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Ekstrakt:

Synkehastigheten for en suspensjon som inneholder finfordelte partikler kan beskrives kvantitativt ved sedimenteringstester og beregninger på grunnlag av kontinuitetsligningen. Metoden omfatter analyser av partikkelinnhold i en vannsøyle mens suspensjonen synker. Beregningene foretas med EDB-programmet SUSPEN og suspensjonens gjennomsnittlige synkehastighet presenteres som funksjon av tid og dyp.

4 emneord, norske:	4 emneord, engelske:
1. Suspensjoner	1. Suspensions
2. Synkehastighet	2. Settling velocity
3. Vann	3. Water
4. Metode	4. Method
5. Flokkulering	5. Flocculation
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SUSPENSJONERS SYNKEEGENSKAPER

Metode for analyse av finfordelte partiklers synkehastighet i vann.

Saksbehandler: Øivind Tryland
Medarbeidere : Egil Støren
Eigil R. Iversen

FORORD

I 1977 startet arbeidet med å utarbeide en ny metode for bestemmelse av partiklers suspensjoners synkeegenskaper. Denne rapporten gir et sammendrag, på engelsk, av den metoden som vi benytter. Cand.real. Egil Støren har utviklet EDB-programmet "SUSPEN". Programmet foretar alle utregningene og det er tilpasset NIVA's Nord 100 anlegg. Ingeniør Eigil Rune Iversen har gjennomført de fleste forsøkene der metoden har vært brukt.

Grunnlaget for metoden er beskrevet i rapporten "Metode for måling av sedimenteringsegenskaper til suspensjoner". XK-22, NIVA, 27.12.1977. Den EDB-tekniske del av metoden med eksempler på anvendelser er videre beskrevet i rapporten "Sedimenteringshastighet til suspensjoner Metodikk og databehandling". DI-04. NIVA, 14.12.1978.

Disse rapportene viser også hvordan SUSPEN-metoden kan brukes for å avgjøre om suspensjonen inneholder flokkulerende partikler under deler av sedimenteringsprosessen.

SUSPEN-metoden er et relativt nytt analysetilbud. Den åpner også mulighetene for å undersøke nye og interessante vannfaglige problemstillinger som omfatter partikler i vann.

Oslo, 29.12.1983

Øivind Tryland
Cand.real.

THE SETTLING VELOCITY OF PARTICLES

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Abstract

The settling velocity of a suspension containing fine particles can be described quantitatively by settling tests and calculations based on the continuity equation. The method includes analyses of particle concentration at various depths in a quiescent water column during the settling process. Calculations are performed by the computer program SUSPEN, and the local mean settling velocity is presented as a function of depth and time. The method is experimentally simple, and requires no data about particle density, particle shape, form, viscosity of water, etc. In principle, the method is applicable to all different kinds of suspensions containing slowly settling particles.

Introduction

The main purpose of mechanical and chemical sedimentation treatment processes is to achieve a fast and effective separation of the wastewater particles or flocculation particles generated by addition of coagulants. In chemical treatment plants designed for the removal of phosphates from sewage the particles mainly consist of voluminous and slowly settling flocs of iron- or aluminum hydroxide. At industrial water treatment plants the suspended particles may consist of many different kinds of particles, such as wood fibres, clays, flotation residue from mineral processing, metal hydroxides, process wastes, etc. The mechanical and chemical treatment prosesses have in common that the particles are settled by gravitation in sedimentation basins. The detention time, the design of the basin, and not least, the settling behaviour of the particles determine the removal efficiency.

The mean settling velocity of a given suspension depends on the shape, size and density of the particles together with dissolved constituents being able to stabilize or destabilize the particles. The pH and concentration of coagulants or other surface active compounds are therefore important factors affecting the settling velocity of individual particles and the suspension. The settling velocities of single particles are also affected by other particles and the mean settling velocity of a suspension will depend on the initial concentration of particles. Other factors important to the settling process are the density, viscosity, temperature and salinity of the liquid.

An unstable suspension is generally composed of particles with varying sizes settling with various velocities. The smallest settling particles have particle dimensions down to about 1 μm, while the smaller particles are stable and remain in suspension by Brownian motion (O'Melia, 1980). The settling velocity of discrete particles can theoretically be calculated according to Stokes equation. This method assumes: 1) particles remain spherical during the entire settling process, and 2) no interaction between particles (cfr. Miller, 1964). These assumptions are very seldom fulfilled during water treatment processes. Therefore the Stokes equation has very limited applications.

A different method was introduced by McLaughlin (1959). This method is based on the continuity equation in one dimension, i.e. vertical particle movement by action of only gravity forces. The principle is briefly explained below. It is used for quantifying the sedimentation properties of particles in suspensions at different chemical and physical conditions. Some of the advantages of the method are:

- Experimentally simple

- Needs no data about particle shape, density, viscosity of liquid, etc.

- Possible to quantify the local mean settling velocity as a function of sedimentation time

- Possible to observe or quantify flocculation or hindered sedimentation

- Suitable for investigating systems where particle properties such as size and density change during the sedimentation process.

- The method is applicable to all different kinds of suspensions containing slowly settling particles.

- The principle can also be used to investigate the stability of emulsions, for example oil in water. However, the main application is directed towards investigations of flocculation and coagulation processes.

Principle

The settling behavior of the suspension is described from tests where the suspension is settling quiecently in a column (Figure 1). Sets of samples are taken during the settling process and the particle concentration is measured and the analytical data are treated according to a method devised by McLaughlin (1959). The method is also described by Vanoni (1975). The calculations are based on the continuity equation in one dimension, i.e. vertical movement of particles:

$$\frac{\partial C}{\partial t} + \frac{\partial (vC)}{\partial z} = 0 \quad (1)$$

where C = Particle concentration (suspended solid or turbidity)

v = The local mean settling velocity of the suspension (cm per minute)

t = Time of sedimentation (minute)

z = Depth below liquid surface (cm).

The equation is derived from the fact that in a short time interval, the quantity of particles settling into an elementary prism, less that settling out of it, is equal to the increase in concentration in the prism in the same short time interval. Integration with respect to z gives:

$$(vC)_{z = D} = - \frac{\partial}{\partial t} \int_{0}^{D} C dz \qquad (2)$$

which is used to calculate v. To calculate v at z = D, one measures the areas on the concentration profile diagram (Figure 2). The values are plotted against the corresponding times (t_1, t_2, t_3 etc). The slope of the curve is the right side of equation (2) and can be used to calculate v at various times because C is known. The procedure is repeated for any

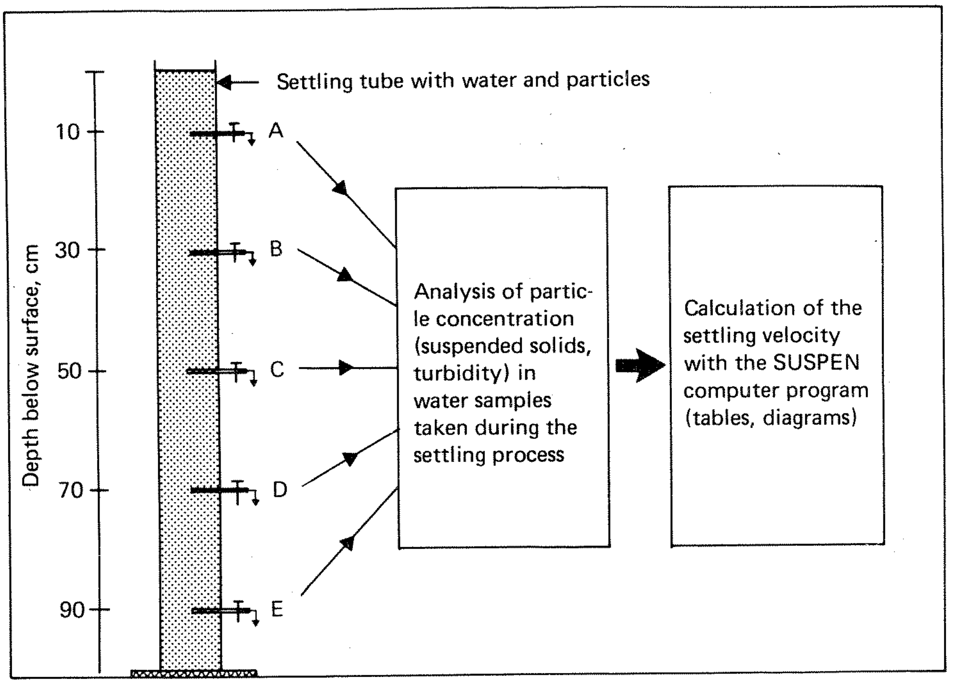

Figure 1. The settling behaviour is investigated in a plexiglass tube equipped with sampling tubes entered through the wall of the column at five different depths. The particle concentration is analysed and the computer program SUSPEN is used for calculation of the local mean settling velocity.

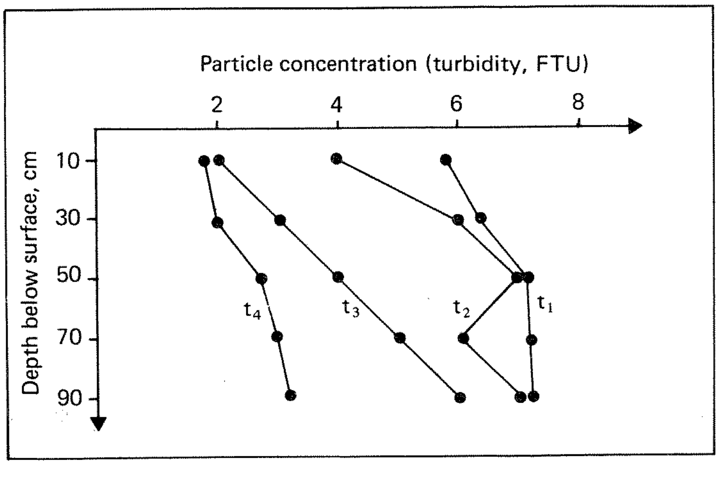

Figure 2. The concentration profile diagram shows the variation in turbidity of aluminum hydroxide particles with depth and settling time ($t_1 < t_2 < t_3 < t_4$). The local mean settling velocity is calculated by integration of the curves in such diagrams.

depth at which samples are taken. Equation (2) can be interpreted in physical terms by noting that the integral gives the amount of particles above level D in a column of unit cross section. The rate of decrease of this quantity must be equal to the rate of the settling of material, i.e. the product v • C. A computer program, called SUSPEN, is developed for doing these operations.

Settling column

A 100 cm long settling tube with an inner diameter of 12 cm is used for the settling tests. Water samples are tapped from the center of the column through small metal tubes placed at five different depths i.e. 10, 30, 50, 70 and 90 cm below the water surface (Figure 1). The tube is made of plexiglass and its volume is ca 11 litres.

Settling test procedure

The suspension to be tested is poured into the column and a paddle stirrer with variable speed regulator (0-200 rpm) distributes the particles uniformly through the tube. To examine that the suspension is completely mixed, samples are tapped from each outlet before the stirrer is stopped. These samples are analysed together with other samples tapped from the column later.

In tests with coagulants containing iron or aluminium, a different procedure is used. The solution containing the coagulant is first added. Then a base solution is added while stirring until the pH is within the optimum range for generation of the metal hydroxide particles. This is followed by a period of slow stirring in order to generate flocs.

The sedimentation time is measured from the moment the stirrer is stopped. While the suspended particles are settling, series of water samples are tapped from the outlets. The volume of each sample should be as small as possible in order to not introduce considerable movements in the water and lowering of the water surface. Each sample should be less than 30 ml. Time intervals between sampling may be choosen according to how fast the particles are settling. In tests with aluminum hydroxide particles, series of water samples were tapped from the column after 2, 5, 10, 30, 60 and 120 minutes.

The particle concentration in all the water samples should be analysed as soon as possible after the settling test is finished. The suspended solids (SS) or the turbidity are the most convenient quantities to use. The turbidity is easy to measure, but it is not generally proportional to particle concentration. However, turbidity will be the best choice in some applications where the particle mass is low.

Data treatment

The settling velocity of the suspension is calculated by the computer program SUSPEN which also takes care of data entry and storage functions. The program is written in FORTRAN, and runs on a NORD 100 computer.

The SUSPEN program opens the following possibilities to achieve the results from settling tests in the form of tables or diagrams:

- Original data. The measured particle concentration at the different depths at each moment of sampling.

- Concentration profile diagrams. Curves which show the variation of particle concentration at various depths during the settling process (Figure 2). These diagrams are used for the calculation of the local mean settling velocity.

- Velocity diagrams. The curves show the changes of the local mean settling velocity during the sedimentation process (Figure 3). The same information may be given in the form of tables.

Interpretation of diagrams.

When the curves have any maximum values, as in Figure 3, it implies that the settling velocity is increasing during a part of the sedimentation process and the suspension contains flocculating particles during that period. During the flocculation process the small particles join together and settle as larger particles with a greater velocity than the original smaller particles. When the cloud of fast settling particles has passed the actual depth, the average settling velocity will decrease. This is shown for aluminum hydroxide flocs in Figure 3.

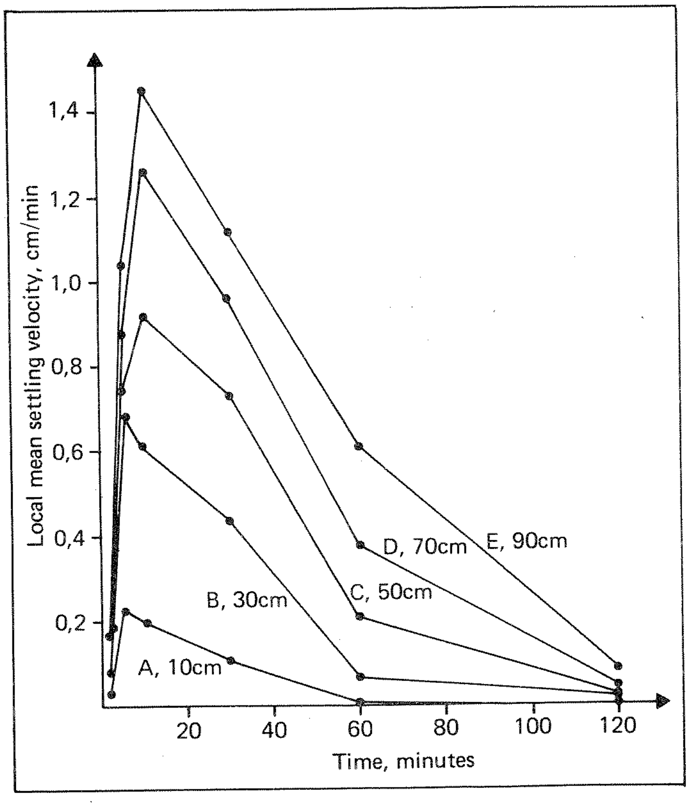

Figure 3. The velocity diagram shows the local mean settling velocity of $Al(OH)_3(s)$ as a function of time. The increase of settling velocity during the first ten minutes show that particles flocculate and that the effect of flocculation increases with depth.

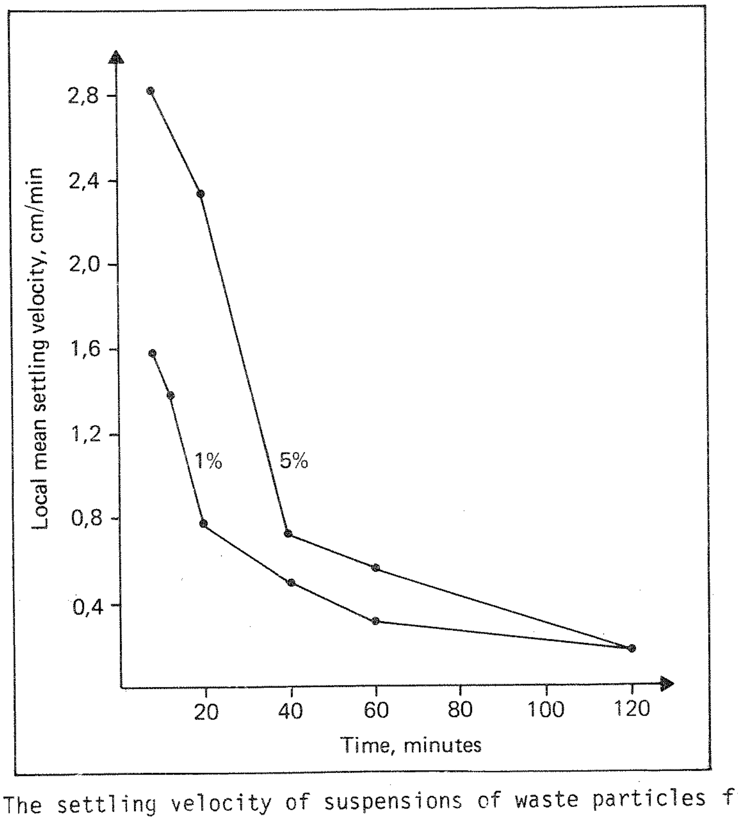

Figure 4. The settling velocity of suspensions of waste particles from mineral processing is shown. The curves, drawn at 50 cm depth, show the effect of increasing the initial particle concentration from 1 % to 5 % dry material.

The settling velocity of suspensions which do not contain flocculating particles will gradually decrease as the heavy and fast settling particles are removed (Figure 4). After a while the average settling velocity becomes more stable because the suspended particles will have smaller dimensions and settle at a continously lower rate.

Settling velocity of aluminum hydroxide

Aluminum sulphate is a coagulant used for water treatment. Voluminous flocs containing aluminum hydroxide are formed when pH is adjusted to 5,5 - 7,0. The sedimentation velocity of these flocs was investigated by the SUSPEN method.

The solution contained 50 mg Al/l and a sodium hydroxide solution was added until pH 6,5 was attained. After mixing, the suspension contained flocs with various sizes which settled with different velocities.

Figure 3 shows that the average settling velocity of the flocs at first increases and afterwards decreases with the time of sedimentation. The maximum values of the settling velocity show that the suspension contains flocculating particles. During the flocculating process small flocs join together and settle faster than the original particles. The curves show that the mean settling velocity increases with depth in the settling column because the flocs are becoming greater and heavier while they are falling through the liquid.

The settling velocity was at a maximum after ca 10 minutes of sedimentation. McLaughlin (1959) also found that the particles in a suspension of alum and bentonite clay had a maximum settling velocity after 10-12 minutes. The maximum settling velocity at 50 cm depth was ca 0,9 cm/min (Figure 3). In the experiments done by McLaughlin the maximum settling velocity was ca 1,8 cm/min at the same depth which shows the effect of bentonite clay increasing the settling velocity.

Settling velocity of mineral particles

By selective flotation processes valuable minerals are separated from the residue and the waste minerals are usually deposited in water. The waste from these flotation processes in the mining industry contain a heterogeneous mixture of fine and coarse particles. The SUSPEN method was used to describe the settling properties of this material at particle concentrations of 1 % and 5 % dry material. The tests were performed simultaneously in two settling tubes and the suspended solids were measured in water samples tapped from the tubes during sedimentation.

The results (Figure 4) show that the mean settling velocity during the first 30 minutes was nearly doubled when the initial particle concentration was increased from 1 % to 5 %. Increase of the original particle concentration will, within certain limits, raise the average settling velocity at least during the first part of the settling process. When the suspension becomes more diluted and contains smaller and more slowly settling particles the settling velocity of the suspension is less influenced by original particle concentration. However, the concentration of salts in the liquid will affect the settling properties of these finely divided particles by electric double-layer compression.

Conclusions

- The settling properties of suspensions can be described mathematically according to the equation of continuity.
- The sedimentation velocity of a suspension containing slowly settling particles can be quantified according to the SUSPEN method.
- The method is used for analysing the settling behaviour of flocculating particles and mineral particles.
- The method is experimentally simple and requires no information about particle or liquid properties.

- The variation of particle concentration during quiescent settling is the basis for the calculation of settling velocity.
- By computer treatment of data, the settling velocity of a suspension is calculated in a few minutes, instead of hours by manual calculations.
- The method is useful for studying flocculation phenomena and the optimum conditions for separation of particles from a liquid.

Mean settling velocities determined by this method are dependent on the specific properties of the liquid suspension and conditions such as temperature, pH, coagulant concentration, and salt concentration. Thus, it is important that the liquid suspension and conditions used for settling tests be representative of those encountered or expected for the situation to be modelled.

Acknowledgment

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