Homogenization of nanocontaining suspensions using ultra-jet methods

Kyaw Myo Htet 1,4 and A L Galinovskiy2,3

1 PhD. SM-12, Bauman Moscow State Technical University, Moscow, 105005, Russia

2 D. Sc, Prof, Head of department of SM-12, Bauman Moscow State Technical University, 105005, Russia

E-mail: 3galcomputer@mail.ru, 4htet2066@gamil.com

Abstract. The article discusses the preparation of suspension and dispersion of liquids using ultra-jet technology. The applied method allows for a sufficiently high level of suspension and dispersion.

Keywords: liquid, ultra-jet technology, suspension, target, dispersion

1. Introduction
Dispersion is a system in which distributed particles of one material are dispersed in a continuous phase of another material. The two phases may be in the same or different states of matter. Most dispersion methods are based on mechanical destruction (grinding, dispersion) of the solid-phase material of the suspension filler [1]. Suspensions are a two-phase fairly homogeneous hydrostructure, consisting of a liquid (colloidal solution, gel, etc.) and finely divided solid particles that are under normal conditions in suspension. Most hydrotechnological media, including ordinary water, can be considered as specific ultrafine suspensions with a very low concentration of solid-phase particles [2].

2. Experimental studies for dispersion and suspension for processing and modifying liquids
According to [3] for dispersion, to prepare a mixture for ultrasonic treatment, 3 g of nanopowders (Boehmite and nanodiamonds) mixed with 1 litre of water in a cup and measured with the Microtrac Bluewave S3500, where in the laboratory hall of the SM-12 department of BMSTU in Moscow. The characteristics of boehmite was mass fraction of the main substance 99%, specific surface according to the BET method 400 m2/g, density 3.06 g/cm3, size of particles, 0.1-0.8 nm and took from Research Institute of Pulse Processes with Experimental Production "OCP NII IP with OP", Minsk, Belarus. The characteristics of nanodiamonds were external diameter 10-20 nm, tube length 2 microns, specific surface according to the BET method 300 m2/g, content of impurities not more than 1% and took from Arkema (France).
Figure 1. Scheme of ultrasonic treatment: 1 - body, 2 - ultrasonic generator, 3 - ultrasonic waveguide, 4 - glass for suspension, 5 - nano-containing suspension.

At the next stage of research, the possibilities of the method of ultra-jet treatment of suspensions were studied. Figure 2 presents the experimentally schematic diagram of ultra-jet dispersion of suspensions [4]. The studies were based on the methodological base, which was formed in the framework of the scientific school “Ultrajet processing and diagnostics of materials and liquids” (NSh-3778.2018.8) at the Department of SM-12 of BMSTU [5, 6].

Figure 2. Schematic diagram of ultra-jet dispersion of nanosuspension suspensions: 1 - hydraulic nozzle; 2 - mixing chamber; 3 - high-speed liquid stream; 4 - container for suspension with nanomaterials; 5 - focusing tube; 6 - high-speed jet of suspension; 7 - target made of synthetic diamond; 8 - processed suspension; 9 - container-trap for collecting suspension.

In the process of experimental development of ultra-jet technology, nanosized suspensions were subjected to processing - dispersion according to the scheme of Fig. 2. Suspensions based on distilled water with boehmite, carbon nanotubes were fed into the mixing chamber, ultra-jet installation using a special measuring dispenser presented to the Fig 2. Acceleration of the suspension was 600 m/s, which corresponds to a maximum working pressure in the hydraulic system of 400 MPa. It was previously established that the...
speed of the ultrajet determines the efficiency of the liquid treatment [7]. The target is a synthetic diamond fixed in a mandrel, which, in turn, using screws is fixed in the nozzle of the container cover (Fig. 3) [7,8].

The results of the analysis were the average particle sizes for the quantitative and volume distributions, as well as the minimum recorded particle size in the samples. After ultrasonic treatment and ultra-jet processing, the treated nanosized suspensions were studied using a Microtrac Bluewave laser particle size analyzer (Microtrac S3500), using the Tri-laser technology shown in Fig. 4 [8,9].

The results of a comparative analysis of the particle size in the composition of the suspensions are shown in the following figures.
For suspension, the main technological parameters and informative data on ultra-jet suspension are presented in Table 1. The nozzle head was moved along the surface of the sample in a spiral of Archimedes, the path length was 575 mm. This made it possible to ensure uniformity of removal of the surface layer of the target material (sample) in comparison with the point impact on the surface and circular motions of small radius, as can be seen in Fig. 8 [9,10]. The materials used in the experiments on the preparation of suspensions were selected: pure silver (Ag 999.9) and electrolytic copper (Cu-ETP) of high purity (99.95%) [10,11].

The experiments were carried out at two pressures in the hydraulic system of 200 and 350 MPa, with a feed rate of 2 mm/s and a distance from the cut of the focusing tube to the sample surface of 2 mm, unit operation time \( t = 4 \text{ min} \), feed rate \( S = 2 \text{ mm/s} \), the distance from the nozzle to the target \( h = 2 \text{ mm} \) (see Table 1) [12,13].

**Table 1 - The results of experimental studies on the preparation of suspensions**

| Target Material: Copper (Cu) | Pressure P = 200 MPa | Pressure P = 350 MPa |
|-----------------------------|----------------------|----------------------|
| Suspension mode             |                      |                      |
| The mass of the target before processing, gr | \( m = 138.67 \) | \( m = 139.04 \) |
| The mass of the target after processing, gr | \( m_1 = 138.63 \) | \( m_1 = 138.67 \) |
The temperature of the suspension, ° C | 54,0 | 73,0
Diameter of material removed from the target, mm | 18 | 18
The speed of the jet at the nozzle exit, m/s | 447 | 592
The flow rate of the working fluid, l/min | 4,7 | 6,3
Power, kW | 45 | 60
The mass of carried away material, gr | 0,040 | 0,460

| Target Material: Silver (Ag) |
|-------------------------------|
| The mass of the target before processing, gr | m=69,62 | m=72,29 |
| The mass of the target after processing, gr | m₁=69,38 | m₁=69,62 |
| The temperature of the suspension, ° C | 55,6 | 78,4 |
| The speed of the jet at the nozzle exit, m/s | 447 | 592 |
| The flow rate of the working fluid, l/min | 4,7 | 6,3 |
| Power, kW | 45 | 60 |
| The mass of carried away material, gr | 0,240 | 2,670 |

At the next stage of experiments using a particle analyzer, the following were determined: mass concentration of ultra-jet suspensions; shape, size and distribution of solid particles formed during hydrodispersion of targets, the particle size distribution of the materials under consideration was determined in the volume of the suspension under investigation (Table 2).

**Table 2 - The results of the analysis of the geometric parameters of the microparticles of the material after ultra-jet hydraulic action**

| Size | Number of particles, % | Average area in the considered range (μm²) |
|------|-------------------------|------------------------------------------|
|      | Over (μm²)               | Before (μm²)                             |                                      |
| Target Material - Silver | 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 |

| Target Material - Copper | 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 |
According to the results of experiments on ultrasonic suspension, the following main conclusions were made.

1. Changes in technological conditions and ultra-jet suspension modes 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 increases the concentration of the target materials in the liquid by an order of magnitude, which was also revealed using "soft" targets (Cu, Ag) instead of steel plates St45.

2. The shape, size and development of the surface of the particles significantly depend on the physico-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.

Taking into account the results of previous studies [12], it can be assumed that the wide possibilities of the ultra-jet suspension technology for varying the input and output processing parameters will allow a very flexible approach to solving a wide variety of specific tasks, such as, for example, increasing the physicochemical activity of a suspension, low-temperature sterilization, changes hydrogen indicator, changes in microbiological and other vitological properties, etc.

**Figure 9.** Typical distributions of copper and silver particles of various fractions depending on their area.

**Figure 10.** Images of microparticles of target materials after hydroerosion of their surface as a result of ultra-jet impact, (a) image of silver microparticles at 425x magnification, (b) image of copper microparticles at 415x magnification
3. 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. Its advantages were noted for dispersing suspensions with carbon nanotubes and boehmite, where the minimum particle size was an order of magnitude smaller in comparison with initial state of samples. 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. Its advantages were noted for dispersing suspensions with carbon nanotubes and boehmite, where the minimum particle size was an order of magnitude smaller in comparison with initial state of samples. Conducted experimental studies for suspension and analysis of the results 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, unlike others, it is based on a powerful shock-dynamic effect, which exerts an ultra-strong on a solid-state target being processed. The power density of the ultrajet is comparable with industrial lasers for this indicator. Moreover, it was previously proved that the high-speed action of the ultra-jet affects the properties of liquids, which is close in its results to the technology of ultrasonic processing. Considering the previously performed studies can be said that the energy of the newly formed surfaces of the target material — the surface energy of microparticles of the solid phase — is very significant. As a result, these particles are very reactive in physicochemical respect. This makes it possible to create new hydraulic technologies for using ultra-jet micro- and nanosuspensions and the corresponding gel structures, in particular, based on water-soluble polymers, high molecular weight organic liquids and liquid crystals.

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References
[1] Tarasov V A and Nelyub V A 2018 Rheological model of viscous incompressible fluid with disperse fillers (edited by International Journal of Mechanical Engineering and Technology, Moscow) pp 488-497
[2] Galinovsky A L, Bethena G F and Petrov I V 2017 Improving the performance of waterjet cutting of materials by selecting rational modes of processing by acoustic emission (edited by metal technology, Moscow) pp 18–27
[3] Ilyukhina A A 2018 Analysis of the interconnectedness of the functional physical capabilities of additive and ultra-jet technologies (edited by Fundamental and applied problems of engineering and technology) pp 73–81
[4] Mugla D R 2019 Selection of Rational Technological Modes and Parameters of Underwater Waterjet Cutting (Lecture Notes in Mechanical Engineering) pp 267-276
[5] Ilyukhina A A and Kolpakov V I 2018 The Features of Hydroabrasive Cutting of Honeycomb Panels of Space Vehicles (Moscow University Physics Bulletin, Moscow) pp 441-446
[6] Nelyub V A 2015 Determination of adhesion interaction between carbon fiber and epoxy binder (Polymer Science - Series D) pp 6-8
[7] Nelyub V A, Borodulin A S, Kobets L P and Malysheva G V 2016 Capillary hydrodynamic of oligomer binder (Polymer Science – Series D) pp 322-325
[8] Nelyub V A, Borodulin A S, Kobets L P and Malysheva GV 2016 A study of structure formation in a binder depending on the surface microrelief of carbon fiber (Polymer Science – Series D) pp 286-289
[9] Nelyub V A 2016 A study of the microstructure of dressed glass fibers (Polymer Science – Series D- 9 (1)) pp 96-100
[10] Nelyub V A 2015 Determination of adhesion interaction between carbon fiber and epoxy binder (Polymer Science - Series D - 8 (1)) pp 6-8
[11] Nelyub V A, Borodulin A S, Kobets L P and Malysheva G V 2016 Capillary hydrodynamic of oligomer binder (Polymer Science – Series D 9(3)) pp 322-325
[12] Puzakov V S 2007 Development and analysis of the functional capabilities of ultra-jet activation of hydrotechnological media for mechanical processing production (Vestnik BMSTU publication, Moscow)
[13] Galinovsky A L, Provators A S and Kyaw Myo Htet 2019 On the question of the effectiveness of various methods of dispersing nanosuspension suspensions (All materials: Encyclopedic reference) No 11 S 2 – 7
[14] Galinovsky A L, Provators A S and Kyaw Myo Htet 2020 Prospects for the Development of Ultra-Jet Dispersion Technology for Nanocontaining Suspensions (IOP Conf. Ser.: Mater. Sci. Eng. 709 044092) volume 709
[15] Galinovsky A L, Provators A S and Barzov A A 2019 Information-physical mechanism of ultrahydrojet diagnostics of the quality of functional coatings (Hardening Technologies and Coatings) No 2 S 51 – 57
[16] Mugla D R and Golubev E S 2019 Surface express ultrajet diagnostics of space vehicle materials (IOP Conference Series: Materials Science and Engineering) Vol 683 Issue 1
[17] Galinovskij A L, Abashin M I and Khafizov M V 2014 Rapid Determining of the Optimum Operation Mode for Abrasive Waterjet Cutting Process by Means of Acoustic Emission (Applied Mechanics and Materials) Vol 698
[18] Zhu J, Imam A, Crane R, Lozano K, Khabasheku V N and Barrera E V 2017 Processing a glass fiber reinforced vinyl ester composite with nanotube enhancement of interlaminar shear strength (Compos Sci Technol) pp 1509–17
[19] Tarasov V A and Baskakov V D 2016 Mathematical modeling of the collision process of flat jets of an ideal fluid (submitted to Vestnik BMSTU, Moscow) p 79–90
[20] Tarasov V A, Stepanishchev N A and Boyarskaya R P 2011 Methods of experimental determination of the characteristic points in time of the technological process of preparing nanosuspensions under conditions of ultrasonic action (submitted to Vestnik BMSTU) p 53–65