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Theoretical and experimental study of cavitation dispersing in "liquid-solid" system for revelation of optimum influence modes

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ABSTRACT: *The paper contains the results of the study of cavitation dispersing in "liquid-solid" system. It is known that cavitation dispersing is one of energy effective methods of "liquid-solid" interface area increasing. For evaluation of cavitation dispersing modes providing maximum interface area the model of the process was developed. The model is based on simulation of bubble collapse near solid particle surface for determination of particle destruction possibility and calculation of particulate composition evolution using of probabilistic approach. Analysis of the model has shown that cavitation dispersing provides increasing a "liquid-solid" interface area up to 2 and more times. The proposed model was confirmed by experiments.*

Keywords - *Cavitation, dispersing, multiphase medium, shock wave, solid particles*

I. INTRODUCTION

Physical and chemical processes on liquid-solid boundary are one of the essential foundations of modern productions [1]. Examples include adsorption, chemisorption processes, surface chemical reactions, dissolution of crystalline substances, a hydrocarbon cracking catalysis, etc. [1] To maximize the efficiency or speed of implementation of such processes it is primarily necessary to provide the largest possible contact surface area between liquid and solid phases [1].

Obviously, this can be accomplished by dispersing of solid particles involved in the liquid and chemically reacting with it into smaller pieces [1, 2].

Existing methods for dispersing solid particles are divided into:

– Vibratory milling [3], ball, planetary, and others mills;

– Shock compression (explosion);

– Cavitation dispersing [1, 2].

The main disadvantage of different types of mills is inability of obtaining particles smaller than 200 μm that causes a hard limited phase contact surface. A shock compression requires high energy due to the need to create high pressures in liquid dispersed medium. Thus, the most expedient way of dispersing solids to improve the efficiency of physical and chemical processes on liquid-solid boundary is the cavitation dispersion. During cavitation dispersion low dense energy (energy of primary influence, for example, hydrodynamic vacuum, high intensity acoustic waves and so on) is converted to high dense energy. This means that energy of the primary influence is stored in cavitation bubble during the bubble expansion stage. Then shock release of stored energy occurs. As a result, the shock release of energy causes the destruction of particulate matter because the amplitude of the pressure generated by the shock wave may be exceed the tensile strength of the majority of solids (more 1000 atms) [2].

The main advantages of the cavitation dispersion are:

– The possibility of dispersing of solid particles down to submicron sizes;

– Uniform distribution of particles in a liquid due to acoustic microflows.

Today one of the most profitable methods of creating cavitation is the introduction of ultrasonic vibrations into the liquid-solid suspension [1, 2]. It is known that ultrasonic vibrations lead to the formation of a plurality of cavitation bubbles which periodically expand and collapse with frequency over 20,000 times per second. However, today, despite a number of advantages, cavitation dispersion under the influence of ultrasonic vibrations (ultrasonic cavitation dispersion) is not widespread distributed in the industry. This is due to absence of system theoretical and experimental researches which explain the mechanism of destruction of solid particles under the influence of ultrasonic vibrations and allow determining the best modes of action depending on the physical properties and characteristics of the two-phase liquid-solid system.

Therefore, the goal of presented research is the evaluation of optimum modes of ultrasonic cavitation dispersion which allows providing maximum surface area between liquid and solid.

To achieve this goal it is necessary to solve the following tasks:

– To develop physical and mathematical model of the cavitation influence on a single solid particle to detect possible destruction of the particle (the emergence of the elementary act of dispersion) depending on the exposure mode and location of cavitation bubbles with respect to the particles;

– To develop probabilistic model of the evolution of disperse composition of particulate solids in a cavitating liquid based on the evaluated influence modes and the cavitation bubbles locations with respect to the particles at which the elementary act of dispersion occurs;

– To evaluate the intensities of influence providing maximum surface area contact between the phases depending on the viscosity of liquid phase and the initial particle size;

– To experimental study ultrasonic cavitation dispersing solid particles to confirm the theoretical results.

The following topics devoted to solve the tasks.

II. PHYSICAL AND MATHEMATICAL MODEL OF INTERACTION OF A SINGLE CAVITATION BUBBLE WITH INTERFACIAL BOUNDARY "LIQUID-SOLID"

To identify the modes of the cavitation influence providing high degree of dispersion of solid particles, analysis of cavitation influence on individual particles is primarily needed.

The developed model of cavitation influence on a single particle is based on the following assumptions:

1-1. During bubbles expanding liquid with particles flowing around cavitation bubbles moves as a continuous medium. This is due to the fact that the maximum size of the bubble achieved during expansion stage is much more than the size of the particles used in practice.

1-2. Minimum size of cavitation bubbles (at collapse) is much less than the linear dimensions of the particle surface.

1-3. The influence of shock waves on the particle displacement or rotation is absent due to short time of collapse that is not enough for the change of momentum or angular momentum of a particle.

1-4. Since the start of the expansion to the point at which the radius of a cavitation bubble will be 1/3 from the nominal diameter of the particle (in the stage of collapse), it retains the vial spherical. The above assumption partly follows from 1-1 and confirmed by modeling of the interaction of a cavitation bubble with a solid surface [1, 4].

A theoretical analysis of the cavitation impact on the single particle consists the following stages.

1) Cavitation bubble expansion.

2) Cavitation bubble collapse.

3) Shock wave generation and propagation.

4) Interaction of a shock wave with a solid particle.

Further consideration of each step is described in more detail.

2.1. Cavitation bubble expansion

Consideration of the expansion stage of cavitation bubble is aimed at determining the maximum radius R_{MAX}.

Maximum bubble radius R_{MAX} is determined by the Nolting-Nepayres equation:

$$\rho\left(\frac{3}{2}\left(\frac{\partial R}{\partial t}\right)^2 + R\frac{\partial^2 R}{\partial t^2}\right) = -4\mu\frac{\frac{\partial R}{\partial t}}{R} + p_v + \left(p_0 + \frac{2\sigma}{R_0}\right)\left(\frac{R_0}{R}\right)^{3\gamma} - p_0 + \sqrt{2\rho cI}\sin(2\pi ft)\ ; \qquad (1)$$

where R is momentum radius of a cavitation bubble, m; R_0 is the radius of a cavitation nuclei, m; ρ is density of a suspension as a continuum, kg/m^3; μ is viscosity of a suspension as a continuum, Pa·s; σ is surface tension of a liquid phase, N/m; p_v is pressure of a liquid phase vapor, Pa; p_0 is static pressure in a suspension, Pa; c is sound speed in a suspension, m/s; I is intensity of a ultrasonic oscillations (primary influence), W/m^2; f is frequency of a ultrasonic oscillations, Hz; t is time, s. The maximum radius calculated by equation (1) will be used for following analysis bubble collapse and its acting on interphase boundary "liquid-solid" (surface of dispersible particles).

2.2. Cavitation bubble collapse

It is known that during the collapse of the bubble its radius decreases from the maximum being much more than the dimensions of the dispersed particles to the minimum being much less than the size of the particles, i.e. less than 1 μm. Thus, cavitation bubble during collapse stage can be in different conditions of around flow by liquid-dispersed suspension. In depending on around flow conditions the bubble collapse stage can be divided into two periods – the initial period and the final period.

During the initial period size of a bubble is still much more than the size of the particles. In this case, liquid dispersed suspension flow around the bubble can be seen as a continuum with equivalent physical properties that are viscosity and density, as well as in the expansion stage.

When the bubble size becomes comparable to the particle size and then continues to decrease to the minimum size forming pulse of a high-amplitude shock wave, the end period of collapse is realized. Obviously, during the final period the cavitation bubble is flowed by liquid continuous phase and interacts with the surface of one of the particles due to Bjerknes forces leading to the convergence of the bubbles to the particles. This cavitation bubble undergoes deformation caused by the reflection of microflows of fluid flowing around the cavitation bubble from surface of a particle. Deformation of the cavitation bubble narrows the directivity pattern of the shock wave and thus provides high concentration of pressure amplitude in a narrow beam that actually leads to destruction particle (dispersing particle).

In the initial period of the collapse of the bubble, his behavior is described by Nolting-Nepayres equation as well as on the expansion stage.

However during the final period a bubble undergoes deformation due to the interaction between shock wave and particle surface as already mentioned.

While the velocity of the bubble wall is not comparable to the speed of sound in the liquid, form of the cavitation bubble can be accurately described by the integral equation (3) with the boundary condition (4) on the wall of the cavitation bubble for the fluid velocity potential [4]:

$$\frac{\varphi(\mathbf{r}_0)}{2} = \int_{S_A \cup S_B} \left(E_{\mathbf{r}_0}(\mathbf{r}) V_{\mathbf{n}}(\mathbf{r}) - \frac{\partial E_{\mathbf{r}_0}}{\partial \mathbf{n}}(\mathbf{r}) \varphi(\mathbf{r}) \right) \partial S(\mathbf{r}) ; \quad (3)$$

$$\frac{\partial \varphi}{\partial t} + \frac{|V_{\mathbf{n}}|^2 + |V_{\tau}|^2}{2} = \frac{2\sigma K}{\rho} - \frac{p_v}{\rho} \left(\frac{3V}{4\pi R_{MAX}^3} \right)^{\gamma} ; \quad (4)$$

where $\mathbf{r}_0$, $\mathbf{r}$ are vectors of coordinates of points of cavitation bubble wall or solid surface, m; φ is the potential of liquid velocity on cavitation bubble wall or solid surface, m^2/s; $V_{\mathbf{n}}$ and V_{τ} are normal and tangential of liquid velocity components, m/s; $E_{r_0}(\mathbf{r})$ is basic solution of Laplace equation; S_A is surface of cavitation bubble wall; S_B is surface of solid particle; σ is surface tension of liquid phase, N/m; ρ is density of liquid phase, kg/m^3; p_v is liquid phase vapor pressure, Pa; V is volume of cavitation bubble, m^3; R_{MAX} is maximum radius of cavitation bubble determined in subsection 1.1, m.

The system of equations (3-4) is used for calculation cavitation bubble wall deformation during time. Equation (3) for evaluation liquid velocity potential distribution is solved by boundary element method [4].

When the speed of the bubble wall becomes comparable to the speed of sound in the fluid, equation (1) can not be used. In this case, the calculation of the evolution of the bubble shape is performed by using the asymptotic decomposition of bubble shape by cosine of the azimuth angle (see equation (5) and Fig. 1).

$$\begin{pmatrix} r(\theta) \\ z(\theta) \end{pmatrix} = \begin{pmatrix} R(\theta)\sin\theta \\ R(\theta)\cos\theta \end{pmatrix} = \left(\sum_{n=0}^{\infty} R_n \cos^n \theta \right) \begin{pmatrix} R(\theta)\sin\theta \\ R(\theta)\cos\theta \end{pmatrix} ; \quad (5)$$

where $\begin{pmatrix} r(\theta) \\ z(\theta) \end{pmatrix}$ are cylindrical coordinates of point of bubble wall, m; θ is azimuth angle, rad.

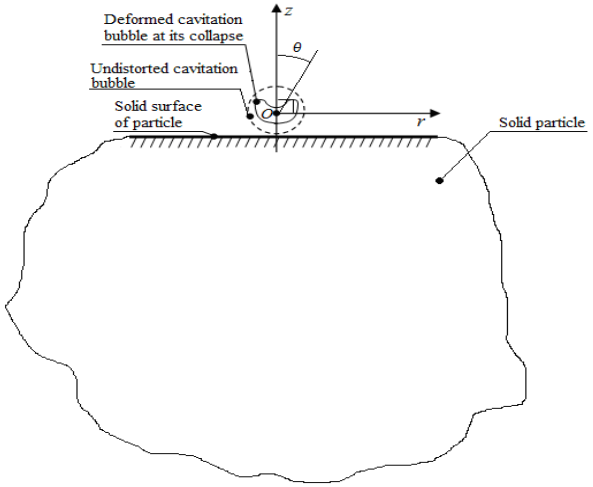


Fig. 1. Diagram of bubble collapsing near solid particle (θ is azimuth angle)

For numerical calculations it must be limited by a finite number N of terms in the decomposition:

$$\begin{pmatrix} r(\theta) \\ z(\theta) \end{pmatrix} \approx \left(\sum_{n=0}^{N-1} R_n \cos^n \theta \right) \begin{pmatrix} R(\theta)\sin\theta \\ R(\theta)\cos\theta \end{pmatrix}; \quad (6)$$

When $N = 1$ the Navier-Stokes equations [5] taking into account liquid compressibility and allowing describing bubble shape at collapse can be reduced to Gilmore equation (7):

$$R_0 \frac{\partial^2 R_0}{\partial t^2}\left(1 - \frac{\frac{\partial R_0}{\partial t}}{C}\right) + \frac{3}{2}\left(\frac{\partial R_0}{\partial t}\right)^2\left(1 - \frac{\frac{\partial R_0}{\partial t}}{3C}\right) = H\left(1 + \frac{\frac{\partial R_0}{\partial t}}{C}\right) + \frac{\partial H}{\partial t}\frac{R_0}{C}\left(1 - \frac{\frac{\partial R_0}{\partial t}}{C}\right); \quad (7)$$

where H is enthalpy of liquid, m^2/s^2; C is local sound speed in liquid, m/s; t is time.

Thus, the proposed model allows calculating the shape of the bubble near the particle surface which is during bubble collapse. Further the resulting shape of the bubble will be used to calculate the generation and propagation of the shock wave.

2.3. Shock wave generation and propagation

In the analysis of shock waves in the fluid acoustic approximation can be considered as valid, because shock wave near the particle surface has fluid velocity that is small in comparison to sound speed.

Therefore shock wave propagation can be described by the wave equation (8)

$$\frac{\partial^2 p}{\partial t^2} - c^2 \Delta p = 0; \quad (8)$$

where t is time, s; p is shock wave pressure, Pa; c is sound speed in suspension, m/s;

At the consideration of stage of shock wave generation and propagation it allows to approximate profile of wave pressure near interface "liquid-solid" by the following expression (9) obtained by the spectral decomposition and the Green formula for the Helmholtz equation.

$$p(\mathbf{r},t) = \frac{\omega}{2\pi}\sum_{n=-\infty}^{\infty} e^{-in\omega t}\int_S iG_{\mathbf{r}_0, n\frac{\omega}{c}}(\mathbf{r})\frac{n\omega}{c}\int_0^{\frac{2\pi}{\omega}} p_c(t_1)e^{in\omega t_1}\partial t_1 \partial S_0; \quad (9)$$

where $\mathbf{r}=(x;y;z)$ are the coordinates of the point of the interphase boundary "liquid-solid", m; ω is the angular frequency of the ultrasonic oscillations (primary influence), s^{-1}; t and t_1 are the moments of time, s; η is the viscosity of suspension, Pa·s; ρ and c are the density and the sound speed of the liquid phase, respectively, m/s; $p_c(t_1)$ is the pressure in the nucleus of the cavitation bubble, Pa; S is the surface of the cavitation bubble at the achievement of maximum pressure in its nucleus, m; $G_{\mathbf{r}_0, n\frac{\omega}{c}}$ is the Green's function [6] at wave number is $n\frac{\omega}{c}$.

Appearing in the expression (9) function of the shock wave pressure in the core of the cavitation bubble is determined based on its shape obtained at each time according to the following relationship:

$$p_c(t_1) = p_V\left(\frac{2R_{MAX}^3}{\int_0^{\pi} r(\theta)\left[z(\theta)\frac{\partial r}{\partial\theta}(\theta) - r(\theta)\frac{\partial z}{\partial\theta}(\theta)\right]\partial\theta}\right)^{\gamma}; \quad (10)$$

where p_V is vapor pressure in liquid phase, Pa; R_{MAX} is the maximum bubble radius determined in section 1.1, m; θ is azimuth angle (see Fig. 1), rad; $(r(\theta); z(\theta))$ is cylindrical coordinates of bubble wall point that were founded in section 1.2, m.

Further founded pressure profile of shock wave will be used to analyze the possibility of the destruction of the solid particles as a result of the elementary act of dispersion and, ultimately, to identify the optimal cavitation influence modes providing maximum surface area "liquid-solid".

Further the interaction of a shock wave with the solid particle will be analyzed to detect the possibility of dispersing the latter.

2.4. Interaction of shock wave with solid particle

Analysis of the interaction of a shock wave with the solid particles is aimed at detecting possibility destruction of the last depending on the distance between a collapse core of a cavitation bubble and a particle. The act of destruction (dispersing) of particle occurs if and only if the mechanical stresses in it exceed threshold of strength of the particle near surface area opposed surface are near the bubble collapse core.

Determination of the mechanical stresses in the material of the solid particles is based on the linear theory of elasticity using the Laplace equation for the components of the stress tensor (11) with the boundary condition (12):

$$\Delta \sigma_{33} = 0 \; ; \tag{11}$$

$$\sigma_{33}\big|_S = p \; ; \tag{12}$$

where σ_{33} is component of the stress tensor of solid particle material, Pa; p is shock wave pressure near the boundary of "liquid-solid" calculated at some distance between bubble and particle surface by expression (9) (see section 1.3), Pa.

Due to decreasing shock wave pressure with increasing distance between cavitation bubble collapse core and surface of particle this distance providing particle destruction is limited by some value calculated by (11,12).

This distance is used to analyze the evolution of the particulate composition of the solid particle. Probabilistic model of dispersing solid particles allowing determining the evolution of the particulate composition is as follows.

III. PROBABILISTIC MODEL OF EVOLUTION OF PARTICULATE COMPOSITION IN CAVITATING LIQUID

Obviously, probability of an elementary act of particles dispersing is proportional to the probability of occurrence and collapse of cavitation bubble in a neighborhood of the particle (breakdown neighborhood) that is a limited by distance at which shock wave passing it keeps pressure amplitude greater than the tensile strength of the particles. This distance (the size of the particles breakdown neighborhood) was determined at the previous stage of consideration of the model (see section 1.4). The breakdown neighborhood is schematically shown in Fig. 2.

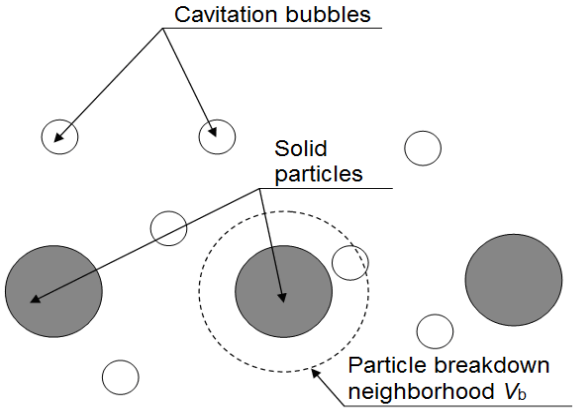


Fig. 2. Cavitation bubbles, solid particles and particle breakdown neighborhood

When concentration of bubbles n_{bub} [7] is known, probability of an elementary act of particle breakdown over small time Δt is defined as:

$$P(\Delta t) = 1 - \left(1 - \frac{N V_b}{(V - N V_p)}\right)^{f \Delta t n_{bub} (V - N V_p)} \; ; \tag{13}$$

where $P(\Delta t)$ is probability of an elementary act of particle breakdown over small time Δt(s); V is local volume of suspension, m^3; N is number of solid particles in volume V; V_b is volume of neighborhood of single particle, m^3; V_p is volume of single particle, m^3.

For a small time Δt and a small volume content of particles probability of single particle breakdown is defined as (14):

$$P(\Delta t) \approx V_b \, f \Delta t n_{bub} \; . \tag{14}$$

The obtained expression (14) for the probability of dispersible particles breakdown allows us to derive the kinetic equation of evolution of the particulate composition of the suspension "liquid-solid" under the ultrasonic cavitation influence. To do this, we take into account the assumption that during the elementary act of breakdown each particle breaks into two identical. This allows to approximate the particulate composition by discrete model by entering the value n_k that is the concentration of particles with a nominal diameter $d_0/2^{k/3}$ (d_0 is initial nominal diameter), V_{bk} is the volume of breakdown neighborhood of a particle with diameter $d_0/2^{k/3}$, $P_k(\Delta t)$ is particle breakdown probability during a small period of time Δt.

Then changing of the concentration n_k during Δt can be determined by the expression (15):

$$\Delta n_k = 2P_{k-1}(\Delta t)n_{k-1} - P_k(\Delta t)n_k = f\Delta t n_{bub}\left(2V_{b(k-1)}n_{k-1} - V_{bk}n_k\right); \quad (15)$$

where $2P_{k-1}(\Delta t)n_{k-1}$ is an increase of particles with a nominal diameter $d_0/2^{k/3}$ due to breakdown of particles with larger diameter $d_0/2^{(k-1)/3}$ in two identical; $P_k(\Delta t)n_k$ is decrease of particles with nominal diameter $d_0/2^{k/3}$ due to the collapse of their own.

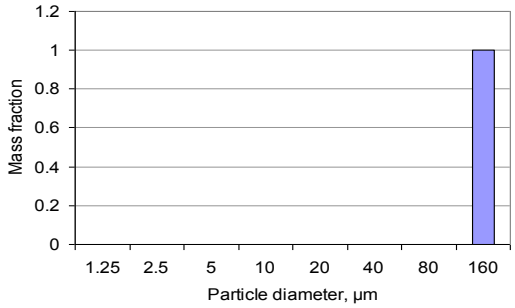
In expression (15) it assumes that $n_{-1}=0$.

When Δt tends to zero, from the expression (15) the kinetic equation of particulate composition evolution follows:

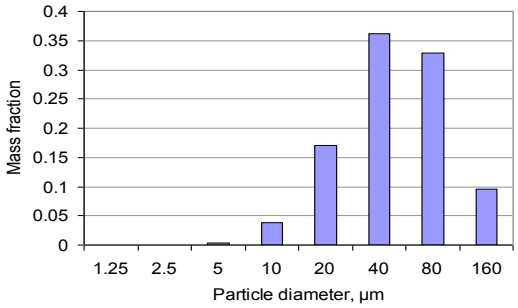
$$\frac{\partial n_k}{\partial t} = fn_{bub}\left(2V_{b(k-1)}n_{k-1} - V_{bk}n_k\right). \quad (16)$$

This equation was solved by Runge-Kutta method and allowed evaluating the evolution of particulate composition of suspension over time.

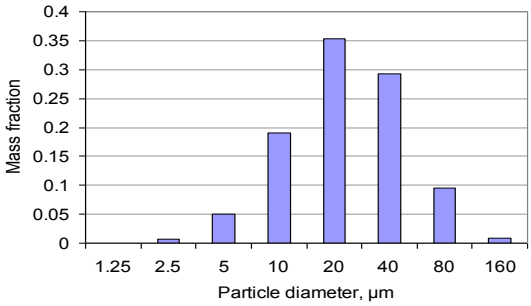
Histograms of particulate composition at different time points are presented in Fig. 3, 4 (frequency of ultrasonic oscillations is 22 kHz).



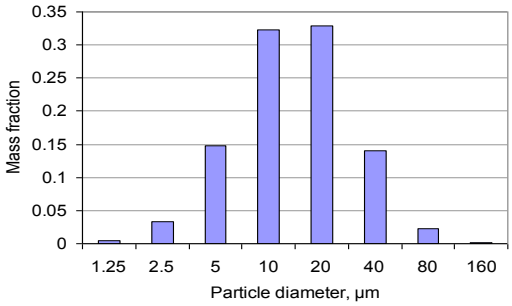
a) 0 min



b) 20 min

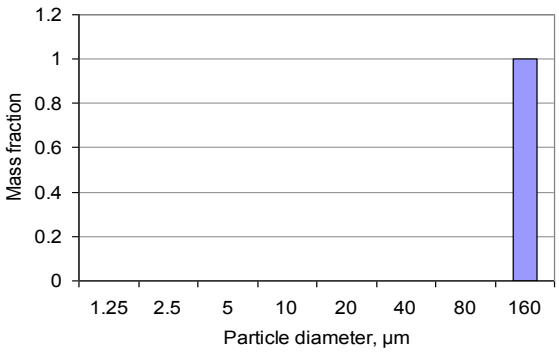


c) 40 min

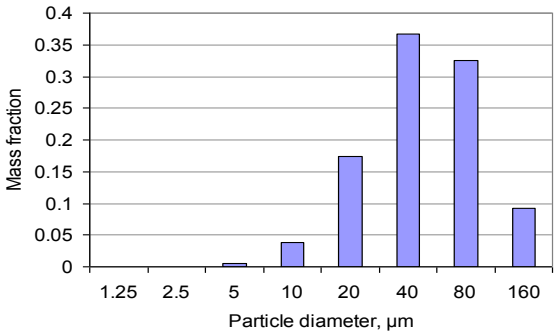


d) 60 min

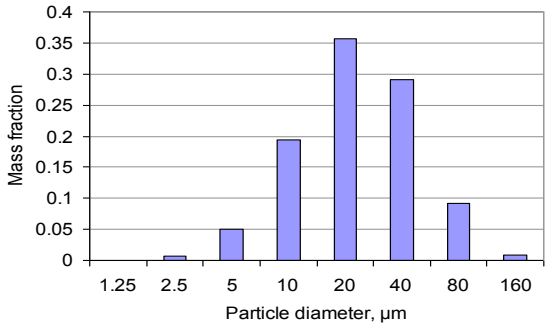
Fig. 3. Histogram of particulate compositions at different time points (initial diameter is 160 μm; viscosity of liquid phase is 1 mPa·s – liquid phase is water; ultrasonic cavitation influence intensity is 10 W/cm^2)



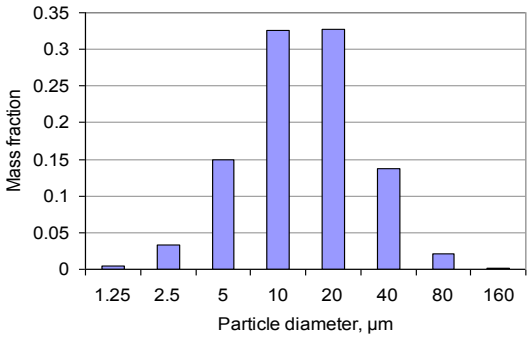
a) 0 min



b) 20 min



c) 40 min



d) 60 min

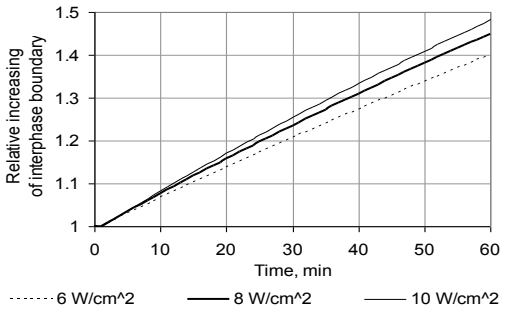
Fig. 4. Histogram of particulate compositions at different time points (initial diameter is 160 μm; viscosity of liquid phase is 100 mPa·s – liquid phase is machine oil; ultrasonic cavitation influence intensity is 20 W/cm^2)

As follows from the histogram over time the share of fines increases and the proportion of large are reduced. This indicates the effect of cavitation dispersion and hence the increase the surface of contact between the phases.

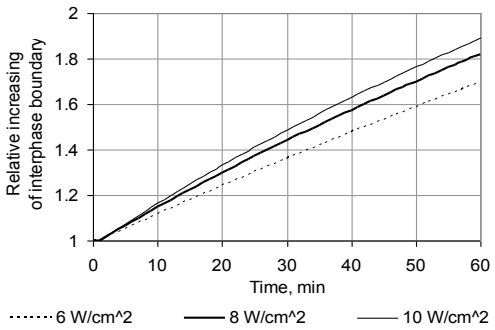
The obtained evolution of the particulate composition allows the degree of the increase the phases contact surface (relative increase the interface area) according to the expression (17):

$$\frac{S(t)}{S_0} = \frac{\sum_{k=0}^{\infty} n_k(t) \frac{d_0^{\,2}}{4^{\frac{k}{3}}}}{\sum_{k=0}^{\infty} n_k(0) \frac{d_0^{\,2}}{4^{\frac{k}{3}}}}. \qquad (17)$$

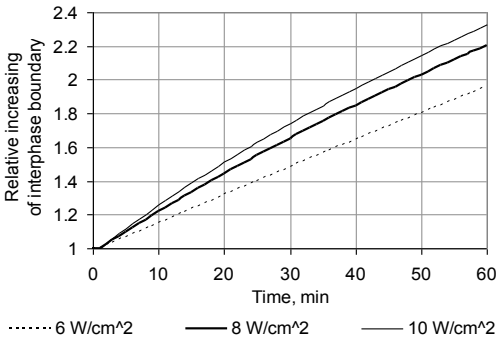
The dependences of relative increase the interface area on physical properties and characteristics of suspension (viscosity and initial diameter of particles) are shown in Fig. 5, 6.



a) Initial diameter is 80 μm

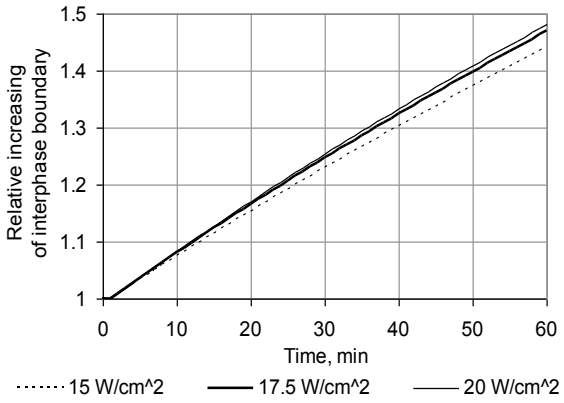


b) Initial diameter is 120 μm

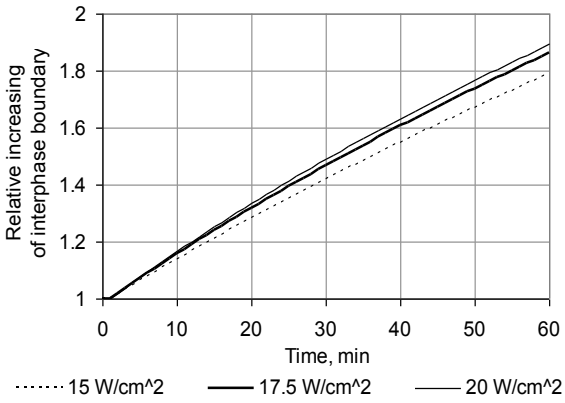


c) Initial diameter is 160 μm

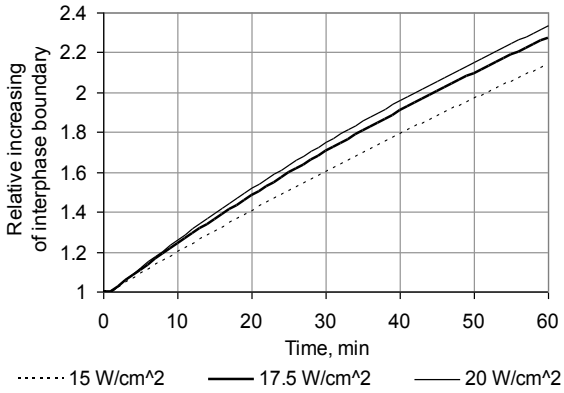
Fig. 5. The dependences of relative increase the interface area on time at various intensities (W/cm^2), initial diameters (μm) and viscosity of liquid phase 1 mPa·s



a) Initial diameter is 80 μm



b) Initial diameter is 120 μm



c) Initial diameter is 160 μm

Fig. 6. The dependences of relative increase the interface area on time at various intensities (W/cm^2), initial diameters (μm) and viscosity of liquid phase 100 mPa·s

Dependencies presented in Fig. 5, 6 allow determining intensity that is necessary for the required interphase boundary relative increasing depending on properties and characteristics of suspension (viscosity and initial diameter of particles).

For example, at intensity 10 W/cm^2 and liquid phase viscosity 1 mPa·s (initial diameter 160 μm) liquid-solid interface area has been increased up to 1.95 times during 40 minutes (or up to more than 2 times during 60 minutes). And at intensity 6 W/cm^2 interface area of the suspension has been increased up to 1.65 times during 40 minutes.

At greater viscosity 100 mPa·s the dispersing requires significantly more intensity of ultrasonic cavitation influence than at viscosity 1 mPa·s to achieve same interface area. For liquid phase with viscosity 100 mPa·s and initial diameter 160 μm, the interface area increasing more than 1.9 times during 40 minutes is achieved at intensity 17.5 W/cm^2 and more (for comparison, at viscosity 1 mPa·s the necessary intensity is 10 W/cm^2).

Obviously, it can be explained lower degree of cavitation intensity. The obtained dependencies can be used to recommend ultrasonic cavitation influence modes depending on physical properties and characteristics of liquid-solid suspension.

However, at smaller initial diameters the interface area increasing is less because reducing of breakdown neighborhood volume that causes reducing of particle breakdown probability. For example, at diameter 80 μm, liquid phase viscosity 100 mPa·s and intensity 17.5 W/cm^2 the increasing of the interface area is not exceed 1.5 even during 60 min.

The obtained theoretical results were confirmed by experiments. Performed experiments are described in next section.

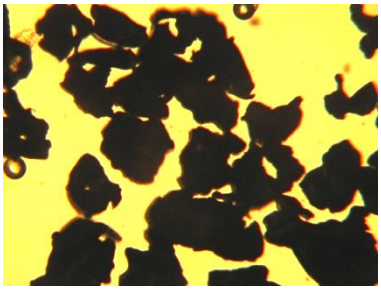
IV. EXPERIMENTAL STUDIES OF CAVITATION DISPERSING

Experimental studies of ultrasonic dispersion were performed to confirm the adequacy of the proposed model.

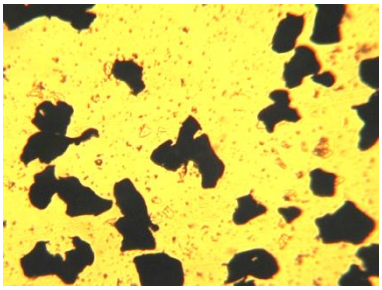
During the experiments aluminum particles with an initial size of 100 ... 400 μm mixed with the water is dispersed by ultrasonic device of series "Volna-M", created by a team of "Center of ultrasonic technologies", Ltd. (Russia, Altay, Biysk) [8].

Dispersing was carried out during 41…43 min at the exposure intensities that are 6 and 10 W/cm^2. The particle size is determined by the sampling and analysis of collected particulate samples using a set of imaging based on optical microscope "MIKMED" (Russia) and high-resolution digital camera.

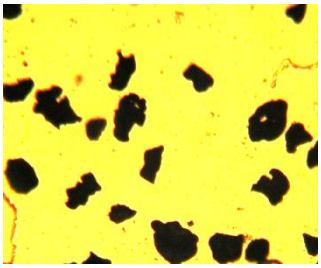
Microscopic picture and particulate composition of samples taken at various time points is shown in Fig. 7, 8.



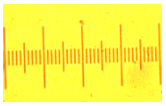
a) 0 min



b) 18 min

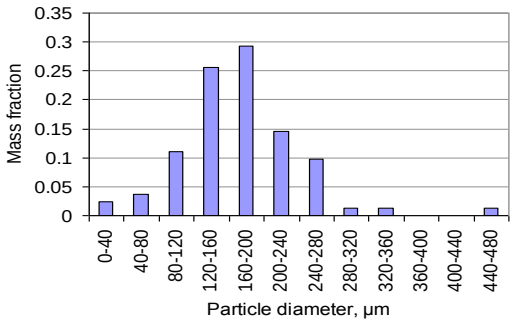


c) 41 min

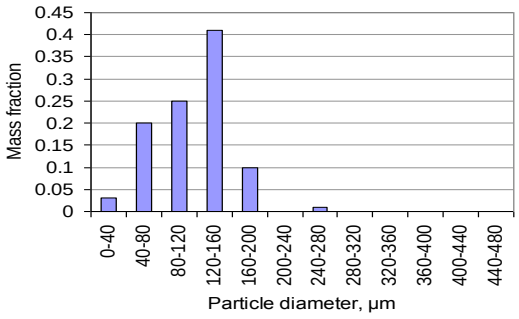


d) Object micrometer (Value of division is 10 μm)

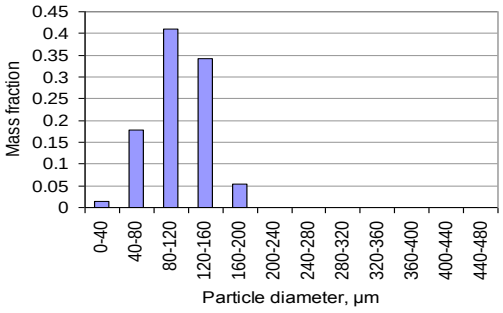
Fig. 7. Microscopic pictures of aluminum particles dispersed at different times (intensity of influence is 10 W/cm^2)



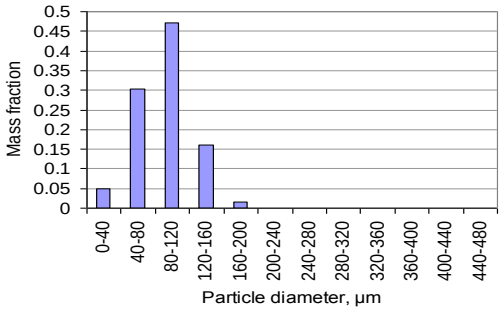
a) 0 min



b) 5 min



c) 18 min



d) 41 min

Fig. 8. Particulate composition of the samples of aluminum particles at different times (intensity of influence is 10 W/cm^2)

These pictures and histograms confirm the theoretical increase in the proportion of fine particles during ultrasonic dispersion.

As has been repeatedly noted, the particulate composition is determined by a specific surface area of contact of phases "liquid-solid body." The experimental dependence in their comparison with the theoretical is shown in Fig. 9.

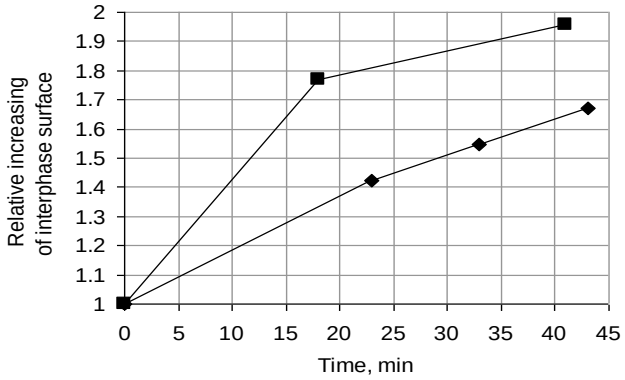


Fig. 9. Theoretical and experimental dependence of the specific surface area of contact between the phases “liquid-solid” on time at different intensities of ultrasonic cavitation influence

According to the given dependences, the experimental curves are different from theoretical curves (See Fig. 5) in less than 20 %. However the difference causes by used assumptions. Thus, the model of ultrasonic cavitation dispersing is adequately.

V. CONCLUSION

Thus in a result of the work the cavitation dispersion model was proposed. It allows evaluating the optimal ultrasonic cavitation influence modes for maximum surface contact between the phases. It was found that the impact of the intensity of 10 W/cm^2 on liquid-solid suspension with viscosity 1 mPa·s (initial diameter 160 μm) causes increase the phase interface area up to the 1.95 times during 40 minutes. And at intensity 6 W/cm^2 interface area of the suspension has been increased up to 1.65 times during 40 minutes.

At greater viscosity 100 mPa·s and at initial diameter 160 μm the necessary intensity of ultrasonic cavitation influence is significantly more than at viscosity 1 mPa·s.

For liquid phase with viscosity 100 mPa·s and initial diameter 160 μm, the interface area increasing more than 1.9 times during 40 minutes is achieved at intensity 17.5 W/cm^2 and more. However, at smaller initial diameters the interface area increasing is less because reducing of breakdown neighborhood volume that causes reducing of particle breakdown probability. For example, at diameter 80 μm, liquid phase viscosity 100 mPa·s and intensity 17.5 W/cm^2 the increasing of the interface area is not exceed 1.5 even during 60 min.

Conducted experimental studies have confirmed the adequacy of the developed model. And evaluated modes of action can be recommended for the design of ultrasonic cavitation devices for dispersing.

VI. Acknowledgements

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