Prospects for the Development of Ultra-Jet Dispersion Technology for Nanocontaining Suspensions

Kyaw Myo Htet\textsuperscript{1,3}, A L Galinovsky\textsuperscript{2,4} and A S Provatorov\textsuperscript{1,5}

\textsuperscript{1} Graduate student SM-12, Bauman Moscow State Technical University,105005, Russia,
\textsuperscript{2} Doctor of Sciences, Head of department of SM-12, Professor, Bauman Moscow State Technical University,105005, Russia,
\textsuperscript{3} htet2066@gmail.com,
\textsuperscript{4} galcomputer@mail.ru,
\textsuperscript{5} provatorov_a@bmstu.ru

Abstract. The article deals with the actual problem of the dispersion of nano-modifiers. At present, the methods used for dispersing are not sufficiently effective and often do not provide the necessary dispersion of nanoparticles in suspensions. The solution to the problem can be found in the application of ultra-jet technology, which allows, as shown in the article, to provide a fairly high level of dispersion. The studies were carried out as part of a grant from the President of the Russian Federation for state support of leading scientific schools (NSh-3778.2018.8) and a grant from the Russian Foundation for Basic Research 18-29-18081.

1. Introduction

Beginning in the 1930s, jet technology began to be widely used in the mining industry in Russia for the extraction of shale, coal, peat, etc. The traditional fields of application of ultra-jet hydraulic technologies for solving a number of scientific and technical problems facing the engineering industry are considered. The classification of hydro-jet technologies based on their practical application in industry is given, in particular, issues of liquid and water-jet cutting, surface treatment, improvement of technological equipment and information and diagnostic support of ultra-jet technologies are considered [1].

Currently, ultra-jet technologies have found wide application for solving various problems of mechanical engineering, aerospace engineering and other industries and national economy. The main advantage of these technology is the prompt receipt of the necessary information about the operational and technological parameters of the state of the surface layer of material of various technical objects. In addition, the ultra-jet effect in a technologically achievable degree is similar to the actual operating conditions of various kinds of technical objects and devices, which is extremely important for obtaining objective information about the object of control [2].

2. Experimental research for obtaining nanosuspensions

The mixing of powders into liquids is a common step in the formulation of various products, such as paint, ink, shampoo, beverages, or polishing media. The individual particles are held together by attraction forces of various physical and chemical nature, including van der Waals forces and liquid surface tension. This effect is stronger for higher viscosity liquids, such as polymers or resins. The
attraction forces must be overcome in order to deagglomerate and disperse the particles into liquid media. The application of mechanical stress breaks the particle agglomerates apart. Also, liquid is pressed between the particles. Different technologies are commonly used for the dispersing of powders into liquids. This includes high pressure homogenizers, agitator bead mills, impinging jet mills, rotor-stator-mixers etc.

The dispersing and deagglomeration of solids into liquids is an important application of ultrasonic devices. Ultrasonic cavitation generates high shear that breaks particle agglomerates into single dispersed particles. Usually, this treatment leads to a decrease in particle size and an increase in the uniformity of their size [3].

To assess the capabilities of the ultrasonic treatment method, studies have been conducted on the dispersion of nanoscale suspensions. Characteristics of the studied samples of nanomaterials are presented in table 1.

Table 1. Characteristics of the samples of the original nanomaterials used for the preparation of suspensions and their further dispersion.

| Manufacturer | Composition | Technological and operational features of the powder |
|--------------|-------------|-----------------------------------------------------|
| Research Institute of Pulse Processes with Experimental Production "OCP NII IP with OP", Minsk, Belarus | Al (OOH) "Boehmite" Nanodiamonds | - Mass fraction of the main substance, not less than 99\%.
- A specific surface according to the BET method, up to 400 [m\(^2\)/g],
- Pycnometric true density, 3.06 [g/cm\(^3\)],
- The size of individual particles, 0.1-0.8 [nm]
- The size of the primary particles, 4-6 [nm]
- Density, 3 ± 0.1 [g/cm\(^3\)]
- Specific surface, 280 ± 60 [m\(^2\)/g]
- The content of the diamond phase, not less 91\%,
- Chemical impurities O, N, H,

| Arkema (France) | Carbon nanotubes | -External diameter: 10-20 [nm],
- Tube length: more than 2 [microns],
- Specific surface according to the BET method: > 300 [m\(^2\)/g],
- Content of impurities not more than 1\% |

According to [4], for the preparation of a mixture for processing, 0.9 g of nanopowders mixed with 30 ml of water in a cup placed under the ultrasonic processing machine were used in the laboratory hall of the SM-12 department of Bauman Moscow State Technical University [4].
1, Case; 2, Ultrasonic generator; 3, Acoustic transformer; 4, Glass for suspension; 5, Nanoscale suspension.

**Figure 1.** Scheme and installation for ultrasonic treatment

High intensity ultrasonication is an interesting alternative to these technologies. When sonicating liquids, the sound waves that propagate into the liquid media result in alternating high-pressure (compression) and low-pressure (rarefaction) cycles. This applies mechanical stress on the attracting electrostatic forces (e.g. van der Waals forces). Ultrasonic cavitation in liquids causes high speed liquid jets of up to 1000km/h (approx. 600mph). Such jets press liquid at high pressure between the particles and separate them from each other. Smaller particles are accelerated with the liquid jets and collide at high speeds. This makes ultrasound an effective means for the dispersing and deagglomeration but also for the milling and fine grinding of micron-size and sub micron-size particles [5].

After the experiment, the analysis was performed using a Microtrac Bluewave laser particle size analyzer (Microtrac S3500), which uses the technology of three lasers (Tri-laser) shown in Figure 4. The laser particle size analyzer (the diagnosable size range is from 0.01 to 2800 μm) allows particle size distribution in suspensions, emulsions, powders using laser granulometry.

**Figure 2.** Microtrac S3500 Laser Particle Analyzer

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 the research of ultrasonic treatment, the possibilities of the method of ultrajetting suspensions were studied. The studies were based on a methodical base, which was formed within the framework of the scientific school “Ultrajet processing and diagnostics of materials and liquids” (NSh-3778.2018.8) at the SM-12 department of the Bauman Moscow State Technical University.
In Figure 3 shows the Flow Waterjet hydraulic system used in the experiment with jet diameter of 0.07–0.2 mm, high-pressure (pressure 100–700 MPa) and high-speed (600–700 m/s) fluid flow of the multiplier type, as well as a schematic diagram of the ultrajet dispersion of suspensions [6,7].

1, Stream forming hydro; 2, Mixing chamber; 3, High-speed liquid jet; 4, Container for premix (nanoscale suspension); 5, Focusing tube; 6, High-speed jet suspensions; 7, Target made of synthetic diamond; 8, Treated suspension; 9, Capacity trap to collect the suspension.

Figure 3. Schematic diagram of the ultra-jet dispersion of nanoscale suspensions.

Ultra-jet technologies are understood as a set of physical methods and technical means ensuring the creation and implementation of such parameters of a high-energy compact hydrojet that, when interacting with the environment, for example, when dynamically braking (hitting) a solid-state target, are capable of lead to instrumentally fixed, targeted changes in the state of the surface and / or volume of the target material, as well as the properties of the hydroenvironment itself, subjected to ultrajet impact condition (treatment) [6,8].

Since the main physical process of the ultra-jet technology is technologically significant, the process of hydro erosion destruction of the surface layer of the target material by ultra-jet is the phenomenon of formation of a jet of fluid in the target of ultra-jet jet in the zone of implementation of all operating ultra-jet hydrotechnologies [6].

Practical significance is the fact that as a result of ultra-jet suspension, a specific hydro-solid-state structure is formed, which has all the features of a classical composite material that is in a liquid-phase state. In the future, it can go into solid phase or gel during solidification (crystallization). One of the most functionally significant results of the use of ultra-jet technologies is the ability to effectively disperse the treated liquid to the micro- and nano-dispersed state. This process is due to the ultra-intensive, dynamic impact of the ultra-jet of the dispersed liquid on a solid-state target [6,10].

For illustration, Figure 4 shows the elements of a tooling specifically designed to collect activated micro-suspensions and hydro-jet equipment.
1, A nozzle for installing a focusing tube in it; 2, A cylindrical target with a diamond single crystal fixed in it; 3, A container for collecting the suspension (bottom of the tank); 4, Screws - fixing element for the top cover to the bottom of the container for collecting the suspension; 5, Screws - target fixation element.

**Figure 4.** Tooling for dispersing micro and nanosuspensions (I, Upper lid of the tank, II, Bottom of the tank and tank assembly)

The results of a comparative analysis of the particle size in the composition of the suspensions are shown in Fig. 5, 6 and 7; in the initial state, after ultrasonic and ultrajet processing, respectively.

![Graphs of values of average particle sizes by quantitative distribution for initial samples](image)

**Figure 5.** Graphs of values of average particle sizes by quantitative distribution for initial samples

![Graphs of values of average particle sizes by quantitative distribution for samples after ultrasonic treatment.](image)

**Figure 6.** Graphs of values of average particle sizes by quantitative distribution for samples after ultrasonic treatment.

![Graphs of values of average particle sizes by quantitative distribution for samples after ultrajet impact.](image)

**Figure 7.** Graphs of values of average particle sizes by quantitative distribution for samples after ultrajet impact.
3. Conclusion
A comparative analysis of the obtained values with the original samples, after ultrasonic treatment and one of the classical methods of dispersion showed the technological efficiency of applying the method of dispersing boehmite, nanodiamonds and carbon nanotubes using the proposed method. The method of ultrajet machining allows to achieve a significant reduction in particle size in the composition of boehmite, nanodiamonds and carbon nanotubes, on average, 4-5 times, which carries the practical significance of this work. The prospect of the development of the research is the establishment of time limits for maintaining a given level of dispersion of boehmite, nanodiamonds and carbon nanotubes, which is extremely important for issuing practical recommendations on their use for the preparation of binders, the introduction of additives, paints and other materials.

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