

Experimental Description Of Sedimentary Events And Their Potential Development

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Abstract – Colloidal chemistry is one of the leading fields of chemical science, covering the largest area of nature and human activity, from cosmic nebulae to the earth, to the vital nutrients of living nature, to the maintenance of human life-sustaining organ Systems, etc. One of the leading parts of colloidal chemistry is electrokinetic phenomena, including parameters such as the sedimentation potential and the double electric layer of the colloidal particle and their relative influence on sedimentation processes. We chose silicon dioxide - the main constituent of natural silicates - as the main solid, dispersive phase for the main study of this master work.

The Zetasizer Nano ZEN 3690 was used to test the particle size distribution of silicon dioxide used in the experiment, which showed that the experimental silicon powder consisted of four fractions particle sizes are given in $90 \div 300$ nm and $460 \div 710$ nm.

The measurement accuracy of the experimental data was checked for all measurements, for digital millivolt-milliampere meters, with a potentiometer of the 0.05 accuracy class. It was found that the measurement accuracy of the measuring instruments was 99.9%, which is completely satisfactory for conducting a quality experiment. Mathematical formulas for 100% accuracy of their data are also developed for all measuring instruments.

Three systems were studied - "SiO₂ - distilled water", "SiO₂ - NaCl - distilled water" and "SiO₂ - KCl - distilled water". The amount of dispersion phase varied during the experiment - at intervals of 0.25, 0.5, 1, 2, 4 and 8 g per 100 ml of dispersion medium solution. Dispersion also changed the chemical composition of the experiments and the number of cations dissolved in the dispersion medium - Na⁺ and K⁺, while the anion type (Cl⁻) did not change.

Finally, it was found that more than 80% of the results of the obtained experimental dependence $\varphi_{\text{sed}} = f(\tau)$ are of a similar nature. The formula $\varphi_{\text{sed}} = f(\tau)$ represents a relationship between the sediment volume fraction (φ_{sed}) and the shear stress (τ) in the context of sedimentation. In sedimentation, particles in a fluid tend to settle under the influence of gravity or other forces. The sediment volume fraction (φ_{sed}) is a measure of the proportion of a fluid's volume occupied by sediment particles. The function $f(\tau)$ indicates that the sediment volume fraction is dependent on the shear stress (τ) experienced by the fluid.

Typical sedimentation processes are divided into two parts - fast and slow coagulation areas. It has also been shown what kind of mathematical models can be used to describe these models with 99% accuracy in matching experimental data. This work belongs to a theoretical, fundamental science approach that integrates and deepens classical approaches to sedimentation potential.

Keywords – Sedimentation potential, Silicon dioxide, Suspensions, Hoppler Viscosimeter.

I. INTRODUCTION

Colloid chemistry is one of the leading branches of chemical science, covering a large area of nature and human activity from cosmic nebulae to the Earth, vital food processes of living nature, human life-capable organ systems, etc.

One of the leading parts of colloidal chemistry is electrokinetic phenomena, which studies such processes as the sedimentation potential, the surface electric double layer of colloidal particles and their influence on sedimentation processes. The latter plays a decisive role in the production technologies of various types of products. For example, in the technologies of making dairy products. Such approaches are the basis of the origin-formation processes of sedimentary rocks in geology. Silicate rocks common on earth are mainly involved in such geological processes. Therefore, the study of sedimentation phenomena in silica dispersed phase suspensions was chosen for the study.

Zeta-sizer Nano ZEN 3690 was used to examine the particle size distribution of the silica present in the experiment, which showed that the silica powder consisted of four main fractions in the particle size range of $90 \div 710$ nm.

The accuracy of measuring the experimental data of the digital millivolt-milliammeter measuring the sedimentation potential was checked with a 0.05 accuracy class potentiometer. It was found that the measurement accuracy of the used measuring instruments was 99.9%, which is quite satisfactory for conducting a qualitative experiment. Before starting the experimental works, mathematical formulas were developed, which were used to convert the data obtained from the milliamper-voltmeter to 100% accuracy.

During the entire sedimentation experiment, three systems were studied - "SiO₂ - distilled water", "SiO₂ - NaCl - distilled water" and "SiO₂ - KCl - distilled water". During the experiment, the amount of the dispersed phase was changed - in the interval of $0.25 \div 8$ g for every 100 ml of the dispersed solution. During experiments, the type and concentration of cations (Na⁺ and K⁺) in suspensions changed along with the amount of dispersed phase, while the type of anion (Cl⁻) did not change.

Sedimentation in highly dispersed colloidal systems is a process during which the particles of the dispersed phase move in the dispersion area in the direction of the force of gravity and form a precipitate [1-3]. When the sediment layer is formed, we can visually see that they are arranged in a certain regularity. Various methods of consolidating sediment are known, for example, natural sedimentation caused by the force of gravity of colloidal systems, centrifugation or sedimentation on an inclined plane. During such processes, a thickened-compacted or pressed sediment is obtained.

II. EXPERIMENTAL APPROACHES

During the course of the experiment, the natural sedimentation of the polydisperse phase caused by the force of gravity in colloidal systems, which is the main process of the research topic, was discussed. Let's start the discussion from the simplest case, let's imagine that one particle of the dispersed phase of a spherical shape with a certain radius sinks (sediments) in the liquid. Then we will gradually complicate the approach to the sedimentation process. A schematic description of the device for studying such a task is shown in Fig. 1 [4, 5].

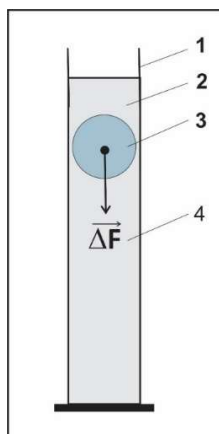


Fig. 1. A simplified form of the tool for studying sedimentation processes, where 1 - vessel wall, 2 - dispersion area, 3 - sedimentable dispersed phase particle.

An instrument like a Hoppler viscometer was used to study the sedimentation phenomena. Let's start with the fact that the sedimentation rate of dispersed phase particles is directly proportional to the magnitude of the force coefficient ($\overline{\Delta F}$) acting on the particle (particles). ($\overline{\Delta F}$) is the resultant force of the simultaneous action of three different forces. The forces acting on the particle are [3]:

1. Force of gravity – F_{gravity} ;

2. Archimedes' repulsive force – F_{arch} ;
3. During sedimentation, the frictional force acting on the particle from the liquid side of the dispersion medium – F_{friction}

The force of gravity acting on astronomical objects (including the Earth) is formed by two components - the first one is the gravitational pull, and the second one is the centrifugal force. Since the second denominator for the earth does not reach even one hundredth of a percent compared to the first one, it is accepted that the force of gravity on the earth is equal to:

$$\overrightarrow{F_{\text{gravity}}} = m\vec{g} \quad (1)$$

where m is the mass of the body, and $g=9.81 \text{ m/s}^2$ and it is the acceleration of free fall. If we take into account that in our simplified situation one spherical particle with radius r and partial density ρ is sedimenting, then formula (1) can be presented in the following form:

$$\overrightarrow{F_{\text{gravity}}} = m\vec{g} = \frac{4}{3}\pi r^3 \rho_{\text{particle}} \vec{g}$$

Archimedes' repulsive force, which acts on a body (particle) immersed in a liquid or gas of a certain density and is directed against the force of gravity, is also well known to everyone. The Archimedean force is calculated by the following formula:

$$\overrightarrow{F_{\text{arch}}} = \frac{4}{3}\pi r^3 \rho_{\text{envir}} \vec{g}$$

where r is the radius of the spherical particle of the dispersed phase, its volume is $\frac{4}{3}\pi r^3$, ρ_{envir} is the density of the dispersion medium, and $\vec{g}$ is the total fall acceleration.

During sedimentation in the laminar motion mode ($Re \leq 2300$), the frictional force acting on the particle from the liquid side is calculated by the formula by Stock:

$$\overrightarrow{F_{\text{friction}}} = 6\pi\eta rV$$

where r is the radius of the spherical particle of the dispersed phase, η is the dynamic viscosity of the fluid medium, and V is the sedimentation rate of the dispersed phase particle during sedimentation.

When considering the sedimentation processes, attention is paid to the density of particles of the dispersed phase, which includes information on their mass and volume, so it is one of the main parameters that can be used to calculate and characterize the sedimentation rate. For particles of different mass and size, the difference in the sedimentation speed can be used to separate the particles participating in the Brownian movement with different sedimentation speeds (sedimentable particles are referred to as Brownian particles in the literature [4 - 6]).

The biggest problem in the description and calculation of the sedimentation flow caused by the gravitational force is the continuous interaction between the particles of the dispersed phase, i.e. the frictional force between such particles, which reduces the sedimentation rate. During sedimentation, the resistance acting on the particles of the dispersed phase from the liquid of the dispersion medium (the same frictional force) has a similar effect. In the description of sedimentation processes, the amount of friction generated during the sedimentation of particles of the dispersed phase on the walls of the research instrument and the friction force of the ascending masses of the convective fluid on the same walls are equally important and acceptable.

During sedimentation processes in suspensions, great attention is paid to the density ratio of the dispersed phase and the dispersion medium. Three options can be considered here:

1. As the density of the dispersed phase (ρ_{phase}) is greater than the density of the dispersion medium (ρ_{envir}), then gravitational sedimentation begins, which is caused by the force of gravity. At this time, the sedimentation process leads to the separation of the dispersed phase and dispersion particles, as a result of which the final formation of the sedimentary layer ends.
2. When $\rho_{\text{phase}} \approx \rho_{\text{envir}}$, in such a case, the process of forming the so-called colloidal cream is taking place, that is, the particles of the dispersed phase will be balanced in the total volume of the suspension, and a sludge-like sediment will no longer be obtained.
3. When $\rho_{\text{phase}} < \rho_{\text{envir}}$, then mainly flotation processes occur in suspensions.

The subject of interest of the experiment is gravitational sedimentation, after the completion of which the former colloidal suspension is divided into two parts, a sediment containing a high concentration of particles of the dispersed phase and a purified supernatant due to the sedimentation process of the diffuse phase above it, i.e. a substance of a pure dispersion environment. A separating surface is formed between them, below which sediment with a high mass fraction of the dispersed phase is formed [7-9].

In most literary sources, it is widely assumed that particles of the dispersed phase during sedimentation do not interact with each other, except directly, during the so-called "repulsion-contact" (the contact at the level of the sliding surface of the double electronic layer is an electrostatic repulsion between two micelles due to the same sign of the zeta potential [10, 11]).

Based on various sources, we can actually conclude that there is no minimum separation distance between two colloidal particles, the same as between micelles (Brownian particles).

Although this assumption may hold for larger (non-colloidal sized) particles, it may not be appropriate for highly charged colloidal particles, since the strong charges of the same sign on the surfaces of colloidal particles lead to the action of attractive forces of a strong electrostatic nature, which virtually cancel at a minimum distance limitation principle [12-14].

The scheme of the device for performing experimental work is shown in Fig. 2. The electrical signal obtained during the sedimentation of dispersed phase particles was entered into the ion-meter to amplify it. The amplified signal was entered into the digital multimeter for measurement and recorded in the program.

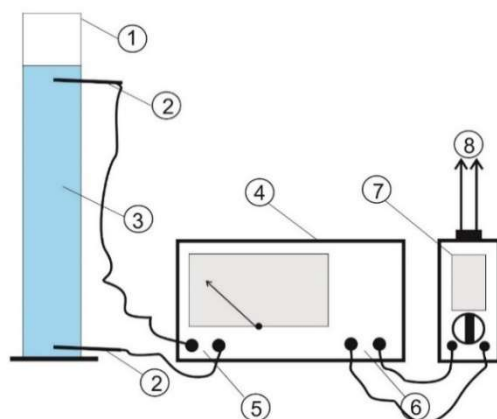


Fig. 2. Schematic of the sedimentation study device: 1. Cylinder for managing the sedimentation process; 2. Platinum electrodes; 3. dispersion environment; 4. Ion-meter; 5. Signal entering the ion-meter (voltage generated during sedimentation); 6. The amplified stable signal coming out of the ion-meter; 7. measuring electric multimeter; 8. The signal from the electric multimeter to the computer.

To check the size distribution of silica particles in the studied suspensions, we used Zetasizer Nano ZEN 3690, which showed that the experimental silica powder consisted of four fractions) in the size range of $90 \div 300$ nm and $460 \div 710$ nm.

The following four main fractions of particles were clearly identified in silicon dioxide powder (see Fig. 3):

1. $3 \div 4.3$ nm fraction with a base width of ~ 1.3 nm and a maximum number of 3.8 nm particles;
2. $25 \div 77$ nm fraction with a base width of ~ 52 nm and a maximum number of 33 nm particles;
3. $90 \div 300$ nm fraction with a base width of ~ 210 nm and a maximum number of 169 nm particles;
4. fraction of $460 \div 710$ nm with a base width of ~ 250 nm and a maximum number on particles of 605 nm size;

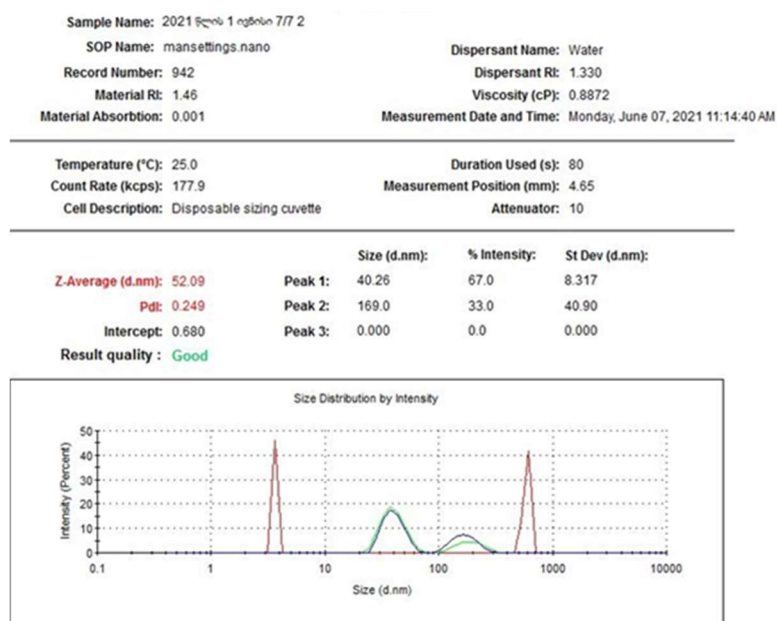


Fig. 3. Results of the sedimentation analysis conducted through Zetasizer Nano

During the experimental work, the highest sedimentation potential was observed: 0.25 g SiO₂, 100 ml H₂O (see Fig. 4.). At the beginning of the sedimentation process, the milliampere-voltmeter showed a voltage of 170 mV. The voltage dropped to 70 mV over a period of about 18 minutes. For 23 minutes, it is clearly visible on the curve how the value of the sedimentation potential increased monotonically, which was equal to 85 mV at the end of the experiment.

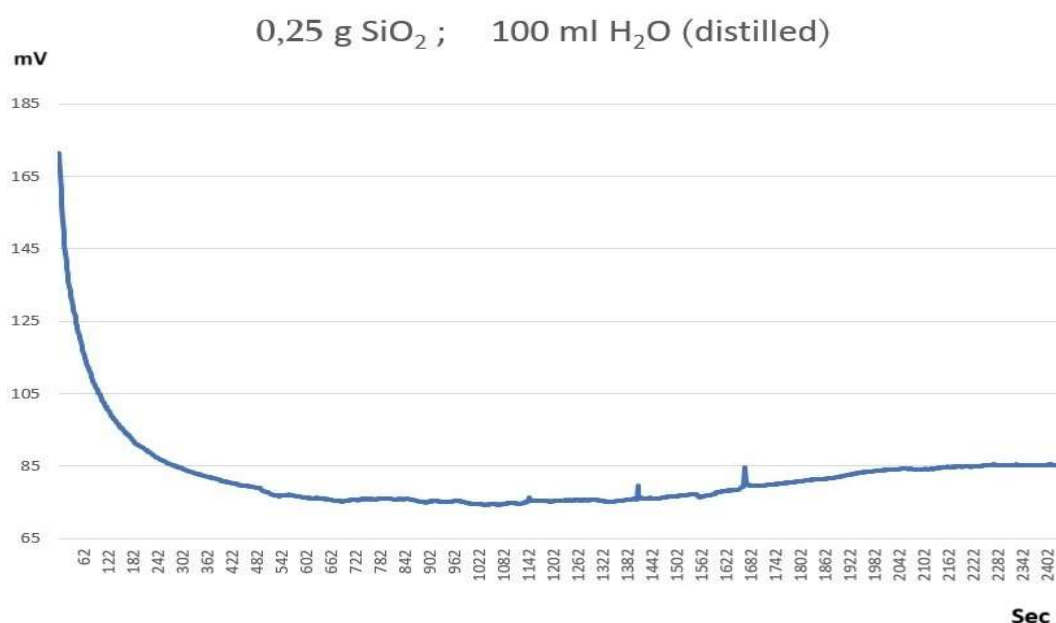


Fig. 4. Dependence of the sedimentation potential of the suspension with the composition of 0.25 g of silicon dioxide powder and 100 ml of distilled water on the sedimentation time.

Experiments have shown that a double electric layer is formed on the surface of silicon dioxide particles, after which they move with a certain amount of surface charge from the surface of the suspension to the bottom of the chemical vessel. Various forces come into play during the sedimentation process, which presumably cause the dips seen in the experimental curves. These forces are the error of the electric field and the ion-meter, as well as the minimal mechanical impact of the environment on the suspension placed in the cylindrical vessel at the time of reading [5].

The sedimentation process shown in Fig. 4 can be divided into two parts, fast sedimentation in the interval of 0÷698 s and slow sedimentation in the interval of 698÷2402 s. Accordingly, the numerical array of experimental data was divided into two. The experimental data arrays were processed separately with the Advanced Grapher 2.2 program, as a result of which we obtained the mathematical equation-models of $V_{sed}=f(\tau)$ describing the fast and slow sedimentation process:

1. Descriptive equation of rapid sedimentation and characteristic parameters of its accuracy:

$$\varphi_{sed} = 257.9079628 * \tau - 0.1328512$$

Standard deviation – 1.666

R²=0.9901

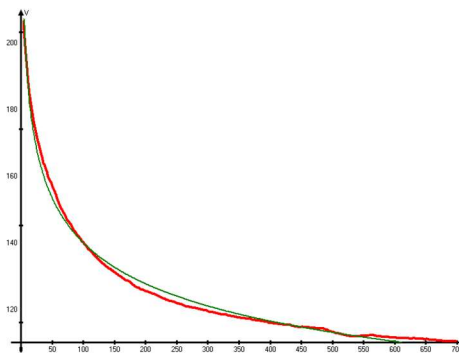


Fig. 5. Accuracy of graphical description of rapid sedimentation

2. 4th degree polynomial equation describing slow sedimentation and its accuracy characteristic parameters:

$$\varphi_{\text{sed}} = -7.7892098 \cdot 10^{-12} \cdot \tau^4 + 4.0365132 \cdot 10^{-8} \cdot \tau^3 - 6.5443284 \cdot 10^{-5} \cdot \tau^2 + 0.0389643 \cdot \tau + 103.9450929$$

Standard deviation: -0.3457

$$R^2 = 0.9926$$

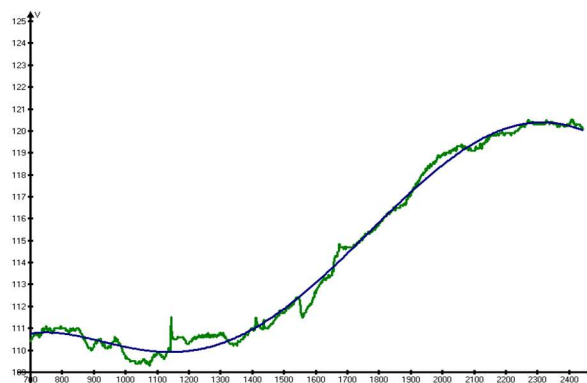


Fig. 6. Accuracy of graphic description of slow sedimentation

III. CONCLUSIONS:

1. It is determined that the experimental silicon dioxide powder consisted of four main fractions:
 $3 \div 4.3 \text{ nm}$, $25 \div 77 \text{ nm}$, $90 \div 300 \text{ nm}$ and $460 \div 710 \text{ nm}$. which is measured by "Zetasizer Nano ZEN 3690".
2. During the experiment, the amount of the dispersed phase was changed in the interval of 0.25, 0.5, 1, 2, 4, 8 grams in 100 ml of dispersion medium solution. At the same time, the chemical composition of the dispersion medium was changed and three systems with different percentages of distilled water, Na^+ and K^+ cations were considered. In the dispersion area containing Na^+ and K^+ cations, the number of anions, namely Cl^- , was unchanged.
3. It is established that the dependence of the speed of the sedimentation process on time is strictly correlated with the amount and concentration of the dispersion electrolytes. Their experimental similarity with each other is $\sim 80\%$, and mathematical models of these relationships provide $\sim 99\%$ counting accuracy.

The future goal of the work is a complete analysis of the sedimentation process based on results that are reliable and relevant to the scientific community. The change of sedimentation potential in the process of sedimentation should be

examined and described in detail. That is why further researches will be constantly aimed at both theoretically and experimentally correct description of sedimentation processes.

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