

Innovative Research of Ultra-Jet Dispersion and Suspension Technologies for Processing and Modifying Liquids

Kyaw Myo Htet, M.P. Glotova, A.L. Galinovsky*

Bauman Moscow State Technical University, building 1, 5 Baumanskaya 2-ya, Moscow, 105005, Russia

* Corresponding author. Tel.: +7 499 263 65 96. E-mail address: galcomputer@mail.ru

Abstract

Currently used dispersion methods are not able to provide sufficient dispersion of nanomodifiers in liquids. This circumstance significantly reduces the effectiveness of the subsequent use of liquid-phase nanomodifiers which are widely used in the production of a variety of composite polymer and ceramic structures. The article discusses a new method of dispersing and suspending liquids using ultra-jet technology. The results of experimental testing confirming the effectiveness of ultra-jet technologies for producing liquid suspensions with nanomodifiers are presented. Two different types of powder were chosen as liquid modifiers: boehmite and carbon nanotubes. Moreover, special technological equipment was developed to conduct the experiment. The results of the analysis of the obtained liquid suspensions containing nanomodifiers allow us to recommend this dispersion technology for use on an industrial scale.

Keywords

Liquid; ultra-jet technology; suspension; dispersion; target.

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Introduction

Suspensions are a two-phase homogeneous hydrostructure consisting of a liquid (colloidal solution, gel, etc.) and fine solid particles that are suspended under normal conditions. Most hydrotechnological media, including ordinary water, can be considered as specific ultrafine-dispersed suspensions with a very low concentration of solid-phase particles. The presence of solid particles of a certain composition, number, concentration, shape, size and other physicochemical parameters in a liquid can significantly change the initial properties of the liquid (matrix) and filler – the particles themselves, for example, due to the manifestation of various boundary effects. In this sense, a suspension is a liquid-solid-phase quasi-equilibrium system that has all the features of a classical composite material: the implementation of the principles of synergy, as well as structural and physicochemical heterogeneity, etc. [1–3].

The dispersion method is based on grinding the initial solid-phase material (materials) to a given degree of dispersion. This process can be carried out both directly in the liquid to be suspended, or as a separate technological operation for obtaining a fine powder,

which is then introduced into the initial liquid. The dominant physical and technological process in the dispersion production of suspensions is the controlled multiple, parallel-sequential fractionation (destruction) of the solid-phase filler of the suspension to a finely dispersed state. This process is characterized by a sharp increase in the specific surface energy of the formed solid particles, changes in the initial dislocation structure of the filler, etc., which leads to a certain activation of the resulting suspension as a whole [4–5].

Most dispersion methods are based on mechanical destruction (grinding, dispersing) of the solid-phase material of the suspension filler. However, other specific methods of dispersing a solid-phase filler can be proposed: evaporation of a solid-state target by a laser beam under a layer of a transparent liquid, implementation of the dispersion process by means of an electrohydraulic discharge, etc. Among the known methods of mechano-physical dispersion, the traditional ultrasonic method and its various modifications should be distinguished as a fairly universal and technologically multifunctional option for obtaining suspensions of various degrees of dispersion, including ultrafine ones (Fig. 1).

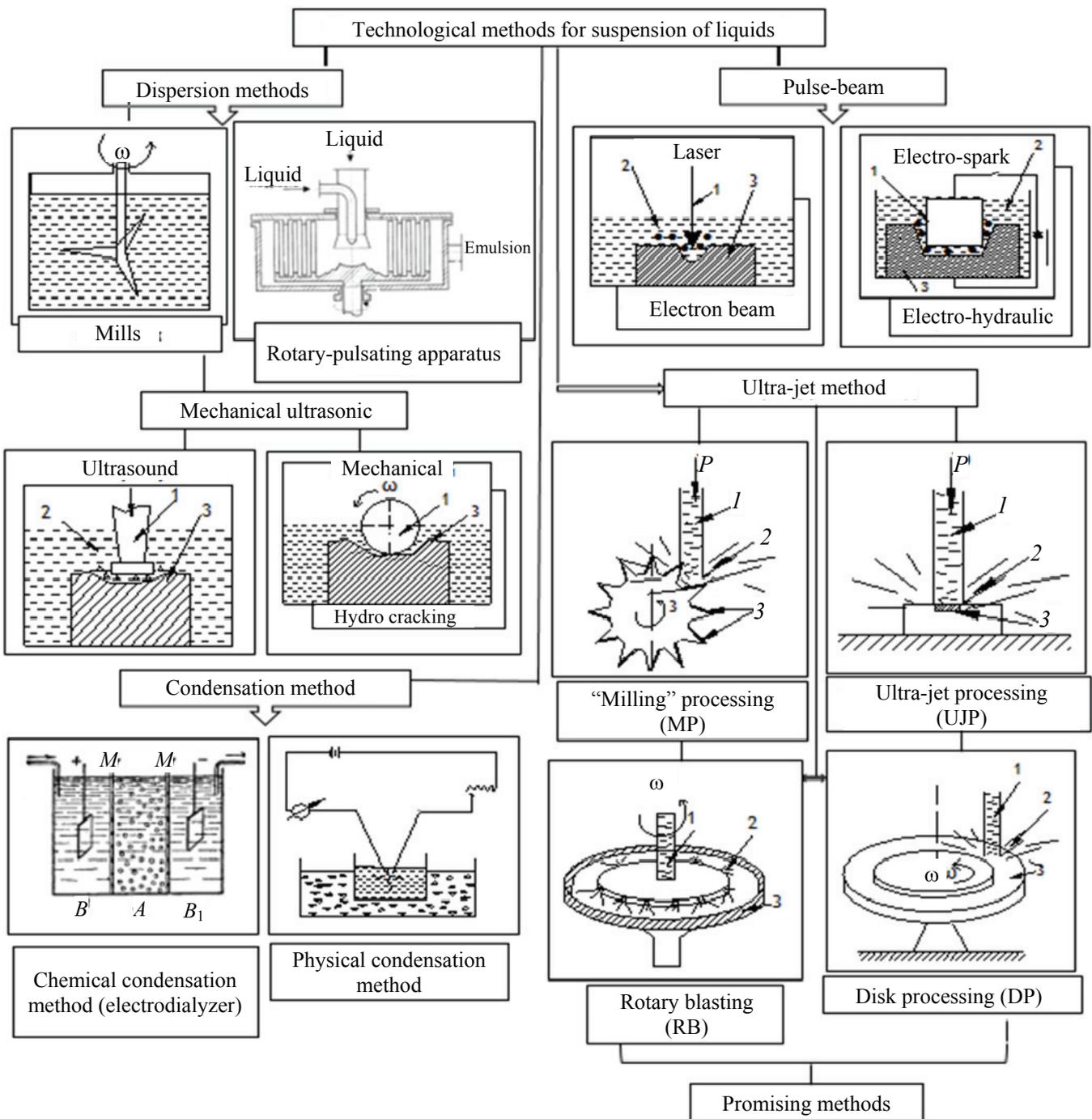


Fig. 1. Main commonly used suspension methods

Experimental studies for dispersion

The purpose of this work is to develop a new method for dispersing and suspending liquids for their modification using ultra-jet technologies.

It is known that dispersion and deagglomeration effects are associated with cavitation which is the result of the action of ultrasonic waves on the processed liquid-phase material – suspension. When treating suspensions with ultrasound, sound waves that

propagate in the liquid lead to alternating high and low pressure cycles. In this case, the mechanical stress acts on the attractive electrostatic forces between the individual particles. Ultrasonic cavitation in liquids causes the formation of microjets in liquids with a high speed of up to 1000 km/h (approximately 600 m/h). Such microjets act on liquid and particles separating them from each other. Some particles are accelerated along with liquid microjets and collide with each other

at high speeds, which also leads to deagglomeration. This makes ultrasound an effective means for dispersing, as well as for grinding micron and submicron particles [6].

According to [4], to prepare a mixture for ultrasonic treatment, 0.3 g of nanopowders mixed with 10 ml of water in a cup placed under an ultrasonic treatment machine in the laboratory hall of the SM-12 department of the Bauman Moscow State Technical University were used (Fig. 2).

But, nevertheless, the method has a number of disadvantages. This is, first of all, an increase in the liquid temperature during ultrasonic treatment which negatively affects a number of processed materials prone to polymerization. This limits the possibilities of the method and raises the question of creating new, more efficient processing technologies. In other words, in a number of cases, there is an urgent need to create new effective technological means for deagglomeration and dispersion of nano-containing suspensions. This would make it possible to realize the full potential of nanoscale structures in matters of their application in the creating new materials with new special properties, first of all, polymer composite materials [4, 7–9].

Thus, at the next stage of research, the possibilities of ultra-jet treatment of suspensions were studied. The research was based on the methodological base which was formed within the framework of the scientific school “Ultra-jet processing and diagnostics of materials and liquids” (NSh-3778.2018.8) at the department SM-12 of the Bauman Moscow State Technical University [10–15]. It should be noted that

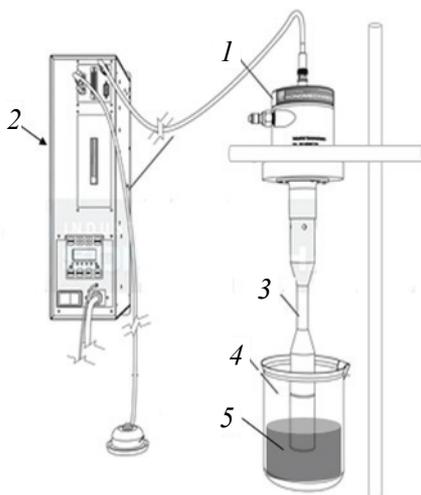


Fig. 2. A set-up of a dispersion process diagram for ultrasonic treatment:

- 1 – unit body; 2 – ultrasonic generator;
- 3 – ultrasonic waveguide; 4 – suspension glass;
- 5 – nano-containing suspension

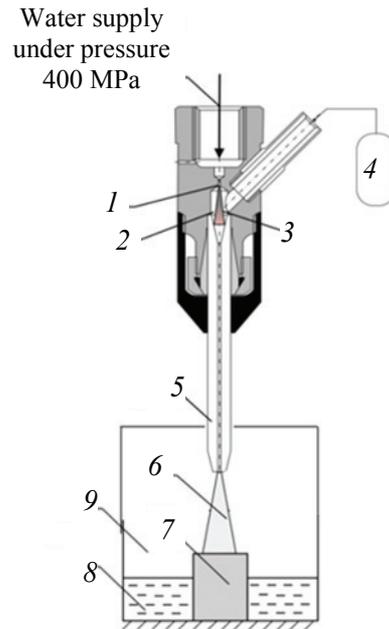


Fig. 3. A schematic diagram of ultra-jet dispersion of nano-containing suspensions:

- 1 – jet-forming hydraulic nozzle; 2 – mixing chamber; 3 – high-speed liquid jet; 4 – capacity for premix (nano-containing suspension); 5 – focusing tube; 6 – high-speed jet of suspension; 7 – target made of synthetic diamond; 8 – processed suspension; 9 – trap tank for collecting the suspension

the works by V.S. Puzakov show that the effects of liquids activation after ultra-jetting can also be associated with the presence of the ultra-jet and the obstacle of ultrasonic vibrations and cavitation processes in the interaction zone [6].

Fig. 3 shows the Flow Waterjet hydraulic unit used in the experiment with a high-pressure (up to 400 MPa) multiplier type system, as well as a schematic diagram of ultra-jet dispersion of suspensions [7].

During the experimental development of the ultra-jet technology, the nano-containing suspensions were subjected to treatment – dispersion according to the scheme presented in Fig. 2. Suspensions based on distilled water with boehmite (produced by the research institute of impulse processes with pilot production “OHP NII IP with OP”, Minsk, Belarus) and carbon nanotubes (Arquema, France) were fed into the mixing chamber 2 of the ultra-jet unit using a special measuring dispenser 4. The suspension acceleration was ~800 m/s which corresponds to the maximum working pressure in the hydraulic system of 400 MPa. Earlier it was found that the ultra-jet speed determines the efficiency of liquid treatment [16–20]. Specially designed technological equipment was used as a container 9 (Fig. 4). The target is a synthetic diamond fixed in a mandrel, which, in turn, is fixed in the tube of the container lid using screws 4 (Fig. 4).

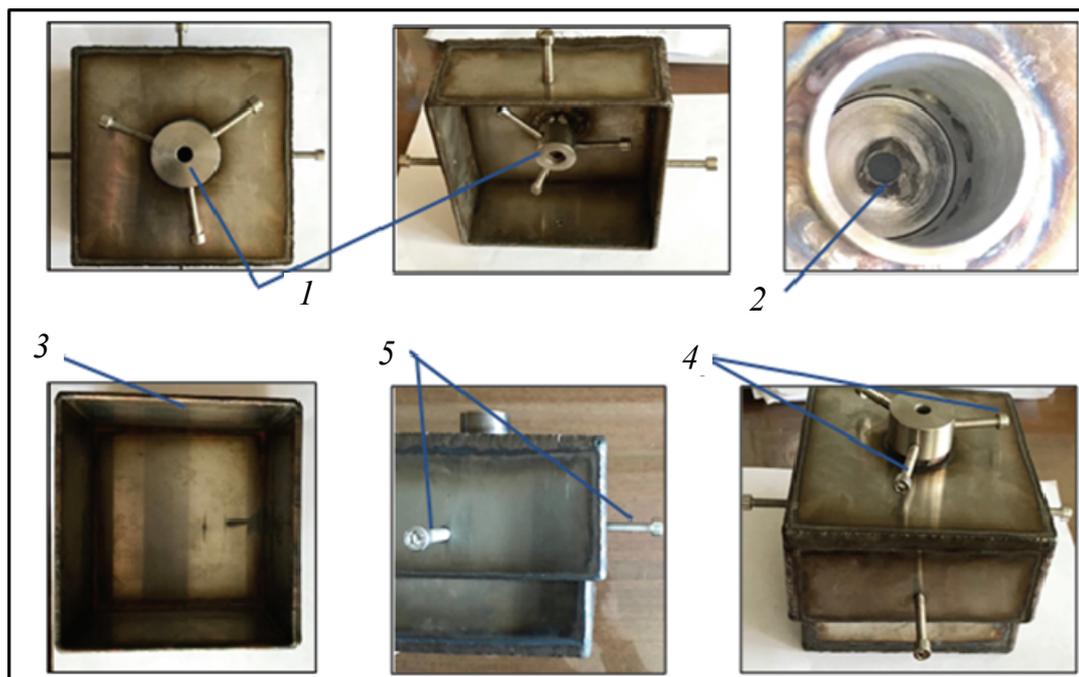


Fig. 4. Technological equipment for dispersing micro and nanosuspensions:

1 – branch pipe for installing a focusing tube; 2 – cylindrical target with a diamond single crystal fixed in it; 3 – tank for collecting the suspension (the tank bottom); 4 – screws – an element for fixing the top cover to the bottom of the container for collecting the suspension; 5 – screws – a target fixing element

Table 1

Characteristics of samples of initial nanomaterials used for the preparation of suspensions and their further dispersion

Composition	Technological and operational characteristics of the powder
Al (OOH) “Boehmite”	<ul style="list-style-type: none"> – Mass fraction of the main substance, not less than 99 %; – Specific surface according to the BET method, up to 400 m²/g; – Pycnometric true density, 3.06 g/cm³; – The size of individual particles, 0.1 – 0.8 nm
Carbon nanotubes	<ul style="list-style-type: none"> – Outer diameter: 10 – 20 nm; – Tube length: more than 2 microns; – Specific surface by BET method: > 300 m²/g; – Content of impurities no more than 1 %

The characteristics of the studied samples of nanomaterials are presented in Table 1.

After the ultra-jetting procedure, the treated nano-containing suspensions were studied using a MicrotracBluewave laser particle size analyzer (Microtrac S3500) operating on the tri-laser technology



Fig. 5. A Microtrac S3500 Laser Particle Analyzer

shown in Fig. 5. The laser particle size analyzer (diagnosed size range – from 0.01 to 2816 microns) allows to distribute particles by size in suspensions, emulsions, powders using the method of laser granulometry.

The analysis results were the average particle sizes in terms of quantitative and volumetric distributions, as well as the minimum recorded particle size in the samples.

The measurement results, which are histograms of the quantitative distribution of the average particle size, are shown in Figs. 6–8 in the initial state, after ultrasonic and ultra-jet treatment, respectively.

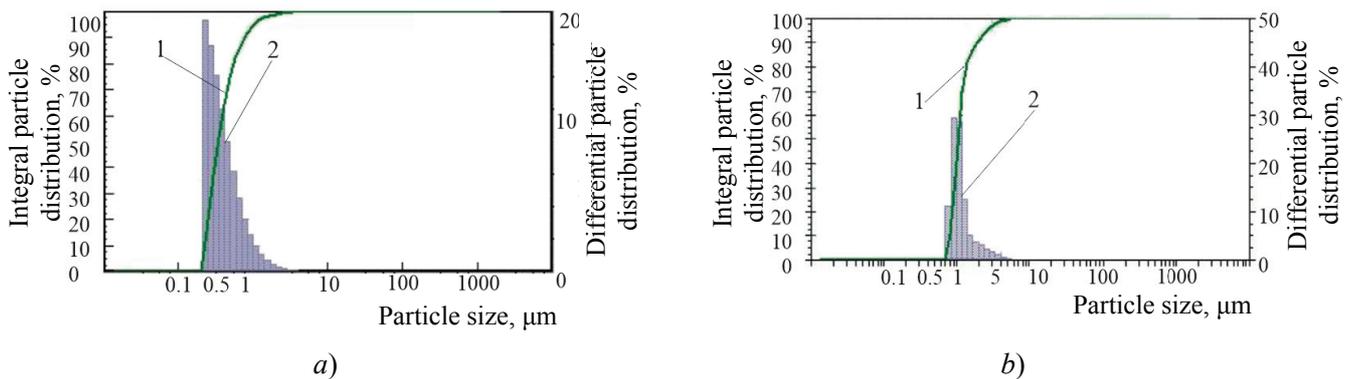


Fig. 6. Quantitative distribution of the average particle size of the original samples:

a – boehmite AL(OOH); *b* – carbon nanotubes

1 – integral particle distribution; 2 – differential particle distribution

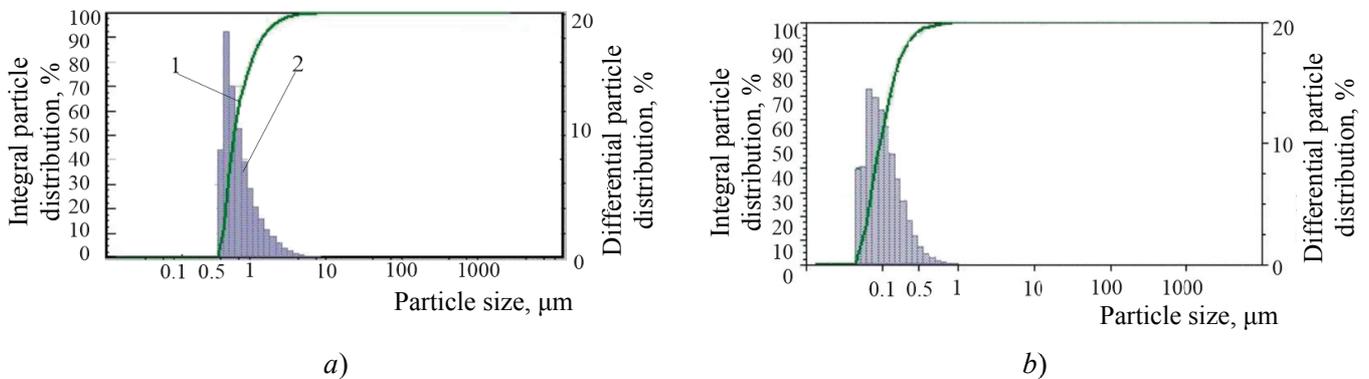


Fig. 7. Graphs of the average particle size values by quantitative distribution for samples after ultrasonic exposure

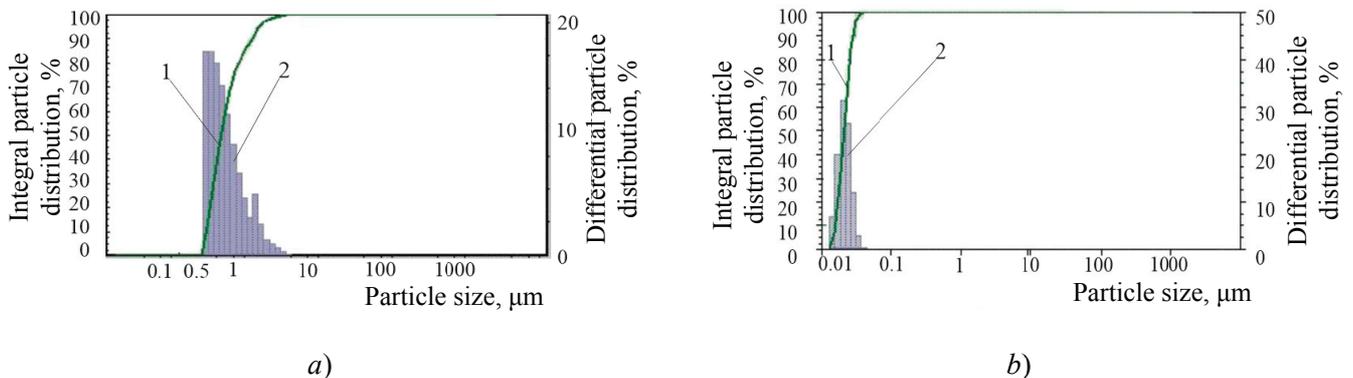


Fig. 8. Graphs of the average particle size values by quantitative distribution for samples after ultra-jet exposure

Experimental studies for suspension

Then, the materials for suspension were selected: pure silver (Ag – 999.9) and electrolytic copper (Cu-ETP) of high purity (99.95 %).

The main technological parameters (Fig. 9) and informative data on ultra-jet suspension are presented in Table 2. The movement of the nozzle head over the sample surface was carried out along the Archimedes spiral; the length of the trajectory was 575 mm. This made it possible to ensure the uniformity of

removal of the surface layer of the target material (sample) in comparison with a point effect on the surface and circular motions of a small radius, which can be seen in Fig. 10.

Based on the dataanalysis of the cause-effect diagram, the experiments were carried out at two pressures in the hydraulic system, 200 and 350 MPa, at a feed rate of 2 mm/s and a distance from the focusing tube cut to the sample surface of 2 mm, the operating time of the setup $t = 4$ min (Table 2).



a) b)

Fig. 9. Technological equipment for obtaining and collecting suspension:

a – securing the specimen in the tooling;
 b – the process of alignment of the ultra-jet hydraulic nozzle with the hole in the disk of the upper cover of the tank for collecting the suspension

At the next stage of experiments using a particle analyzer, the following was determined: the mass concentration of ultra-jet suspensions; the shape, size and distribution of solid phase particles formed during the hydrodispersion of targets. The distribution of particles of the materials under consideration by size in the investigated volume of the suspension was determined (Table 3).

Table 2

Results of experimental studies on the suspension production

Target material: Copper (Cu)		
Pressure <i>P</i> , MPa	200	350
Target weight before processing <i>m</i> , g..	138.67	139.04
Target mass after processing <i>m</i> ₁ , g	138.63	138.67
Suspension temperature, °C	54.0	73.0
Diameter of the material removed from the target, mm	18	18
Jet speed at the nozzle exit, m/s	447	592
Working fluid consumption, l/min	4.7	6.3
Power, kW	45	60
Mass of the carried material, g	0.040	0.460
Target material: Silver (Ag)		
Target weight before processing <i>m</i> , g..	69.62	72.29
Target mass after processing <i>m</i> ₁ , g	69.38	69.62
Suspension temperature, °C	55.6	78.4
Jet speed at the nozzle exit, m/s	447	592
Working fluid consumption, l/min	4.7	6.3
Power, kW	45	60
Mass of the carried material, g	0.240	2.670

Table 3

Analysis results of the geometric parameters of the microparticles of the material after ultra-jet hydraulic action on them

Size Number over, μm ²	up to, μm ²	Number of particles, %		Average area in the considered range, μm ²
<i>Target material – Silver</i>				
0	9000	69	89,60	2184
9000	18000	6	7,80	12974
18000	27000	0	–	–
27000	36000	1	1,30	28608
36000	45000	1	1,30	41418
<i>Target material – Copper</i>				
0	2500	136	85,50	816
2500	5000	17	10,50	3556
5000	7500	4	2,48	5363
7500	10000	0	–	–
10000	12500	1	0,62	11962
12500	15000	3	1,90	13117

The following main conclusions were drawn from the results of the experiments on ultra-jet suspension.

1. Changes in technological conditions and modes of ultra-jet suspension significantly affect the mass concentration of the final product. In particular, it was found that ultra-jet suspension at high pressure (350–400 MPa) of the hydraulic system by an order of magnitude increases the concentration of target materials in the liquid, which was also revealed when using “soft” targets (Cu, Ag) instead of steel plates St45 (Fig. 10).

2. The shape, size and development of the particle surface significantly depends on the physical and mechanical characteristics of the sample material.

3. The fractional composition of the solid phase of suspensions obtained by ultra-jet technology is very different, which obviously can affect their functional properties.

Considering the results of previous studies [21–23], it can be assumed that the broad capabilities of ultra-jet suspension technologies for varying the input and output processing parameters will allow a very flexible approach to solving a wide variety of specific problems, such as, for example, increasing the physicochemical activity of the suspension, low temperature sterilization,, changes in pH, changes in microbiological and other vitological properties, etc.

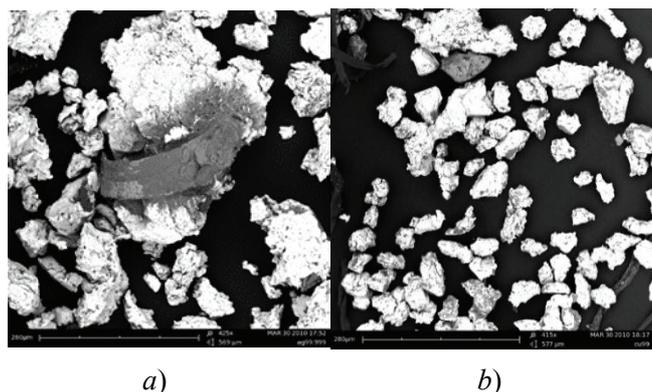


Fig. 10. Images of microparticles of target materials after hydroerosion of their surface as a result of ultra-jet:

a – an image of silver microparticles at 425× magnification;
b – an image of copper microparticles at 415× magnification

Conclusion

A comparative analysis of the obtained particle size distributions of the studied suspension samples with their initial distributions showed that the ultra-jet treatment method can be used in practice and is quite effective.

Experimental studies for suspension and analysis of the results obtained showed that, in general, we can talk about the possibility of using ultra-jet technologies to obtain suspensions. This technology has a number of advantages and has a number of fundamental differences, in particular, in contrast to others, it is based on a powerful shock-dynamic effect that ultrasound has on a solid-state target. The power density of the ultra-jet is comparable to that of industrial lasers for this indicator. Moreover, it was previously proven that the high-speed action of an ultra-jet has an effect on the properties of liquids.

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