Sedimentation of Alumina Powders and Soil Quantified on a Surface Tensiometer

Particles in a fluid settle in response to externally applied forces such as gravity, centrifuge acceleration, or electromagnetism. Over time these particles accumulate at a boundary (e. g. the bottom of a beaker or at the interface between different density media) at which point the particles are called sediment. Sedimentation describes how particles settle in a lake or how dust settles in air. The sedimentation rate, or settling, is an important property for many industries and applications such as mining, biological samples, water treatment, and powder characterization.

Sedimentation is quantified (in mg/s) by measuring the rate of mass gain over time of a balance suspended in a particular medium. Alternatively, sedimentation rate can be calculated (in µm/s) using Stokes' law to determine the particle velocity through a medium. The sedimentation rate is directly affected by the particle size and shape, the density difference between the particle and the medium, and the viscosity of the medium. To increase the sedimentation rate, for instance, particles need to have a larger diameter or a shape that reduces drag through the medium, a larger difference between the density of the particle and density of the medium, and/or a decrease in the viscosity of the medium.

Stokes' law, as shown in Equation 1, calculates the sedimentation rate or velocity of a particle through a medium, where v is the velocity of an individual particle, d is the diameter of the particle, ρ_1 is the density of the particle, ρ_2 is the density of the medium, g is the acceleration of gravity, and η is the viscosity of the medium.

$$\text{Equation 1:} \quad v = \frac{d^2(\rho_1-\rho_2)*g}{18\eta}$$

In order to demonstrate how to quantify sedimentation, Ebatco's NAT Lab tested three different particulate samples on a surface tensiometer with sedimentation measurement capability. The first two samples were alumina powder of different sizes (1.0 µm and 0.3 µm in diameter), while the third sample was a potting mix soil. Water was chosen as the liquid medium. A large plate was placed in the liquid and suspended from the mass balance. The sample was mixed into the liquid, then allowed to settle. The mass of the particles settling onto the submerged plate was recorded as a function of time. Each sample was tested five times at room temperature for a total of 60 seconds. The weight gain data was then averaged between 10 and 60 seconds for each test. Table 1 shows the sedimentation measurement results for each sample.

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Table 1 Sedimentation of Particles in Water Suspension

Test	Sedimentation Rate (mg/s)		
	1.0 μm Alumina	0.3 μm Alumina	Potting Mix Soil
1	0.616	0.445	0.313
2	0.638	0.458	0.351
3	0.631	0.409	0.397
4	0.616	0.429	0.379
5	0.610	0.445	0.389
Average	**0.622**	**0.437**	**0.366**
S. D.	0.012	0.019	0.034

As can be seen from Table 1, the 1.0 μm alumina particles had the highest settling rate, followed by 0.3 μm alumina and potting mix soil, respectively. The 1.0 μm diameter particles settled more quickly than the 0.3 μm diameter particles, indicating that larger particle size increases the sedimentation rate. However, the soil particles had larger diameters than the alumina (several microns to millimeter size), but exhibited a slower sedimentation rate. The explanation for this apparent contradiction is the difference in densities. The alumina and potting soil samples had average densities of 3.97 g/cm^3 and 0.241 g/cm^3, respectively. Lower density results in lower gravitational pull and slower sedimentation rates. Furthermore, the soil was composed of many different types of particles. Some of the soil particles had densities lower than water and floated on the surface, while the other particles settled to the bottom of the testing vessel. Although the wide range of particle sizes and densities in the potting soil mixture made it too complex to model theoretically with Stokes' law, empirical measurements like this one still provide the information necessary for practical applications.

Table 2 shows the sedimentation rate for the alumina particles calculated using Stokes' law. Comparing the calculated sedimentation rates with the sedimentation measurement results, we can see that they correlate very well: a higher sedimentation rate measures a higher mass settling rate.

Table 2 Sedimentation Rates of Alumina Particles in Water Calculated Using Stokes' Law

Sample	Sedimentation Rate (μm/s)
1.0 μm Alumina in water	1.82
0.3 μm Alumina in water	0.16

In conclusion, sedimentation is an important aspect of particles in a fluid suspension system from environmental, biological, to chemical applications. Using the Stokes' equation, the sedimentation rate can be calculated and used to understand the sedimentation process and how to influence it to achieve desired purpose. The sedimentation quantified using the mass settling rate correlates very well with the particle velocity calculations and can be used as a complementary technique for sedimentation studies - or for systems too complex to model.

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