Effect of ultrasound on sedimentation of suspended solids in water

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Abstract. Physico-chemical effects in the aqueous medium that arise in the ultrasonic field contribute to a change in the deposition rate of the coagulated slurry. An indispensable condition for the development of the process is the ultrasonic field in the cavitation regime. There is a change in the potentials of the medium. Experimental studies of the influence of ultrasonic vibrations on the processes of coagulation of suspended solids in the purification of water by physical methods expand their field of use, which is topical. The purpose of the work is conducting experiments on the effect of ultrasound on the deposition of suspended solids and determining the efficiency of the process assigned to the dose of the coagulant, with finding the numerical values of the constants of the theoretical equation. The condition of the experiment is the effect of ultrasound on the water with clay substances before the introduction of the coagulant. The magnetostriction method with the help of an ultrasonic generator of batch production was used to obtain ultrasonic oscillations. When sampling and performing analyzes, standard techniques were used. The concentration of clay particles in water was estimated using a photoelectrocolorimeter. As a result of the studies, data were obtained that allow to determine the increase in the sedimentation efficiency of suspended particles assigned to the coagulant dose, depending on the time of ultrasonic treatment. Experiments have confirmed the relationship between the effect of precipitation in the coagulation process, the dose of coagulant and the time of scoring. As studies have shown, an increase in the duration of ultrasound treatment causes a decrease in the administered doses of the coagulant.

1. Introduction

Various physicochemical effects arising in the ultrasonic field are associated with the transformation of the energy of elastic vibrations. In this case, we can say that they are one of the types of mechanochemical reactions [1, 2]. These effects are accompanied by the phenomenon of cavitation [2].

On the other hand, the elementary processes of sound chemical reactions are close to radiolysis, reactions in an electric discharge, photolysis [3, 4].

Neipairas and Nolting advanced the theory of the occurrence of high temperatures in the adiabatic compression of a cavitation bubble in the process of its collapse [4]. According to their calculations, at a continuously increasing velocity of the bubble-liquid interface, the temperature in the collapsing bubble can reach 10,000 ° K, and the pressure in the shock wave up to 104 atm. [5]. Such high temperatures appearing in the gas-filled bubble cavity can cause the appearance in it of electric charges of dissociated and ionized molecules, atoms, free radicals [6]. Thus, cavitation cavity can serve as a source of formation of products with high reactivity and initiation of physicochemical phenomena in ultrasound field.

Soviet physicist Ya. I. Frenkel suggested the occurrence of electric charges of the opposite sign on the walls of the lens-shaped cavity formed. In the initial stage of cavitation cavity formation, electric charges appear on it. Ya. I. Frenkel believes that when the continuity of the medium ruptures in the places of rarefaction, lens-shaped cavities, rather than spherical cavities, are formed of molecular dimensions. For such a break, a pressure amplitude of the order of 103-104 atm is required.

The transition from the lens-shaped cavity to the spherical cavity occurs as a result of the penetration of dissolved gases or vapors of the surrounding liquid.

The structure of the cavitation cavity is shown in Fig. 1 [7].

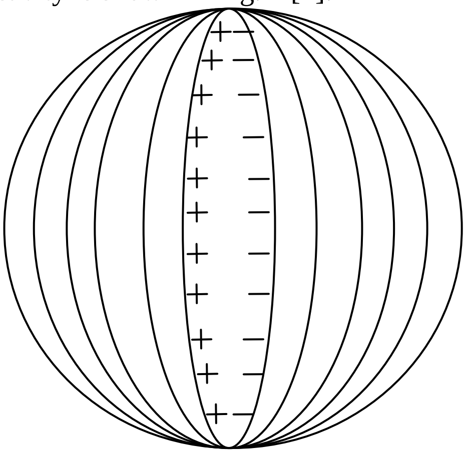

Figure 1. The structure of the cavitation cavity.

According to the theory of Ya. I. Frenkel, under the conditions of an electric discharge, energy-rich particles, ionized molecules and ions, free radicals arise in the cavitation cavity [7].

Assuming that the charges were formed as a result of the uneven distribution of ions on the walls of the bubble when the liquid is ruptured, Ya. I. Frenkel determined the field strength inside the cavity at the time of its formation:

$$E_{п} = \frac{4\bar{e}}{r_{п}} \sqrt{N_{п} \delta_{п}}, \quad (1)$$

where E_p – electric field strength, B/cm;
δ_p – the distance between the ruptured fluid layers, $\mathring{A}$;
N_p – number of dissociated molecules per the volume unit;
r_p – radius of cavitation cavity, sm;
$\bar{e}$ – electron charge, C.

Experimental studies of the coagulation process under the action of ultrasonic vibrations were carried out by R. Parker [8]. The experiments were done on the smoke of magnesium oxide in the air. It was noted that in the absence of an acoustic field, normal coagulation and the settling process were negligible.

There are examples of the use of coagulating effects of ultrasound in the deposition of suspended matter. At intensities of the order of 0.3 - 0.5 W / cm2, ultrasound promotes the coagulation of suspended particles. The sounding of a suspension of calcium carbonate (particle size 47 μm), quartz dust (23 μm) and anthracite (76 - 152 μm) leads to an acceleration of the settling process.

Studies were made of the possibility of coagulation of high-ash coal suspensions by polymers and ultrasound. For experimental studies, a high-pressure ultrasound generator (HPUG) -2 was used with a frequency range from 0.1 to 10.0 MHz [9, 10].

Studies carried out at the All-Union Scientific Research Institute VODGEO on ultrasonic

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coagulation of fine-dispersed systems L - T and L - L (iron hydrosol, activated sludge, polystyrene latex, copper ore concentrate, watered coal tar, etc.) have shown that ultrasound effects coagulate fine-dispersed systems with a particle size of 1 to 5 μm; For the L - T system, the best results take place at a frequency of 8-18 kHz, and for the L - L system at a frequency of 400-800 kHz. With increasing intensity of ultrasonic oscillations, the coagulation effect increases.

Coagulation of liquid systems, for example, an aqueous suspension of Al_2O_3 under the influence of ultrasound, is observed. Experiments have shown that after a few minutes, a sharp coagulation of the suspension is observed, whereas under normal conditions it is completely absent [11, 12, 13].

Analyzing the above, we can say that ultrasonic vibrations in the water system can have a significant effect on the processes associated with the oxidation of the impurity, with the phenomenon of crystallization and with the coagulation of suspended solids.

It should be emphasized that the required effect for the above processes in the ultrasonic field can be achieved only if there is a cavitation regime in the volume. The process by which ultrasound can be affected is the coagulation of a fine dispersion in water [14].

- The goal of the work.

The goal of this work is to carry out experimental studies on the deposition of suspended solids in an ultrasonic field and to obtain data that allow us to verify the theoretical equation [15, 16, 17, 18]

$$\frac{\Delta G}{G \cdot q} = a + b \cdot t, \tag{2}$$

where a and b – constants;
G – concentration of clay particles per unit volume of water, mg/l;
ΔG – concentration of settled clay particles, mg/l;
q – coagulant dose, mg/l for Al_2O_3;
t – time of the scoring, minutes.

- The task of the paper.

The task of the paper consists in obtaining numerical values of the constants a and b of the theoretical equation (2) and in determining the relative standard deviation (dispersion) [19].

2. Methods

The main experiment was the deposition of clay particles with a concentration of 120 mg / l with the addition of coagulant - aluminum salts with a dose of Al_2O_3 - 2.5, 5.0 and 10.0 mg / l to water [20, 21].

The ultrasonic field cavity in the water was maintained by an ultrasonic generator (USG) -2-4 and a magnetostrictive transducer (TMS) 6-22 (frequency and intensity for excitation in cavitation water f = 18-22 kHz, I = 2.0 Wt / sm2).

Preliminary treatment of water with suspended clay particles was performed by ultrasound for 0.1; 0.5; 1.0; 2.0 and 5.0 minutes. The concentration of clay particles in water was estimated by standard methods using a photometric method by comparing the samples of the water under investigation with standard suspensions (GOST (State Standard) 33 51-74 C.4)

3. Results

To test the theoretical equation (2), a decrease in the concentration of clay particles suspended in water was determined as the difference between the initial and final concentrations (the deposition process is complete). As a value characterizing the deposition process, the ratio of the decrease in the concentration ΔG to its final value G2 attributed to the dose of the coagulant to be injected.

Experimental data on the effect of ultrasound on the coagulation process are placed in Table 1.

Table 1. Experimental data.

No	Initial concentration of suspension *G*, mg/l	Final Concentration of Suspension G_2, mg/l	Decrease in the concentration of suspension ΔG, mg/l	Time of the scoring *t*, min	Coagulant dose *q*, mg/l	$\frac{\Delta G}{G_2 q}$
1	120	91	29	0.5	2.5	0.1
2	120	83	37	1.0	2.5	0.12
3	120	71	49	2.0	2.5	0.16
4	120	51	69	5.0	2.5	0.23
5	120	69	51	0.17	5.0	0.09
6	120	66	54	0.5	5.0	0.09
7	120	57	63	1.0	5.0	0.11
8	120	54	66	2.0	5.0	0.11
9	120	34	86	5.0	5.0	0.14
10	120	114	6	0	2.5	0.023
11	120	86	34	0	5.0	0.079
12	120	31	89	0	10.0	0.287

As can be seen from the experimental data of Table 1, the maximum precipitation of clay particles was observed at a dose of 10 mg / l of the coagulant in Al_2O_3 without ultrasound treatment, which is the MAX level.

When measuring the concentrations of suspended solids, the instrument constant was determined, allowing one to switch from its scale to the weight concentrations of clay particles in the water. It was established for the case of stationary uniform distribution of particles in a given volume of water, so the colorimeter measured the concentration of particles in the water only before the start of the experiment (initial concentration) and after all the coagulated flakes settled, and in water there was a final (residual) concentration of only one clay particles. All intermediate indications of the device cannot fix the clarification process as such, but only indicate the duration of the dynamics of the process.

Processing of the measurement results.

The statistical processing of the experimental data was performed with the aim of finding the coefficients a and b in equation (2), and also the relative RMS deviation (variance) of experimental values was calculated [19].

Based on the experimental data on the sedimentation of suspended solids using the cavitation regime in the ultrasonic field, we form the figure 2. For the calculation, the following notation is adopted: the time of scoring $t = x_k$, the ratio of the concentration of settled clay particles to the final concentration of suspended matter, referred to the coagulant dose $\frac{\Delta G}{G_2 q} = y_k$. Deviations from the arithmetic mean of the k - x experimental results were used in the calculation.

Table 2. Experimental - calculated data.

No	$t = x_k$	$\frac{\Delta G}{G_2 q} = y_k$	$x = \overline{x} - x_k$	$y = \overline{y} - y_k$	$x \cdot y$	x^2	y^2
1	2	3	4	5	6	7	8
1	0.5	0.1	+1.41	+0.028	+0.039	1.990	0.0008
2	1.0	0.12	+0.91	+0.008	+0.007	0.828	0.00006
3	2.0	0.16	-0.09	-0.032	+0.003	0.0081	0.001
4	5.0	0.23	-3.09	-0.102	+0.315	9.548	0.0104
5	0.17	0.09	+1.74	+0.038	+0.0066	3.027	0.0014

6	0.5	0.09	+1.41	+0.038	+0.054	1.988	0.0014
7	1.0	0.11	+0.91	+0.018	+0.016	0.828	0.00032
8	2.0	0.11	-0.09	+0.018	-0.002	0.0081	0.00032
9	5.0	0.14	-3.09	-0.012	+0.037	9.548	0.00014
∑	17.17	1.15			0.535	27.77	0.0164
Average value	1.91	0.128			0.0594		

The calculation was made by the formula

$$K_{xy} = \sum_{k=1}^{n} x_k y_k - \overline{xy}, \tag{3}$$

while from the coordinates of all the experimental points we subtract the coordinates of some point located in the middle of the area [19].

The correlation coefficient is determined by the formula

$$r = \frac{\overline{xy}}{\sigma_x \sigma_y}, \tag{4}$$

where σ_x and σ_y are the standard deviation.

To calculate the dispersion formulas were used

$$\sigma_x^2 = \frac{1}{n}\sum_{k=1}^{n}\left(x_k - \bar{x}\right)^2 \text{ и } \sigma_y^2 = \frac{1}{n}\sum_{k=1}^{n}\left(y_k - \bar{y}\right)^2, \tag{5}$$

substitute the obtained experimental data and calculate the values with respect to *x*

$$\sigma_x^2 = \frac{27.77}{9} = 3.09,\ \sigma_x = \sqrt{3.09} = 1.76; \tag{6}$$

and also on *y*

$$\sigma_y^2 = \frac{0.0164}{9} = 0.00182,\ \sigma_y = \sqrt{0.00182} = 0.0425; \tag{7}$$

then we find the correlation coefficient

$$r = \frac{0.0594}{1.76 \cdot 0.0425} = \frac{0.0594}{0.075} = 0.79. \tag{8}$$

We use the general expression (9) for calculating the coefficients according to equation (2)

$$y - \bar{y} = \frac{\sum xy}{x^2}\left(x - \bar{x}\right). \tag{9}$$

It is taken as y (ordinate), and on it the value of the expression $\frac{\Delta G}{G_2 \cdot q}$ was plotted and on the *x*-axis (abscissa) -expression in the form $x = t$, then we can write

$$\frac{\Delta G}{G_2 \cdot q} - \bar{y} = \frac{\sum xy}{x^2}\left(t - x\right). \tag{10}$$

When the obtained numerical values are substituted, expression (10) takes the form

$$\frac{\Delta G}{G_2 \cdot q} - 0.128 = \frac{0.535}{27.7}\left(t - 1.91\right). \tag{11}$$

As a result of solving equation (11) we get equation (12)

$$\frac{\Delta G}{G_2 \cdot q} = 0.071 + 0.03 \cdot t. \tag{12}$$

The obtained equation (12) is substituted for the values of t and the ratio $\frac{\Delta G}{G_2 \cdot q}$ was calculated, the results of which are given in Table 3.

Table 3. Results of calculations with the duration of ultrasound treatment from 0 to 5 minutes.

t (minutes)	0	1	2	3	5
$\frac{\Delta G}{G_2 \cdot q}$	0.071	0.101	0.131	0.161	0.221

Graphical representation of the obtained data (Table 1, Table 2 and Table 3) is shown in Figure 2:
– experimental and theoretical values;
– theoretical line;
– MAX level;
– area of maximum dispersion, equal to3σ.

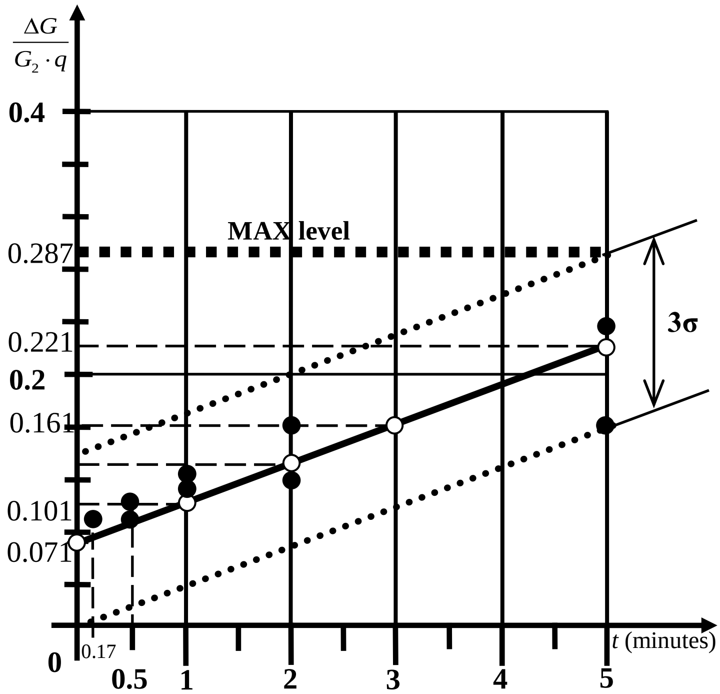

Figure 2. Schedule of changes in the relative content of suspended solids in water treated with a coagulant from the duration of ultrasound exposure.
○ – theoretical points, ● – experimental points

The graph of Figure 2 shows the values $\frac{\Delta G}{G_2 \cdot q}$ depending on the time of the scoring *t*. The treatment of water containing suspended solids with the ultrasound, in all cases remained preliminary, i.e. before the introduction of the coagulant, as was previously suggested about the possible effect of ultrasonic vibrations on suspended substances.

The graph shows a horizontal dashed line, passing through a value $\frac{\Delta G}{G_2 \cdot q} = 0.287$, that shows the maximum level with a 10 mg / l coagulant dose of Al_2O_3 (without scoring, Table 1).

As can be seen from the graph of Fig. 2, the experimental points lie in the region of a possible spread of 3σ. Thus, the assumption of the description of the phenomenon of coagulation using ultrasound is confirmed by the equation (2).

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4. Conclusions

1. Experimental studies confirmed the above assumptions about the change in the potentials of suspended particles in water, as a result of the action of an ultrasonic field.
2. The change in potentials under the action of ultrasound leads to an increase in the deposition effect.
3. Numerical values of the constants a and b of the theoretical equation (2) are determined.
4. Statistical processing of the experimental data made it possible to obtain a scatter region equal to 3σ.
5. The performed experiments confirmed the relationship between the quantities:
   – duration of scoring;
   – coagulant dose;
   – sedimentation effect during coagulation.
6. Increasing the duration of ultrasound treatment leads to a reduction in the injected doses of coagulant.

Experimental studies and mathematical calculations have shown that the effect of sedimentation of suspended solids in water, depending on the time of scoring and the dose of the coagulant, increases threefold.

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