Experimental Investigations of the Effectiveness of Acoustic Vibration Influence of Ultrasonic Frequency on Fogs

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Abstract: - Results of development of piezoelectric ultrasonic radiators (in form of flexural-vibrating titanium disks) for gas mediums are presented in this article. Results of investigations of usage efficiency of these radiators for fogs destruction are pointed. These radiators allow creating maximal level of sound pressure in range from 140 to 150 dB, in frequency range 27±2.0 kHz and ensure reducing a self-destruction time of fogs into aerosol chamber up to 11.5 times.

Keywords: - Acoustic vibrations, Fog, Radiators, Ultrasound

1. INTRODUCTION

Fogs are stable structures and in the constant natural conditions they evolve slowly [1, 2]. Fog dissipation in natural conditions occurs because of changes in the thermodynamic parameters of the environment (temperature, humidity, atmosphere pressure) and it can last from several hours to several days.

In order to improve weather conditions in the period of fog formation and to avoid low visibility fog can be influenced in different ways to speed up its dissipation [3]. Nowadays the methods of fog dissipation based on the application of special reagents for artificial vapor condensation are widely used [4–6].

However in spite of know-how of the practical application such methods have a number of disadvantages, which minimizes their efficiency:

– environmental deterioration;

– application for supercooled fogs;

– considerable consumption of resources.

All the advantages mentioned above caused the development of new methods of fog dissipation based on the energetic influence on the droplet dispersion.

One of the forward-looking ways of fog dissipation is the application of high-intensity acoustic vibrations (including ultrasonic ones) [6].

Unfortunately, all carried out investigations do not let design the equipment suitable for practical use of acoustic method of fog dissipation. It can be explained that all radiators of high-intensity vibrations were dynamic or static sirens providing energy conversion of compressed air flow into the air vibrations [7]. Such radiators have some disadvantages:

– poor efficiency (less than 20%);

– short life of mechanical components because of abrasive particles (working life is less than 100 h);

– use of powerful and expensive compressors (for the work of the whistle with the frequency of 2 kHz and the power of 2 kW it is necessary to use the compressor which costs $150);

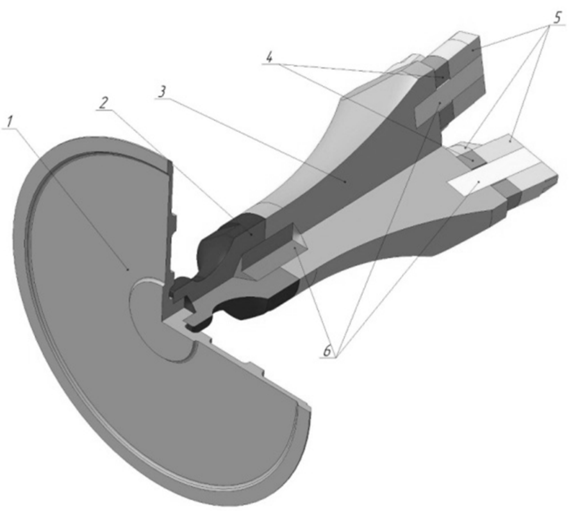
– low intensity of acoustic radiations on the frequencies of ultrasonic range. The jet-edge generator cannot produce vibrations with the power of more than 1…10 W and the frequency of more than 20 kHz (the nozzle diameter of jet-edge generator is less than 1 mm). Necessity of the formation of high-intensity vibrations (more than 135 dB) causes the application of radiators with nozzle diameter of 5…10 mm generating vibrations of low frequency (1…4 kHz). It makes impossible to use the acoustic method of fog dissipation in open space and in the presence of people and animals.

The absence of high-intensity radiators of ultrasonic vibrations does not allow investigating the influence of acoustic vibrations on fogs. In order to meet this lack and carry out the researches on the efficiency of acoustic influence on fogs in the ultrasonic frequency range the radiators in the form of flexural-vibrating disks were developed [6].

2. THE LABORATORY SETUP

Novelty of engineering solution is the use of piezoelectric ultrasonic vibrating systems with developed radiating surface of special form, which provides the energy transformation of longitudinal vibrations of piezoelectric transducer into flexural vibrations of titanium disks. The size and form of the disk are chosen according to the necessary frequency and radiation directivity of ultrasonic vibrations [7–9].

Basic scheme of the developed radiator is presented in Fig. 1.



1 – disk radiator; 2 – concentrator;
3 – transducer; 4 – piezoelectric elements;
5 – back reflecting cover plates; 6 – shrinking pins
Figure 1. Designed radiator

The radiator consists of a double-half-wave transducer (position 1-4), a concentrator (position 5) and a disk (position 6). The disk surface (position 6) is the source of ultrasonic vibrations. The flexural vibrations of the disk are excited by longitudinal vibrations generated by piezoelectric elements (position 2). Acoustic coupling inside the ultrasonic vibrating system is provided due to the fact that piezoelectric elements are pressed between the transducer (position 4) and back frequency-lowering cover plate (position 1) with force, which in many times exceeds the value of alternating force generated by piezoelectric elements.

Tightening force is provided by back frequency-lowering cover plate and pins (position 3). Special generators of electric vibrations of ultrasonic frequency are created for the power supply of the radiators [8, 10].

For the experiments four radiators varying in disk diameter and power of generated ultrasonic vibrations were designed and constructed. Performance specifications of the radiators (together with electronic power generators) are given in Table 1.

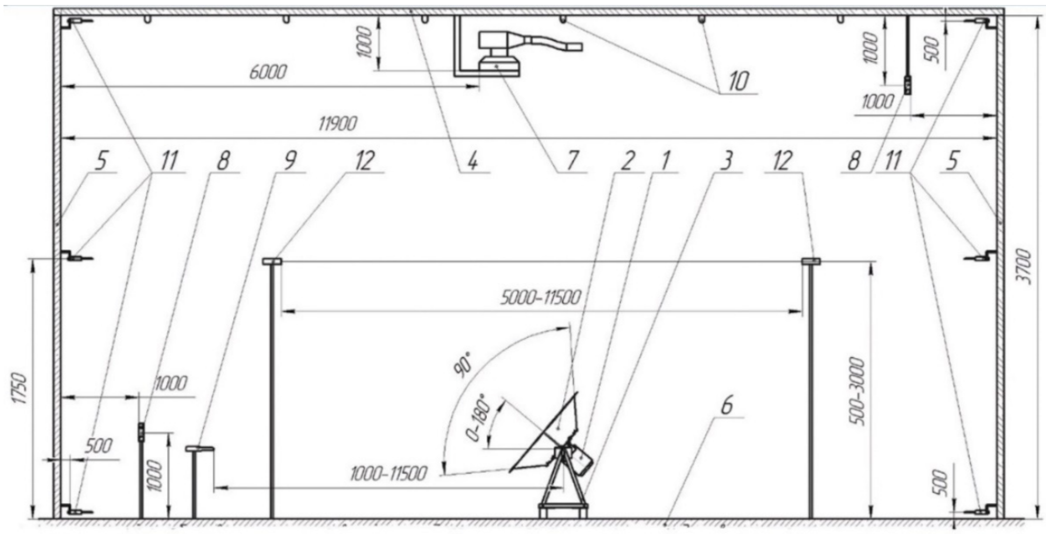
Table 1. Performance specifications of designed radiators

№	Parameter	Value
1	AC supply, V	220±22
2	Diameter of the radiator disk, mm	250; 320; 360; 420
3	Maximum consumed power, no more than VA	270; 270; 400; 600
4	Adjustment range of radiating power, %	10-100
5	Mass, kg, no more than	5
6	Sound pressure level at the distance of 1 m, dB, no less than	140; 144; 146; 150
7	Frequency of mechanical vibrations, kHz	27±2.0

To enlarge the emitting area (the use of radiation from the backside of the disk) the radiator was placed on the moving rotating platform and provided with the reflector of special form. The appearance of the radiator mounted on the moving platform is shown in Figure 2.

For carrying out researches of the effectiveness of fog dissipation by the influence of acoustic vibrations the laboratory setup was developed, it let observe studying process and record the changes of fog density and its disperse composition during the destruction. The appearance of laboratory setup is presented in Figure 3.

Figure 2. The photo of the radiator with the reflector



1 – ultrasonic vibrating system with disk-type radiator; 2 –reflector; 3 – rotating unit; 4 –upper covering of the chamber; 5 –side walls; 6 –basement of the chamber; 7 – ultrasonic atomizers; 8 –fans; 9 – microphone of the sound level meter; 10 – fluorescent lamps; 11 – resistance thermometers; 12 –optical sensor.

Figure 3. Draft of the laboratory setup

The base of the laboratory setup is aerosol chamber, which is technological room consisting of upper covering (position 4), side walls (position 5) and basement (6) on which rotating unit with the reflector and ultrasonic radiator are placed. Three ultrasonic atomizers (position 7) are mounted to the upper covering; they are intended for modeling of natural radiation fog and provided the formation of droplet dispersion with the average diameter of drops equals 5…20 μm. The application of ultrasonic atomizers lets form droplet dispersion which will be stable during long period of time enough for making the experiment [11]. For uniform filling of aerosol chamber the fan was placed (position 8). The volume of the aerosol chamber is 250 m^3.

For measuring parameters of sound pressure there is a microphone of the sound level meter (position 9). To measure temperature fields the resistance thermometers are placed inside the aerosol chamber (position 11). The resistance thermometers were connected to the personal computer through the matching device and analog-to-digital converter.

In order to obtain quantitative characteristics of effectiveness of acoustic influence the optical sensors were used (position 12). Measuring of transparency of droplet dispersion helps to determine quantitative indicator, liquid-water content, which characterizes fog. This indicator varied from thousandths up to 1.5–2 g/m^3 (from mist to dense fog).

3. RESULTS OF EXPERIMENTS

All the experiments carried out in the aerosol chamber were divided into three stages.

1. Investigating of evolution of disperse composition in the aerosol chamber during the acoustic influence and natural destruction of aerosol.
2. Determining of visibility range in the aerosol chamber with ultrasonic influence and without it.

3. Measuring of specific consumed power of the electronic generator.

To get reliable results the conditions of the experiments were constant (Table 2).

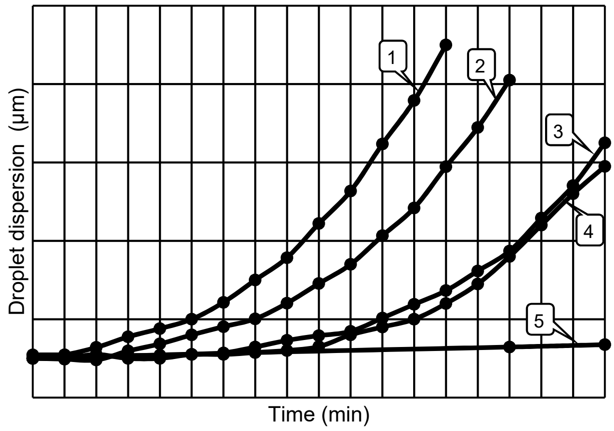
Table 2. The conditions of the experiments in the aerosol chamber

Parameter	Unit	Measured value
Height of the fog	m	4
Humidity	%	92
Stratification	degree/m	0.6
Average temperature in the chamber	degree	2.2
Speed of airflow moving	m/s	0.2
Pressure in the large aerosol chamber	Pa	10^5

For temperature measuring the temperature sensors (TSM 9417) were used located in the different parts of the aerosol chamber. Humidity was evaluated with the help of psychrometer (PBU-1) mounted in the center of the aerosol chamber at a height of 1500 mm. The pressure was measured by laboratory barometer LB-750. Speed of airflow moving inside the aerosol chamber was gauged with the help of anemometer LV 110. Starting height of droplet dispersion modeling fog equals to the height of the aerosol chamber (4000 mm). Visibility range was defined by measuring attenuation coefficient of laser radiation with the wave length of 0.63 μm according to the procedure described in [12]. Disperse composition of aerosol was evaluated by modified method of small-angle laser radiation scattering by aerosol drops [12].

At the first stage of the investigations the evolution of droplet dispersion composition during its natural destruction and at the influence of acoustic vibrations at the ultrasonic frequency was studied. For this purpose the volume of the aerosol chamber was cooled by the supply of airflow with the temperature of +2…+3 °C with relative humidity 90%. Aerosol atomizing took place in the central part of the chamber at the height of 4000 mm. In order to provide even filling of the chamber with droplet dispersion low-speed fans worked inside the chamber generating additional airflows with the speed of 0.2 m/s. The chamber was filled with dispersion to achieve initial visibility no more than 20 m. Further the sampling was carried out: each 15 min in the case of natural destruction of droplet dispersion and each 2 min at the influence of acoustic vibrations. The experiment lasted until the achievement of visibility, which equals 100 m.

In Figure 4 the relations, which characterize the changes of mean diameter of fog particles during its destruction, are presented.



1 – influence by the radiator with the diameter of 420 mm;
2 – influence by the radiator with the diameter of 360 mm;
3 – influence by the radiator with the diameter of 320 mm;
4 – influence by the radiator with the diameter of 250 mm;
5 – without acoustic influence

Figure 4. Relations of changes of droplet dispersion during its destruction

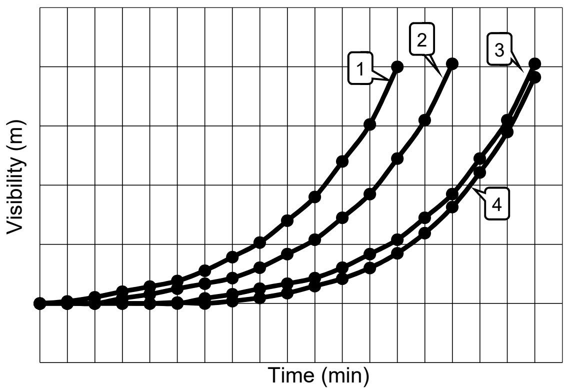
As it was to be expected at acoustic influence the mean drop diameter of the droplet dispersion became larger due to their coagulation. The more is the diameter of the radiator and higher level of sound pressure, the quicker process occurs.

During the test experiment without acoustic influence the time was maximal (36 min) but the evolution of disperse composition was not observed and visibility range did not increase.

The next stage of the investigations was to determine efficiency level of the influence of the created radiators on fog. As a measure of influence efficiency the most critical value (the setup time of needed visibility range (100 m)) was evaluated. As at the previous stage of the investigations the chamber was filled with droplet dispersion to reach initial visibility no more than 20 m. Acoustic influence lasted until the achievement of visibility, which equals 100 m.

First the check time of visibility range increase from 20 up to 100 meters during the natural destruction of droplet dispersion was defined. The measurements were carried out each 15 min. It was stated that the time of visibility range increase (up to 100 m) was 5 h.

In Figure 5 the diagrams of visibility changes in the aerosol chamber during ultrasonic influence by the radiators with different diameters are demonstrated.



1 – influence by the radiator with the diameter of 420 mm;
2 – influence by the radiator with the diameter of 360 mm;
3 – influence by the radiator with the diameter of 320 mm;
4 – influence by the radiator with the diameter of 250 mm.

Figure 5. Dependence of visibility range changes in the chamber on time (sampling was carried out each 2 min) during acoustic influence

Further investigations were focused on determining of dependence of dispersion destruction speed on the power of acoustic influence, which varied from 200 W to 600 W with the step of 50 W. Lower limit was fixed at 200 W, as if the consumed power was lower, effect from acoustic influence on the droplet dispersion was not evident. As a source of acoustic vibrations the radiator with 420 mm diameter and maximum consumed power (600 W) was used. The measurements were carried out with the help of measuring instrument of quality of electric energy MT-1010. Before the experiment the aerosol chamber was filled with droplet dispersion to reach initial visibility no more than 20 m. Acoustic influence lasted until the achievement of visibility, which equals 100 m. Obtained results are shown in Figure 6.

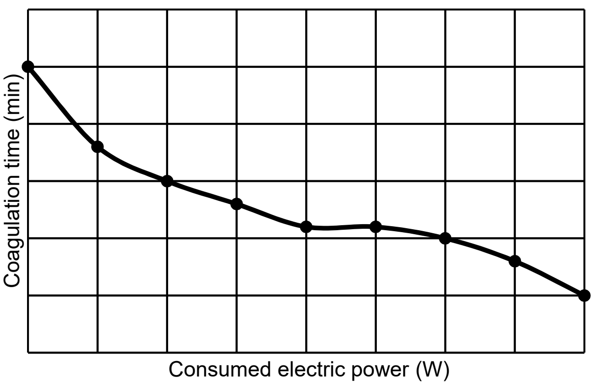


Figure 6. Dependence of destruction time of droplet dispersion in the aerosol chamber on power of acoustic influence

The obtained data let confirm that the application of high-powered ultrasonic radiators reduces the destruction time of droplet dispersion.

Last stage of researches carried out was to define specific electric power required for destruction of 1 m^3 droplet dispersion. The measurements were done during the operation of ultrasonic generator at maximum power. Calculation of specific power of the electronic generator was made according to the following expression:

$$p_{specific} = \frac{P_{eg}}{\mathrm{V}_{ac}}, \qquad (1)$$

where P_{eg} – power consumed by electronic generator, W; V_{ac}– volume of the aerosol chamber, m^3, equals 250 m^3.

In Table 3 the obtained results are presented.

Table 3. Power characteristics of acoustic radiators with different diameters

	Consumed power, W	Specific power, W/m^3
Disk radiator with the diameter of 250 mm	270	1.08
Disk radiator with the diameter of 320 mm	270	1.08
Disk radiator with the diameter of 360 mm	400	1.6
Disk radiator with the diameter of 420 mm	600	2.4

From the results it can be concluded that the most favorable according to the ratio energy cost/ time of influence is the radiator with diameter of 320 mm. However it should be mentioned that it can be applied only for small volumes of droplet dispersion (250 m^3). In real-life conditions of the use of radiators for radiation fog dissipation it is better to utilize the radiators with the diameter of 420 mm and more, as they have power reserve, which is enough for work in open space.

4. CONCLUSIONS

Thus after carried out researches following results were obtained.

1. It was demonstrated the efficiency of acoustic influence in the ultrasonic frequency range on droplet dispersion, it was also proved, that developed disk radiators were suitable for the destruction of natural fogs.

2. It was found out that designed radiators provided maximum level of sound pressure within 140...150 dB, at the frequency range of 27±2.0 kHz.

3. The time of natural destruction of droplet dispersion in the aerosol chamber was reduced by 11.5 times and the power consumption was no more than 2.4 W/m^3 and sound pressure level was 150 dB.

4. On the base of the obtained results it was stated that the application of high-powered radiators essentially cut down destruction time of droplet dispersion.

5. The obtained data has shown the necessity of creation and practical application of power ultrasonic radiators for increasing the efficiency of coagulation of droplet dispersion with different origin (including fogs) in open space.

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