml	Streptococci number /100ml
0.2	4300	54200	54200	1609
0.1	3100	54200	54200	700
0.05	2720	160900	160900	240
0.033	2900	54200	54200	240
0.025	4100	91800	91800	240

In order to understand the complex character of the results, it was determined the variation of pH and dissolved oxygen (DO) depending on the water flow, as presented in Figure 7.

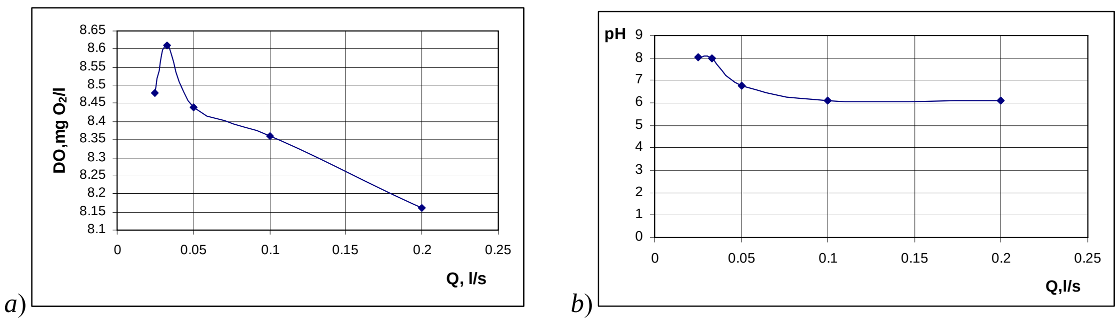

Fig. 7. The variation of dissolved oxygen (*a*) and pH (*b*) depending on the water flow at the sonic treatment (Sound Intensity Level 131 dB, Frequency 27.2 kHz).

The reduction of pH value with two units at the water flow higher than 0.05 l/s indicate that inside the sonic reactor appears the cavitation phenomenon [7], which leads to reduction of dissolved oxygen in water due to water degassing. The content of dissolved oxygen depends on the water temperature [8] an also on the balance between aeration and degassing in ultrasound field, which needs to be more investigated.

The behavior of the microorganisms is different under the influence of ultrasounds and cavitation. Thus, the streptococci and total germs are especially destroyed under ultrasound waves, during the total and fecal coliforms are resistant to ultrasound waves but are destroyed due to cavitational bubbles implosion (“hot spot” phenomenon) [3]. The water pH and dissolved oxygen values are presented in the Table 2.

Table 2. The water pH and dissolved oxygen values depending on the water flow rate.

Water flow rate Q, l/s	0.025	0.033	0.05	0.1	0.2
Water pH	8.02	7.99	6.94	6.11	6.11
Dissolved oxygen (DO)	8.48	8.61	8.44	8.36	8.16

3.2. The intermittent sonic treating regime

The microbiological water indicators was investigated depending on the working time of the generator at different values of the operation time ratio t_{rap}, which describes the generator operating conditions, which could be continuous or discontinuous [9]:

$$t_{rap} = \frac{t}{t_0}, \qquad (1)$$

where: t is the operation time and t_0 is the break time of a cycle.

To determine the optimal values for the depth h and the ratio of time t_{rap} have watched the following:

- 0 minutes operation, $t_{rap} = 0$;
- 5 minutes operation /15 minutes break, $t_{rap} = 0.33$;
- 10 minutes operation /10 minutes break, $t_{rap} = 1.0$;
- 20 minutes operation / 10 minute break, $t_{rap} = 2.0$.

The water flow rate was constant and its value is $Q = 0.9914$ m^3/h or $Q = 0.254$ m^3/s.

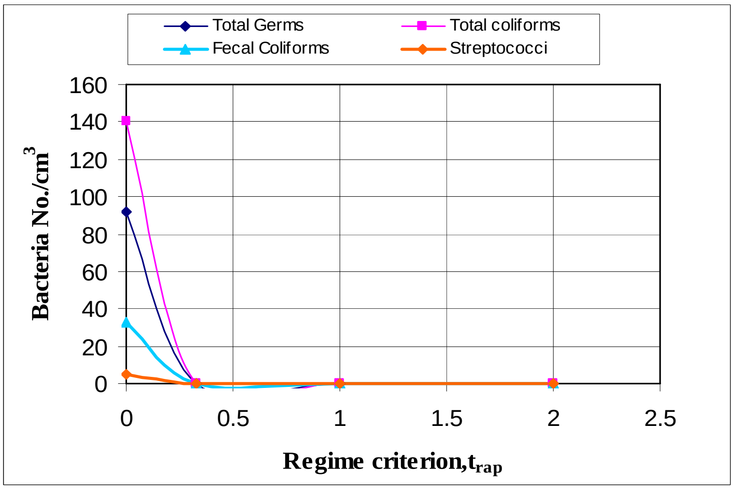

Fig. 8. The microbiological water indicators depending on the time ratio t_{rap} at the intermittent regime (Sound Intensity Level 112.32 dB, Frequency 21.52/10.76 kHz).

As shown in Figure 8, starting with the time ratio t_{rap}=0.33 (Table 3) the indicators concentration reach to zero, which allow us to choose the lowest duration of generator operating time - 5 minutes operation /15 minutes break.

Table 3. Experimental microbiological data for intermittent sonic water treating regime.

Treatment Regime	Regime Criterion t_{rap}	Total Germs Bacteria No./100ml	Total Coliforms Bacteria No./100ml	Fecal Coliforms Bacteria No./100ml	Streptococci Bacteria No./100ml
Initial data	0	92	140	33	5
5min/15 min	0.33	0	0	0	0
10min/10 min	1.0	0	0	0	0
20min/10 min	2.0	0	0	0	0

3.3. The criterion for sonomicrobiological water treatment

In order to include the results at different ultrasound generators and flow rate variation, considering the sonomicrobiological treating regime, we propose a criterion to determine the minimum energy required for a water unit volume to obtain the best result. This criterion is the ratio of acoustic intensity of ultrasound field and the water flow rate.

$$So = \frac{L \cdot t}{V} = \frac{L \cdot t}{Q(t + t_0)} = \frac{L \cdot t_{rap}}{Q(t_{rap} + 1)} \qquad [\frac{dB \cdot s}{l}] \tag{2}$$

where: L, [dB] – the acoustic intensity level of generator, t, [s] – generator's operation time, t_0, [s] - break time of a cycle, Q, [l/s]=Q x 10^{-3} m^3/s– water flow rate, V, [l] = Vx10^{-3} m^3– treated water volume, t_{rap} - time ratio.

The microbiological indicators variation depending on the sonic treatment criterion are shown in Figure 9 and the numerical values are presented in Table 4, where „initial” refers to the raw water bacteria number and „final” means bacteria number of the water after ultrasound treatment.

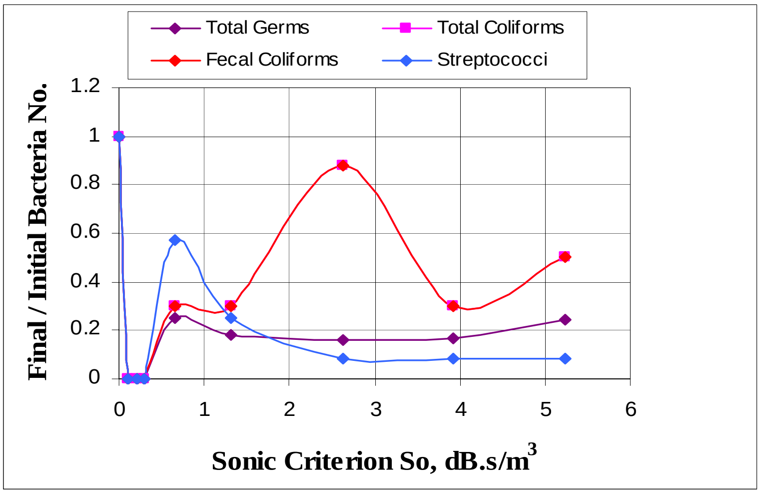

Fig. 9. The microbiological water indicators depending on the sonic criterion.

As shown in graphics, for higher values of S_0=0.295 dBs/m^3, occurs the increase of the bacteria number. The intensity increase is accompanied by increasing volume of working air introduced into the water during generator's operation that could influence the increasing of bacteria number.

Table 4. The sonic criterion values depending on the microbiological indicators.

Sonic Criterion, So $\left[\frac{dB\cdot s}{l}\right]$	Total Germs Final/Initial Bacteria No./ml	Total Coliforms Final/Initial Bacteria No./100ml	Fecal Coliforms Final/Initial Bacteria No./100ml	Streptococci Final/Initial Bacteria No./100ml
0	1	1	1	1
0.110	0	0	0	0
0.221	0	0	0	0
0.295	0	0	0	0
0.655	0.253	0.297	0.297	0.575
1.310	0.182	0.297	0.297	0.250
2.620	0.160	0.88	0.88	0.085
3.930	0.170	0.297	0.297	0.085
5.240	0.241	0.504	0.504	0.085

In order to understand the complex process that takes place must take into account that two processes occur simultaneously: cavitational degassing and aeration by bubbling. Also the volume of air introduced into the water is very high and represents the ratio 8:1 (the working air flow of the generator is of 5.29 m^3/h, the working time in the range of 5-40 seconds, the water volume treated of one liter).

The oscillations that are observed in graphics likely indicate the stress resistance of various bacteria, which must be studied further. The graph curves tend to stabilize (see the streptococci curve) that confirm a balance between aeration and degassing in the ultrasound field.

The results analysis allows setting the criterion value of the sonic treatment on which is obtained total water disinfection, namely:

$$S_0=0.11\div0.295\left[\frac{dB\cdot s}{l}\right] \tag{3}$$

4. CONCLUSIONS

The microbiological indicators of treated raw water by sonic technology with experimental sonic reactor were studied. The experimental installation for raw water treatment was performed on the Braila water treatment plant and contains: vertical sonic reactor with two types of air-jet ultrasound generators, the systems for raw water supply, for air pressure and for coagulant solutions-Al_2SO_4.

The air-jet ultrasound generators used in this installation were:

- the ultrasound whirlwind generator with two working frequencies (10.76 kHz and 21.520 kHz) and the overall sound intensity level of 112.32 dB;
- the air-jet stem generator (Figure 4) with frequency of 27.2 kHz and sound intensity level of 131.0 dB.

The research of sonic technology was made in a continuous and discontinuous operation regime. The microbiological indicators determined to assess the quality of water were total germ, streptococci number, total coli forms and fecal coli forms.

The behavior of the microorganisms is different under the influence of ultrasounds and cavitation. Thus, the streptococci and total germs are especially destroyed under ultrasound waves, during the total and fecal coliforms are resistant to ultrasound waves but are destroyed due to cavitational bubbles implosion (“hot spot” phenomenon).

A physical criterion So was introduced, which represents the ratio of acoustic intensity of ultrasound field and the water flow rate. The results analysis allows setting the criterion value on the sonic treatment on which is obtained total water disinfection.

The new raw water sonic treatment technology was developed that will eliminate a very harmful process that is chlorination for the drinking water plants. The advantage of the sonic reactor is that no antibacterial chemicals are required for drinking water. The sonic technology is an economic solution for water treatment and represents a new green technology. The disadvantage is the consumption of electrical energy for the compressor station, which compensates with the water aeration, which improves the water quality.

REFERENCES

[1] Trofin, P., Alimentări cu apă, Ed. Didactică şi Pedagogică, Bucureşti, 1983.

[2] Pîslăraşu, I., Rotaru, N., Teodorescu, M., Alimentări cu apă, Ed. Tehnică, Bucureşti, 1981.

[3] Iordache, I., Iordache, M., Sonochimia in epurarea energo-intensiva a apelor, Ed. Casa Cartii de Stiinta, Cluj Napoca, 2009.

[4] Stefan, A., Balan, G., The Microbiological Effect of the Water Sonic Treatment, The XXI-th SISOM-2010, The Annual Symposium of The Institute of Solid Mechanics and of The Commission of Acoustics, Bucharest, Romanian Academy, 2010, p. 277-282.

[5] Cirnu, C., Balan, G., Dumitras, P., The Sonic Settler For Drinking Water Treatment Plants, Rev. Meridian ingineresc, no.4, 2010, p. 48-55.

[6] Ştefan, A., Bălan, G., Efectul tratării sonice asupra microbiologiei apei de Dunăre, Meridian ingineresc, no.4, 2009, p. 36-41.

[7] Bălan, G., Pulverizarea gazodinamică a lichidelor, Conferinţa Naţională de Termotehnică cu participare internationala, editia a XIV-a, Lucrările Conferinţei, UTC, Bucureşti, 2004.

[8] Ştefan, A., Cercetări privind utilizarea generatoarelor sonice gazodinamice in procesele tehnologice de epurare a apei, Teza de doctorat, UDJG, Galaţi, 2010.

[9] Amza, Gh., Ultrasunetele. Aplicatii active, Ed. AGIR, Bucuresti, 2006.