Ultrasonic atomizers of nanomaterials

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***Annotation* – The article is devoted to the design of promising means of nanomaterial atomization. The construction of developed ultrasonic atomizers is described and the methods of their application are recommended.**

***Index terms* – ultrasonic atomizing, piezoelectric element, vibrating system.**

I. Introduction

THE ATOMIZATION OF MATERIALS for obtaining nanoparticles (cavitation damage of coatings), different granules and aerosols (atomizing drying of nanoparticles suspensions, aerosol atomization containing nanoparticles of medicines for disinfection of premises or introduction of medical substance in blood through lung alveoli), deposition of nanomaterials in the form of films and coatings (deposition of wear-resistant, energy-efficient, medicinial coatings) are widely used nowadays.

Necessity of fine-dispersed atomization and high requirements to the materials and products make demands to means and methods of practical atomization.

The advantages of this method are possibility of fine-dispersed and even atomization, monodisperion of obtained drops, possibility of fine-dispersed atomization of high-viscous materials containing nanoparticles without preliminary viscosity decrease with the help of solvents, no need in spray agent, low power-consuming and high efficiency of the process. All these facts promote its wide application at solving of different tasks in the sphere of nanotechnology [1,2].

II. The Created Designs of Ultrasonic Oscillatory Systems

For creation of models of ultrasonic equipment, which is able to realize all advantages of ultrasonic atomization in nanotechnologies, some projects, oriented on the investigation of atomization of different materials under various conditions and detection of optimum modes of ultrasonic influence at the formation of disperse systems with specified characteristics, have already been realized and are being carried out in the Biysk Technological Institute. These projects are supported both by the government (the researches are accomplished in the context of the federal project “Scientific and Research and Educational Staff of Innovation Russia”), Scientific Institutions (Moscow State University, Chernogolovka) and by the private clients such as Angioline and Sudo.

The developed ultrasonic atomizers are based on the method of high-production liquid atomization in liquid layer, which is located on the firm vibrating surface. Each ultrasonic atomizer consists of ultrasonic vibrating system such as sprayers with vibrating atomizing surface of special form, the electronic generator which is intended for power supply of vibrating system and the devices for liquid supply to the spraying surface.

All designed atomizers are divided into three main groups according to their field of application, necessary atomization capacity and viscosity of atomizing liquid:

– high-performance ultrasonic atomizers of low-frequency range (from 20 upto 44 kHz).

– high-frequency ultrasonic atomizing devices with average performance.

– low-frequency atomizers characterized with low productivity, but able to provide atomization of high-viscous materials.

Further each group will be described.

III. High-Performance Ultrasonic Atomizing Devices of Low Frequency Range

High-performance ultrasonic atomizing devices of low-frequency range (from 20 upto 44 kHz) are presented in Fig. 1.

Fig. 1 – High-performance ultrasonic atomizers of low-frequency range

Ultrasonic vibrating system of such atomizers is made according to Langevin transducer scheme [3], in which total wave length of frequency-reducing cover plates, two piezoelectric ring elements and operating cover plate – concentrator corresponds to half wave length of formed vibrations. The concentrator is made in the form of rod with stepwise variable diameter, the form and the size of steps is defined according to required value of amplification and the size of radiating surface. Designed half-wave construction arrangement helps to integrate quarter-wave piezoelectric resonance transducer and quarter-wave concentrator of mechanical ultrasonic vibrations having working ending, which has atomizing surface of specified area and form. The application of quarter-wave concentrator provides not only generation of ultrasonic vibrations but also their amplification upto values which are enough for atomization process [4].

To increase vibration amplitude of radiating surface it is possible to perform working cover plate in the form of the concentrator of quarter-wave length and all vibrating system will have the size, which equals to two half-wave lengths.

The size and the form of spraying surfaces are determined according to providing of specified atomization productivity, generation of the surface with defined slope angle of the conical surface of atomization to form spray and definition of number and location of holes for liquid supply to the atomization surface.

Changes in slope angle of the conical surface of atomization provides generation of the spray with specified form. In Fig. 2 the process of droplet detachment (i.e. atomization) from the liquid film covering conical surface of atomization is shown.

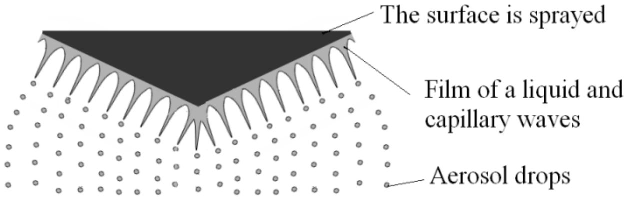

Fig. 2 – Generation of the spray

Formation of atomizing liquid drops takes place from the crest of the capillary waves generated by cavitation bubbles exploding on the atomizing surface. Capillary waves are always perpendicular to interface of media (in this case liquid-gas) and owing to their small size they are not exposed to gravitation forces. That is why droplet detachment during its atomization is perpendicular to atomization process and it does depend on its angle slope.

Dependence of spray decrease in regard to the diameter of atomization surface on the angle of the atomizer at any distance from the atomizer surface (e.g. $h = 0{,}8$ m) is shown in Fig. 3.

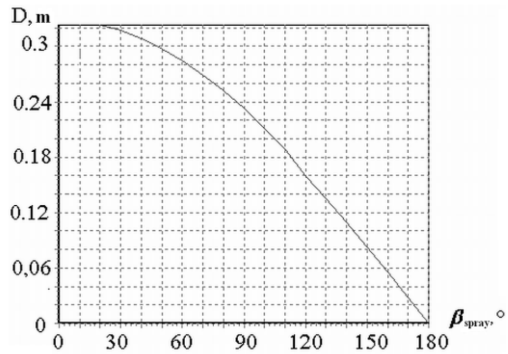

Fig. 3 – Dependence of diameter of torch of dispersion on spray corner

Arrangement place and the number of holes on atomizing surface is determined by providing its even covering by the layer of sprayed liquid. Liquid flowing from the hole upon the influence of ultrasonic vibrations is spread on the atomization surface and occupies some place, which depends on surface tension of liquid, the angle of the atomizer and ultrasonic vibration amplitude.

Thus if the area occupied by liquid after its spreading is insufficient (i.e. atomization surface is not covered by liquid), it is necessary to make additional holes for the supply of liquid.

To determine optimum sizes and forms of atomizing surface the procedure [5] is created; it allows to calculate all shape parameters of the atomization surface of the vibrating system, which are necessary for designing of the ultrasonic liquid atomizers generating spray of specified form. For practical use of designed atomizers and providing of maximum productivity of atomization measuring methods of main parameters of generating aerosol are developed.

Fig. 4 shows dependence of mean diameter of formed drops on operating frequency of the atomizer, the photo of generated spray and appearance of obtained drops.

The first group of the ultrasonic atomizing devices provides aerosol generation with the following characteristics: mean diameter of formed drops from 80 upto 30 μm is defined by operating frequency of the atomizer (from 22 upto 44 kHz); productivity of atomization is upto 15 ml/s (it is rated on the base of water), if viscosity of spraying liquid is upto 30 cSt. This group of the atomizers it is characterized by high efficiency, possibility to use changeable spraying tools of different forms and it lets to generate spray of any form.

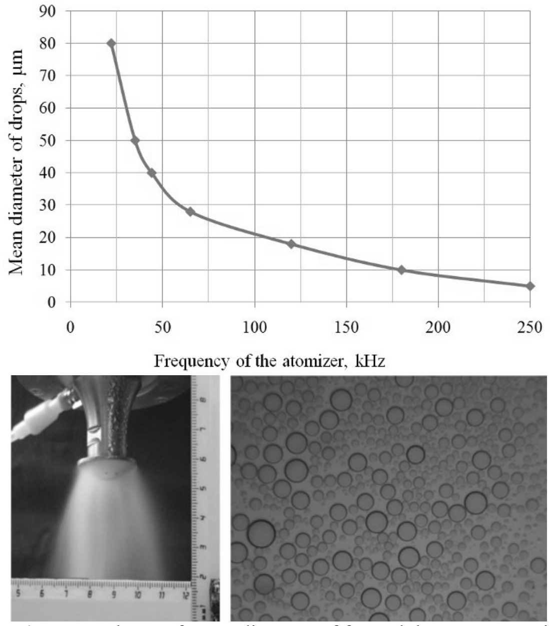

Fig. 4 – Dependence of mean diameter of formed drops on operating frequency of the atomizer

It is the most effective to use low-frequency atomizers for coatings containing nanoparticles and spray drying of nanomaterials.

Relatively big diameter of the particles of generating aerosol (30...80) μm is the main disadvantage of the atomizers of the first group, it restricts their application and requires further development and application of the atomizers, which are able to form aerosol with mean diameter of the particles less than 30 μm. Obvious way of further development of the ultrasonic atomizers is the increase of vibration frequency of the atomizing surface.

IV. High-Frequency Ultrasonic Atomizers Medium Productivity

The construction of such atomizers is shown in Fig. 5. The distinctive feature of them is that the thickness of each piezoelectric element equals a quater of wave length of vibrations formed in piezomaterial, i.e. total length of two piezoelectric elements corresponds to half of wave length. Thus two piezoelements are independent ultrasonic electroacoustic transducers, which provide generation of ultrasonic vibrations with necessary operating frequency.

In order to provide necessary compressing of two piezoelectric elements in the form of disks with the central hole metal pin and end tightening cover plate are used.

For the operation of all vibrating system at the resonance frequency of the piezoceramic elements resonance frequency of the end tightening cover plate should fit the frequency of the transducer. It can be achieved in a following way the thickness of the end tightening cover plate fits half of wave length of vibrations in the material of the cover plate, i.e. its resonance frequency conforms to the frequency of the transducer.

Longitudinal size of the concentrator fits the resonance frequency of the piezoelements, i.e. it is made equal one or two half-waves of vibrations generated in the material of the cover plate.

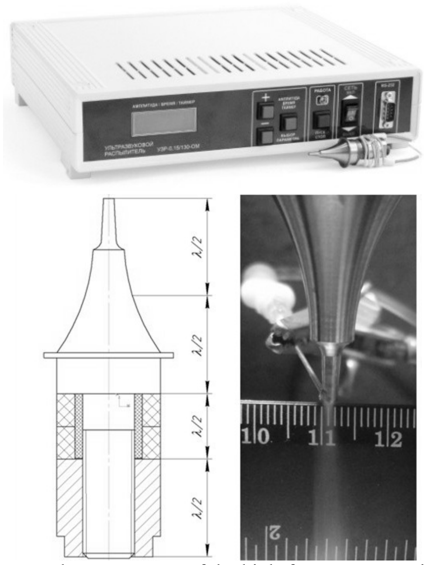

Fig. 5 – The appearance of the high-frequency atomizers

To reduce mechanical stress appearing in the place of the junctions the concentrator has smooth radial or exponential junctions in the middle of each half-wave area. Smooth junctions decrease the dependence of resonance frequency on load, that lets provide the operation of the vibrating system in optimum mode, i.e. always at resonance frequency.

The main advantage of the ultrasonic atomizing devices from this group is, that due to the usage of the piezoelectric elements, which are thicker it is possible to achieve their greater extension, i.e. to provide higher vibration amplitude at the same applying voltage. In turn it lets reduce its amplification coefficient for further amplification at the use of the concentrator excepting problems concerning with application of stepped junctions or it helps to obtain high amplitudes on the radiating surface providing atomization of viscous liquids. Thus the choice of the thickness of piezoceramic ring elements lets create the system with necessary frequency of atomization and provide required size of drops.

The second group of the ultrasonic atomizing devices provides generation of the aerosols with the following characteristics: operating frequency of such atomizers is in the range of 130 and 250 kHz; mean size of formed liquid drops is from 5 upto 15 μm. The productivity is no more than 0.5 ml/s, if viscosity of spray liquids is upto 10 cSt.

The main spheres of application of atomizers from the second group are precise coatings, e.g. coatings from antibiotics onto artificial cardiac vessels, obtaining of nanomaterials by spraying of starting materials.

Due to the use of high-frequency atomizers it is possible to obtain nanomaterials from the material of spraying surface of the atomizer due to its cavitation damage. Fig. 6 shows time dependence of quantity and form of nanoparticles generated by cavitation damage of titanium alloy.

To record particles the optic register in liquid with four channels: 30, 50, 100, 150 nm of the firm Particle measuring systems was used. It was found out, that at the initial stage of cavitation erosion the number of generated material was small and small and basically equiaxed particles were recorded. At the second stationary stage of cavitaion damage the particles, which were in two and more times bigger than the ones generated at the first stage, were formed. At the same time the number of "fine" particles decreased (see Fig. 6). Generated nanoparticles were enclosed into the drops of atomizing liquid, that lets realize effective encapsulation of nanomaterials by the others.

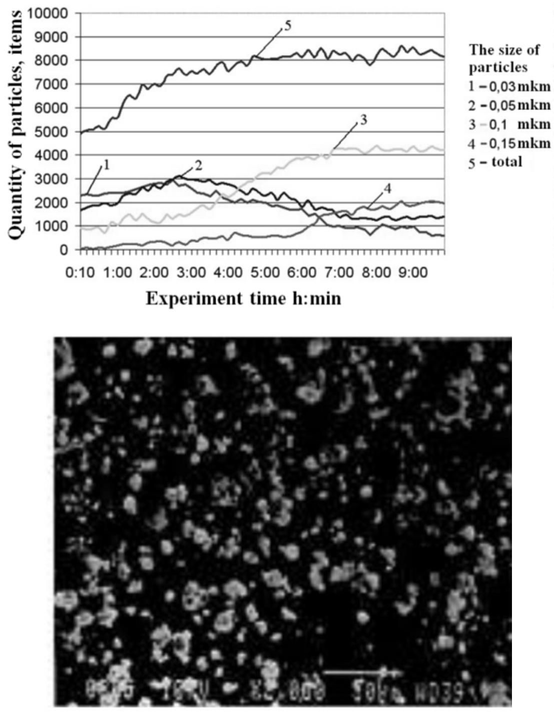

Fig. 6 – Dependence of quantity on the duration of ultrasonic influence and form of generated particles

The disadvantages of these atomizers are low productivity of atomization and impossibility of using them for spraying of high-viscosity liquids.

There is a necessity to design new group of the atomizers, which are able to combine the advantages of the atomizers of both groups providing possibility of fine-dispersed atomization of high-viscosity liquids.

V. LOW-FREQUENCY ATOMIZERS, WHICH CHARACTERIZED BY LOW PRODUCTIVITY, BUT ABLE TO PROVIDE ATOMIZATION OF HIGH-VISCOSITY MATERIALS

The appearance of such equipment is shown in Fig. 7. In Fig. 7: 1 – atomizing chamber; 2 – internal volume of the atomizing chamber; 3 – atomizing needle; 4 – channels for supply of atomized liquid and carrier gas; 5 – concentrator; 6 – piezoelements; 7 – reflected cover plate.

The atomizer has an ultrasonic vibrating system, an electronic generator of ultrasonic frequency for power supply of the ultrasonic vibrating system, a system, which supplies and regulates consumption of atomizing liquid, compressor with the pressure regulator providing stable air flow for supply of aerosol from the internal atomizing chamber to the working ending of atomizing needle.

The operation of described group is based on the principle of “double” atomization. Sprayed liquid is supplied to the atomizing chamber, which is influenced by vibrations of ultrasonic frequency, and it is sprayed from vibrating surface of the bottom and walls of the chamber. Generated as a result of initial atomization aerosol is carried by air flow from the chamber through the internal channel of atomizing needle, which is mechanically joined with the wall of vibrating chamber and makes complicated flexural-bending vibrations in the free needle ending with maximum amplitude. In the internal walls of atomizing needle and on its free ending (crosscut end) secondary atomization of particles takes place. The secondary atomization of aerosol drops leads to the reduction of mean size of the aerosol. Moreover application of thin atomizing tubes lets form directed flow of aerosol.

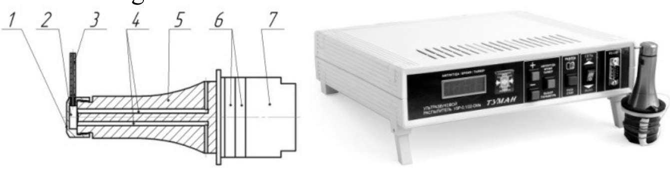

Fig. 7 – Ultrasonic atomizers of high-viscosity liquids

The distinctive feature of such vibrating system is the presence of two channels: the first is intended for supply of sprayed liquid and the second one – for supply of carrier gas. The introduction of atomized liquid and carrier gas is realized at minimum vibrations of the system and that is why it does not influence on the productivity and parameters of the system. The exit of the channels to vibrating surface in the internal volume of the atomizing chamber provides initial atomization. Small volume of the atomizing chamber excludes coagulation of initial aerosol and provides its supply into atomizing needle, which is fastened in the wall of the atomizing chamber [6].

Air flow guarantees the supply of the initial aerosol generated in the atomizing chamber to the internal walls and crosscut end of atomizing needle for aerosol carring.

Developed construction lets achieve following characteristics of the atomization: frequency range is from 20 to 60 kHz; maximum productivity is 0.02 ml/s; mean diameter of generated drops is from 10 to 20 μm.

This equipment is intended for atomization of viscous and high-viscosity (upto 60 cSt) liquids and nanomaterials, for example for spectral investigation of their composition.

Application of double atomization provides obtaining of particles of high-viscosity liquids, which corresponds in size to ones of high-frequency atomization.

VI. CONCLUSION

Thus, developed ultrasonic atomizers of different functional groups and different purposes can help to solve many technological problems nowadays, and in future they will be operating tools of modern nanoindustry providing effective generation of new materials and their practical application.

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