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SEDIMENTATION RATE OF LIQUID-SOLID SUSPENSIONS, AS A PARAMETER OF WASTEWATER TREATMENT

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Abstract

The need to separate the solid phases from the liquid ones is probably the most common requirement for separation in the wastewater treatment process, the most common method being by gravity, called sedimentation. Sedimentation rate is an important hydrodynamic quantity for the characterization of particle motion and for the technological design of equipment used to separate heterogeneous systems through the sedimentation process. Our work aims is to determine the sedimentation rate in the case of three types of suspension consisting of water - calcium carbonate, water - soil, water - blue clay, with concentrations of 2%, 4%, 6%, 8% and 10%. The particle size for calcium carbonate and blue clay was 0.2 mm and that of the soil was 0.4 mm. Stokes' law was applied to determine the sedimentation rate of solid particles and the following parameters were determined: material particle density (using the pycnometer), dynamic density and viscosity of the suspension (using the Hoppler viscometer). The obtained results showed that the sedimentation rate is influenced by the concentration, size and density of solid particles, these results being correlated with the results obtained from the literature.

***Key words**: wastewater treatment, sedimentation rate, dynamic viscosity, density.*

INTRODUCTION

A major challenge facing a sustainable global future is the growing demand for clean water. The continuous growth of the world's population has led to an increase in the demand for drinking water, so that during the years 1942-1990 the process of taking drinking water from rivers, lakes, reservoirs and groundwater sources has increased significantly, more than four times (Bagtzoglou et al., 1992). The availability of a clean and safe source of water is essential for human health and well-being, as well as for agriculture, industry and transport (Veolia, 2014).
At European level, the most effective methods of environmental protection are constantly sought, the main method of combating water pollution, and a means of improving the quality of wastewater is the treatment process, which is currently the most widely used (Figure 1).
The term water pollution occurs when the presence of any foreign substance (organic, inorganic, biological or radiological), contaminates a water source, degrading its quality and making it toxic to humans or the environment (Denchak, 2018; The Romanian Water Law, 1996).

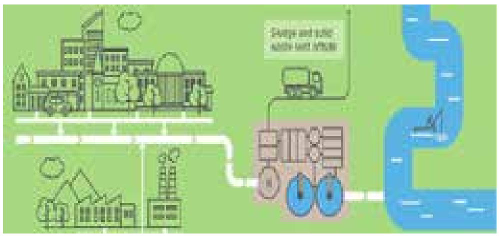

Figure 1. Urban wastewater circuit (EPA, 2019)

The European Union's Urban Wastewater Treatment Directive sets standards for the treatment of urban wastewater in urban areas. Standards are set to protect the environment and human health from the adverse effects of wastewater discharges.
In the European Union, comparisons between water consumption in Member States are not always straightforward.
Recent efforts to address the protection of water resources have led to the development of

new processes for purification and improvement of water management techniques. However, over the next 20 years, human behavioural changes and technological innovations will be needed to find a balance between water supply and demand (Ichem E., 2007).

Wastewater treatment is mandatory to protect future sustainable economic growth (Special Report, 2015).

Wastewater treatment is a basic method for the protection and reuse of water resources, which is clearly demonstrated by the consequences of its implementation in many countries around the world.

Scientific research in recent decades has made great strides in understanding the complex and interdisciplinary aspects of the biological, biochemical, chemical, and mechanical processes involved in wastewater treatment (Gavrila, 2001; Ichem E., 2007; Florea & Robescu, 1982; Florescu, 2007; Panaitescu, 2011; Robescu et al., 1999; Safta et al., 2012; Vanderhasselt & Vanrolleghem, 2000).

The wastewater treatment process is a complex process that includes several stages that allow the gradual elimination of different types of impurities: coarse, fine, mineral or organic. There are two basic steps in the treatment process: primary and secondary treatment, (EPA, 1998).

The removal of solids by gravity is, according to studies in the literature, the main method of water purification from treatment plants.

The process of separating the liquid-solid mixture is influenced by many factors related to both the solid component, the liquid component and the construction parameters of the decanter.

Following studies by Camp and Fitch researchers on the settling of various types of suspensions, they classified the phases of the settling process according to the concentration of the suspension and the nature of the solid particles as follows: type I clarification, type II clarification, mass sedimentation and sediment compaction (Figure 2) (EPA, 1997).

Data on the rate of the sedimentation process are very important for the design of equipment used in chemical and metallurgical practices for the separation of suspended solid particles from liquid or gaseous flow (Mondal and Majumdar, 2004).

Through the sedimentation process, the sedimentation rate of a particle increases until the settling force (the particle's own weight) becomes equal to the resisting forces. In this case, there is a balance between the forces acting on the particle, for which (dvp/dt) = 0.

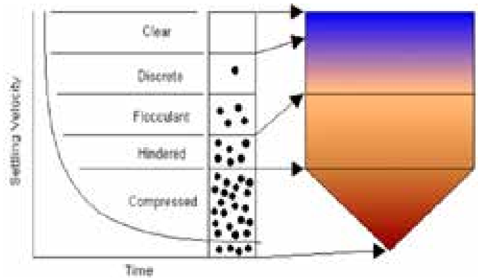

Figure 2. Diagram of the settling phases (Suntech, 2020)

Sedimentation rate is an important hydrodynamic quantity for the characterization of particle motion and for the technological design of equipment used to separate heterogeneous systems by sedimentation, (Coldea & Ionescu, 2005; Gavrila, 2001).

The settling rate varies greatly depending on the concentration of solid particles. The weight of the particles G, the strength of Archimedes F_A and the viscous resistance F_R act on the spherical particles isolated from the fluid (Figure 3). Gravity tends to deposit particles on the bottom of the tank, and the other two forces prevent the particles from settling. In the steady state of the force system, the sedimentation rate of the particles can be evaluated according to the scheme (Racoviteanu, 2003):

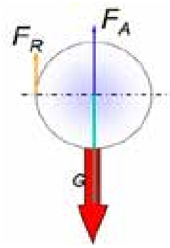

Figure 3. The system of forces acting on the solid particle in the suspension (Gavrilă, 2001)

Several models have been reported in the literature to estimate settling rates. Al-Naafa and Selim (1992) studied both theoretically and experimentally two-dimensional gravitational sedimentation and three-dimensional concentrated suspensions ranging from 13 to 45% (by volume). The authors concluded that the model equations developed by Mirza and Richardson (1979) and later used by Selim et al. (1983) for two-dimensional suspensions were valid.

In another study by Tarpagkou R. et al. (2013), the results showed that at low water temperatures, more precisely in the region of non-linear density, the efficiency of the sedimentation process decreases, the viscosity of the water increases, the resistance as the solid particles increase and, as a result, the sedimentation rate decreases, the turbidity at the free surface increases (Tarpagkou et al., 2013).

The work aims to determine the sedimentation rate in the case of three types of suspension consisting of water - calcium carbonate, water - soil, water - blue clay, concentrations 2%, 4%, 6%, 8% and 10%, for solid particle size of 0.2 and 0.4 mm.

MATERIALS AND METHODS

To determine the sedimentation rate of the three types of suspension consisting of water - calcium carbonate, water - soil, water - blue clay, concentrations 2%, 4%, 6%, 8% and 10% respectively and the particle size of 0.2 mm in the case of calcium carbonate and blue clay and 0.4 mm in the case of soil, Stokes' law was applied:

$$v = \frac{{d_p}^2 \cdot g \cdot (\rho_p - \rho_S)}{18 \cdot \vartheta \cdot \rho_S} = \frac{{d_p}^2 \cdot g \cdot (\rho_p - \rho_S)}{18 \cdot \eta} \qquad (1)$$

where:

d_p - particle diameter, (m); g - gravitational acceleration, (m/s^2); ρ_p - solid particle density (kg/m^3); ρ_S - suspension density, (kg/m^3); η - dynamic viscosity of the suspension, (Pa·s); ϑ - the kinematic viscosity of the suspension, (m^2/s).

In order to determine the sedimentation rate, the following parameters had to be determined, in turn: the density of the three types of material, the density of the suspension and the dynamic viscosity of the suspension.

Determination of the density of the three types of solid particles

The density of the three types of solid particles was determined using a pycnometer, using a Kern analytical balance, and xylene was used as the working liquid, which has a known density of 860 kg/m^3.

The empty pycnometer was first weighed using the analytical balance, filled with working liquid - xylene, and then weighed again. 2-5 g of material was added to the empty and dry pycnometer using a funnel and weighed again. Knowing the mass of the empty pycnometer, the exact mass of the material under analysis was obtained by subtraction. The reference liquid was added over the amount of material to the pycnometer mark, stirred gently so that no air gaps remained between the material particles, the outside of the pycnometer was wiped with filter paper and weighed (Torfs et al., 2016).

The density of the analysed material was determined by relation (2):

$$\rho_p = \frac{(m_c - m_a) \cdot \rho_l}{(m_b + m_c) - (m_a + m_d)} \qquad (2)$$

where:

ρ_p represents the density of the analysed material (g/cm^3); m_a - empty pycnometer mass (including capillary plug) (g); m_b - the mass of the pycnometer filled with the reference liquid (g); m_c - mass of the pycnometer with 2-5 g of material (g); m_d - mass of the pycnometer with material and filled with the reference liquid to the mark (g); ρ_l - density of the reference liquid (g/cm^3).

Determination of the density of the liquid-solid mixture

To calculate the density of the liquid-solid mixture of 2%, 4%, 6%, 8% and 10% concentration, the calculation formula was used:

$$\rho_S = \frac{m}{V} \qquad (3)$$

where:

ρ_S represents the density of the liquid-solid mixture (g/cm^3); m - suspension mass (g); V - suspension volume (cm^3).

A graduated cylinder with a known volume of 50 cm^3 was used, the mass of solid particles corresponding to the five concentrations being 1 g, 2 g, 3 g, 4 g, 5 g. These masses were weighed using the analytical balance, each quantity was subsequently added to the cylinder, the mass of the empty cylinder being determined first, and distilled water was added to the 50 mL mark. The mixture was homogenized to remove air gaps between the solid particles and the cylinder was subsequently weighed using the Kern electric balance to determine the mass of the suspension.

Determination of the dynamic viscosity of the liquid-solid mixture

The dynamic viscosity of the three liquid-solid mixtures for each concentration was measured using the Hoppler ball viscometer (Figure 4).

Figure 4. Determination of viscosity using a Hoppler ball viscometer

Before starting the determinations, the glass tube of the viscometer was washed with distilled water to remove various impurities, then it was fixed on the support of the viscometer and overturned, detaching the lid with which it is provided. The suspension was placed in the viscometer tube approximately 2 cm below its upper edge and the temperature value, displayed by the thermometer incorporated in the apparatus, was expected to stabilize at 25°C. The appropriate ball was selected for the viscosity range to be investigated (approx. 1 to 7 mPas) and was inserted into the tube using tweezers (the ball of choice was the one with the following characteristics: density 8.126 g/cm^3, correction factor K 0.1167). Cover the empty stopper with the rubber stopper and replace the screw cap. The tube was brought to the original position, timing the time of the sphere falling between marks A and C, marked on the glass tube. The stopwatch was triggered when the lower part of the sphere reached the A mark and stopped when the lower part of the sphere reached the C mark.

After the sphere reached the bottom of the vessel, the tube was returned to its original position and the steps were repeated three times, the chosen time being the average of the three measurements (LD Leaflets Chemistry).

Viscosity was determined using the relationship (4):

$$\eta = \frac{2}{3} \cdot \frac{(\rho_2 - \rho_S) \cdot g \cdot r^3}{d^2} \cdot t \cdot ln\frac{R}{r} = k \cdot (\rho_2 - \rho_S) \cdot t \quad (4)$$

where:

ρ_2 - ball density (kg/m^3); ρ_S - suspension density (kg/m^3); g - gravitational acceleration (m/s^2); r - tube radius (m); R - radius of the ball (m); d - ball radius (m); t - time (s); k - the constant that characterizes the device and the sphere used.

RESULTS AND DISCUSSIONS

In determining the density of the three types of solid particles, the same steps were performed for all three materials. For each material, three types of tests were performed, the final density value being the average of the three determinations (ρ_{pm}).

Table 1 presents the experimental results, which have values close to those found in the literature (ρ_{lit}).

Table 1. Experimental results obtained for the calculation of the density for three samples of material, using the pycnometer

Material type	m_a, g	m_c, g	m_b, g	m_d, g	ρ_l, g/cm^3	ρ_p, g/cm^3	ρ_{pm}, g/cm^3	ρ_{lit}, g/cm^3
Calcium carbonate	25.194	27.315	45.759	47.049	0.86	2.195	2.412	2.93
	25.196	28.517	45.746	47.941	0.86	2.536		
	25.204	27.975	45.752	47.572	0.86	2.506		
Blue clay	25.284	28.452	45.811	47.733	0.86	2.186	2.384	2.52-2.78
	25.257	27.739	45.714	47.289	0.86	2.354		
	25.489	28.158	45.786	47.579	0.86	2.619		
Soil	25.237	27.406	45.769	47.134	0.86	2.319	2.564	2.55-2.60
	25.319	27.213	45.709	47.000	0.86	2.692		
	25.257	27.384	45.727	47.172	0.86	2.682		

To determine the density of the liquid-solid mixture, the same steps were taken for each mixture, for all five related concentrations. The experimental results are presented in Table 2.

Table 2. Experimental results obtained for the density of the three types of liquid-solid mixture, of known concentrations

Material type	c, %	ρ_S, g/cm^3		c, %	ρ_S, g/cm^3		c, %	ρ_S, g/cm^3
Calcium carbonate	2	1.011	Blue clay	2	1.014	Soil	2	1.006
	4	1.016		4	1.036		4	1.019
	6	1.023		6	1.047		6	1.024
	8	1.045		8	1.059		8	1.041
	10	1.067		10	1.063		10	1.060

The second part of the formula (4) was used to determine the viscosity, the steps taken to perform the determinations were the same for all three liquid-solid mixtures.
The experimental results obtained are presented in Table 3.
Given that all parameters are known, the experimental data obtained for all three types of liquid-solid mixture, for the five concentrations for each mixture, were used to determine the sedimentation rate, according to Table 4.

Table 3. Experimental results obtained for the dynamic viscosity of the three types of liquid-solid mixture

Material type	c, %	t, s	η, mPa·s		c, %	t, s	η, mPa·s		c, %	t, s	η, mPa·s
Calcium carbonate	2	2.54	2.101	Blue clay	2	2.76	2.282	Soil	2	2.72	2.252
	4	2.72	2.249		4	2.80	2.308		4	2.81	2.322
	6	2.78	2.296		6	2.92	2.403		6	2.89	2.386
	8	2.81	2.313		8	2.99	2.457		8	2.99	2.463
	10	2.93	2.405		10	3.08	2.529		10	3.07	2.522

Table 4. Sedimentation rate values for three types of liquid-solid mixture

Material type	c, %	v, m/s		c, %	v, m/s		c, %	v, m/s
Calcium carbonate	2	$1.45 \cdot 10^{-2}$	Blue clay	2	$1.31 \cdot 10^{-2}$	Soil	2	$6.03 \cdot 10^{-2}$
	4	$1.35 \cdot 10^{-2}$		4	$1.27 \cdot 10^{-2}$		4	$5.80 \cdot 10^{-2}$
	6	$1.32 \cdot 10^{-2}$		6	$1.21 \cdot 10^{-2}$		6	$5.63 \cdot 10^{-2}$
	8	$1.29 \cdot 10^{-2}$		8	$1.17 \cdot 10^{-2}$		8	$5.39 \cdot 10^{-2}$
	10	$1.22 \cdot 10^{-2}$		10	$1.13 \cdot 10^{-2}$		10	$5.20 \cdot 10^{-2}$

Based on the experimental results, the variation curves of the sedimentation rate were plotted, according to Stokes' law, depending on the concentration of solid particles, for each type of liquid-solid mixture separately (Figure 5 and Figure 6).

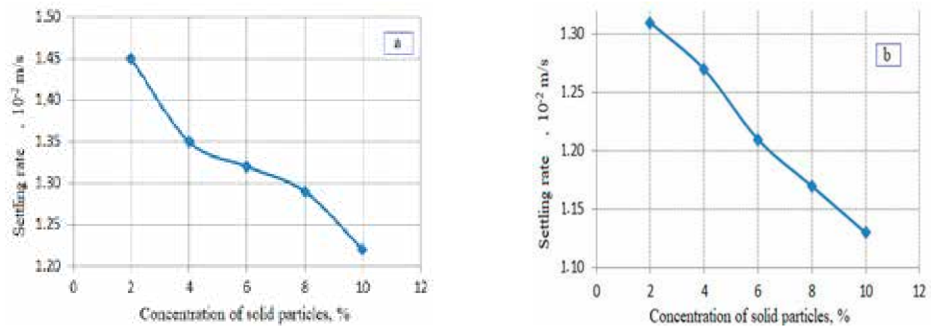

Figure 5. Variation of settling rate depending on the concentration of solid particles, in the case of the suspension water - calcium carbonate (a), water - blue clay (b)

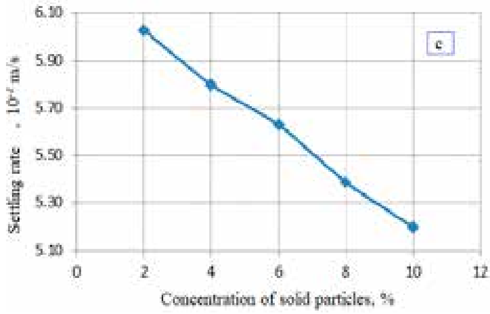

Figure 6. Variation of settling rate depending on the concentration of solid particles, in the case of the suspension water - soil

Numerous studies have been performed regarding the sedimentation rate of solid particles, as a result of which results have been obtained in correlation with those of the study performed in this paper.

For example, in (Torfs et al., 2016) it was studied the sedimentation rate of a particle with a diameter of 400 µm and a density of 1.010 kg/m^3. The authors obtained that it has a value of 2-9 m/h for temperatures between 5-40°C. At low temperatures, it was observed that the separation of small and low-density particles (with typical settling speeds below ± 5 m/h) became difficult.

Tarpagkou R. et al. (2013) found that wastewater temperature plays an important role in the settling process. At a temperature of 29°C a sedimentation rate of 1.5 m/h was obtained, while at a temperature of 11°C the sedimentation rate decreased to 0.95 m/h, for a solid particle concentration of 60 mg/ml.

Experimental results have shown that at low water temperatures, the efficiency of the sedimentation process decreases, the viscosity of the water increases, the resistance to the advancement of solid particles increases and as a result the sedimentation rate decreases, the efficiency of the settling process reaches 50%, compared to 80% in case of summer temperatures.

CONCLUSIONS

The removal of solids by gravity is, according to studies in the literature, the main method of water purification in treatment plants.

The process of separating the liquid-solid mixture is influenced by many factors related to both the solid component, the liquid component and the construction parameters of the decanter. Data on the speed of the sedimentation process are very important for the design of equipment used in chemical and metallurgical practices for the separation of suspended solid particles from liquid or gaseous flow.

In the experiment, in order to determine the sedimentation rate, the following parameters had to be determined, in turn: the density of the three types of material, the density of the suspension and the dynamic viscosity of the suspension.

The highest density of solid particles was obtained in the case of soil (2.564 kg/m^3), followed by that of calcium carbonate (2.412 kg/m^3), and finally that of blue clay (2.384 kg/m^3), the highest high sedimentation rate is obtained in the case of water-soil suspension, its value decreasing as the concentration of solid particles increased.

According to the experimental results obtained from the study, it can be noticed that the sedimentation rate is influenced both by the concentration of solid particles (speed decreases as the concentration of particles increases), by the size of solid particles (speed increases as the size of particles increases), but also the density of solid particles (as their density increases, so does the rate of sedimentation).

The results obtained are correlated with the results obtained in the literature.

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