EXPERIMENTAL STUDIES AND SIMULATIONS ON GRAVITATIONAL SEDIMENTATION OF THE SOLID POLUTANTS IN SUSPENSION

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Abstract
Sedimentation of suspensions process is important, especially in pollution and biologic studies. Unlike usual methods, as those using pipettes, aerometer or balances, the optical ones are nondestructive and more accurate. During the sedimentation produced by the braked fall off the solid particles in suspension, fluctuations induced by an opposite vertical diffusion occur. We used a scattering method, based on the attenuation of a laser beam, which allows plotting sedimentation curves (the dependence on time of the suspended solid particles concentration) of the process. We obtained an empirical relation describing sedimentation curves as a function of some main parameters (related to initial concentration, height in suspension, dimensions of suspended solid particles) and we performed a simulation of the experimental sedimentation curves using the obtained relation and Mathcad software facilities. We notice that the results of these studies allow using a fast method in order to determine the sedimentation time, which often can be very long.

Keywords: light scattering, gravitational sedimentation, sedimentation time

1. INTRODUCTION

A suspension contains solid particles mixed in liquid. Gravitational sedimentation occurs under the action of the field of the gravitational force. The features of the process depend on dimensions, form, concentration and chemical nature of the suspended particles [4].
During the sedimentation, two processes are important: the fall of the particles (under the action of the weight and of the resistant force in liquid) and the vertical diffusion produced by the difference of density which occurs as a result of the first process [3].
Supposing that the initial concentration is the same in the whole volume of the suspension, that the particles are approximately spherical and they do not chemically react, the analysis of the movement of particles across a thin layer considered in the suspension (figure 1) leads to the equation (1) for the dependence c(x,t) on the height x and time t [1].

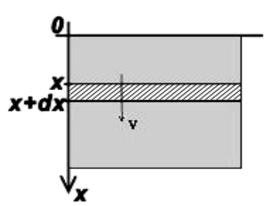

Figure1 Movement of a solid particle through the suspension

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2} - v\frac{\partial c}{\partial x} \quad (1)$$

It is difficult to find a general and simple solution c(x,t) of the equation (1) [2]. However, one can observe that $\frac{\partial c}{\partial t}$ can be positive or negative (concentration increase or decrease as a function of time), as long as the term $D\cdot\frac{\partial^2 c}{\partial x^2}$ is bigger or smaller than the term $v\cdot\frac{\partial c}{\partial x}$. During the sedimentation, fall or diffusion can prevail in different periods and the equilibrium between these processes is possible in some moments. Thus, fluctuations of the concentration can occur during the sedimentation.

2. EXPERIMENTAL METHOD AND RESULTS

2.1 Experimental Method

The experimental used set-up (figure 2) is based on the scattering of a laser beam produced by suspended particles in a suspension. The attenuation of the incident beam describes the concentration of solid particles in the region of the suspension crossed by the laser beam;

concentration as a function of time, in different h positions, can be measured.
A He-Ne laser 10 mW power and a selenium photoreceiver were used in order to investigate the concentration of some suspension of SiO_2, $Al(OH)_3$ and $Mg(OH)_2$ in water. The error in the concentration determination was about 2 %.

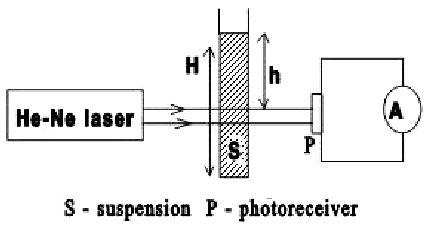

Figure 2 Experimental set up

Let I_0 - incident, I_i and I(t) initial and at t moment intensities of the transmitted beam, c_i and c(t) - initial and at t moment concentration of the studied suspension. We can write:

$$I_i = I_0 \cdot e^{-A \cdot c_i},\ I(t) = I_0 \cdot e^{-A \cdot c(t)} \quad ; \quad A - \text{constant}$$

where from:

$$\frac{c(t)}{c_i} = \frac{1}{\ln \frac{I_0}{I_i}} \cdot \ln \frac{I_0}{I(t)} \qquad (2)$$

2.2 Experimental Results

We determined dependencies $\frac{c(t)}{c_i}$ at several h depths, for different initial concentration.
Some experimental obtained sedimentation curves are presented below (figures 3,4,5).
One can observe that sedimentation time increase with the depth in suspension, i.e. a higher volume of suspension has a slower decantation than a lower one.
In the absence of the vertical diffusion, the decrease during the time of the concentration would be exponential; exponential shape of the curves is modified because of the vertical diffusion of the solid particles, which generates fluctuations of the concentration. The duration and the amplitude of the fluctuations increase with the depth in suspension, fact shown by the normalized sedimentation curves (representation as function of t/τ, τ– sedimentation time for all depth of measurement) presented in figure 4.

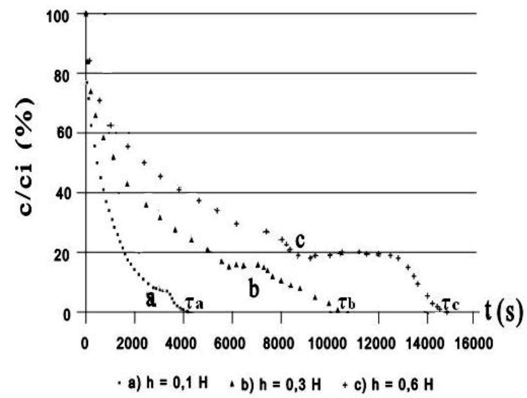

Figure 3 Sedimentation curves at several depths in suspension, for the same initial concentration and over 10 µm dimension of the particles.

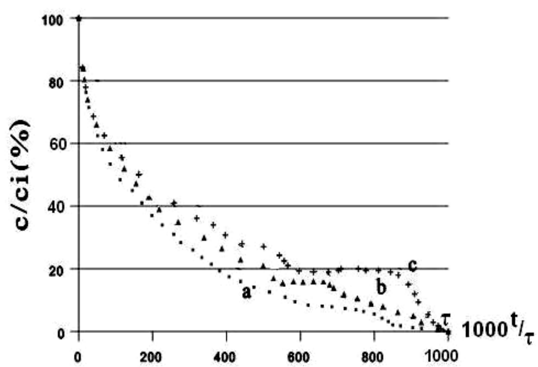

Figure 4 Normalized sedimentation curves

The studies on sedimentation also point out the influence of the dimensions of the solid particles on the process. The features of the sedimentation curves are strongly influenced by the size of these dimensions.
When these dimensions are over 10 µm, the braked fall prevails against the vertical diffusion and the c(t) dependence is approximately an exponential decrease, as in figures 3 and 4.
For dimensions under 10 µm, diffusion prevails and c(t) is a function as in figure 5. Because of the vertical diffusion, the concentration of solid particles can exceed the initially concentration at the beginning of the process. Also, in case of

small dimensions, fluctuations of the concentration occur and intensify as dimension decrease, so that, for under 1 μm dimensions of the particles, sedimentation becomes a very slow process (because of the equilibrium between fall and diffusion); the movement of the solid particles becomes hap hazarded, like Brownian movement.

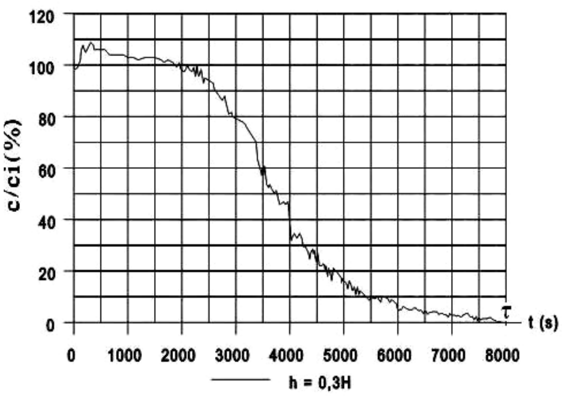

Figure 5 Sedimentation curve for small (6 μm) dimension of particles in suspension

The experimental results and the basic physical processes involved (braked gravitational fall and opposite vertical diffusion) suggest for the dependence of time of the concentration a function as:

$$c(t) = c_i(t)\,[\,\exp(-\frac{t}{a}) + b\exp(-\frac{(t-c)^2}{d})] \qquad (3)$$

where the first term in square bracket describes the fall and the second the diffusion (on the form of Gauss curve).

This is an empirical relation, which express only the evolution in time of the concentration of solid particles in suspension. The relation contains a number of four parameters (a, b, c, d), whose significance will be further presented in the paper.

3 SIMULATION

Using Mathcad software facilities, we plotted a function such as that expressed by (3) and scanned different values of the parameters a, b, c, d.

We noticed that, defining different values of the mentioned parameters, we get all kinds of sedimentation curves experimentally obtained, as those presented below in figure 6.

Let consider a function of the form:

c(x)=exp(-x/a) + b.exp{1/d *.(x-c)^2}

$$x := 0, 0.1 ... 3000$$

$$f(x) := e^{-\left(\frac{x}{300}\right)} + 0.1 \cdot e^{-\frac{(x-800)^2}{40000}}$$

$$g(x) := e^{-\frac{x}{600}} + 0.06 \cdot e^{-\frac{(x-1800)^2}{80000}}$$

$$m(x) := e^{-\frac{x}{400}} + 0.75 \cdot e^{-\frac{(x-600)^2}{200000}}$$

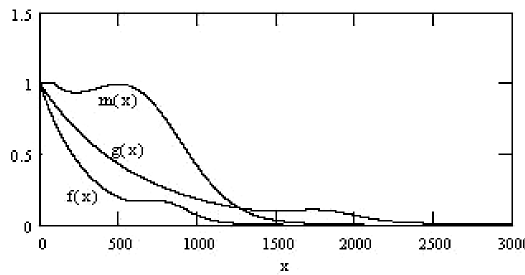

Figure 6 Simulated sedimentation curves

Experimental determination and the mathematical simulation allowed us to characterize the used parameters and their significance, as follows:

- *a* is related on the sedimentation time τ, which increases with the increase of a. Also, decreases as dimensions of solid particles increase and as concentration and depth decrease;

b, c, d describe the vertical diffusion of the solid particles as follows:

- *b* describes the maximum value of Gauss curve, i.e. the intensity of the diffusion;
- *c* expresses the moment when Gauss curve has the maximum value;
- *d* describes the width of Gauss curve, i.e. the duration as the diffusion prevails against lowering movement.

Experimental results show that b increases as depth in suspension and concentration increase and as dimensions of solid particles decrease. Also, c decreases and d increases as dimensions of solid particles decrease and b and d increase as the depth in the suspension increase, i.e. diffusion is more intense and it takes more time as the depth in suspension is greater.

Correlations between the parameters contained by relation (3) and some main characteristics of the suspension (initial concentration, dimensions of solid particles and height in suspension) are summarized in Table 1.

Table 1. Correlations between parameters describing the sedimentation of suspensions

Para meter	Depth ↗	Initial concentr ation ↗	Dimensions of solid particles ↗
a	↗	↗	↘
b	↗	↗	↘
c	↗	↗	↘
d	↗	↗	↘

4. APPLICATION

The studies performed on the sedimentation of suspensions process reveal the following fact: although fluctuations change the shape of sedimentation curves, the value of sedimentation time (τ) is the same as in the case of exponential decrease of concentration expressed by the first term in relation (3).
So, the extrapolation of logarithmic representation of the exponential decrease in time of the concentration leads to the proper value of the sedimentation time, as shown in figure 7.
Taking into account that sedimentation process is usually very long, using only the first point of the experimental curve represents a fast and practical method in order to determine the sedimentation time of a considered suspensions. In the case of suspensions containing solid pollutants in water, the determination of sedimentation time is important in designing of sewage clarifying systems used in order to control wastewaters.

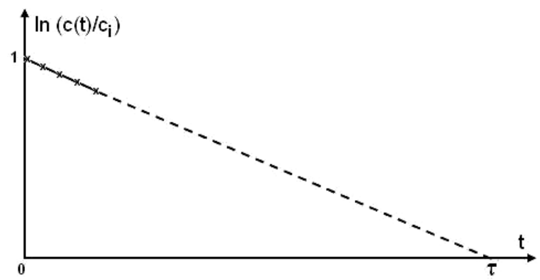

Figure 7 Extrapolation of logarithmic curve of sedimentation using the first points

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