LAB EXPERIMENTS

Sedimentation

Flocculent settling

Framework
This module explains the lab experiment on flocculent settling.

Contents
This module has the following contents:

1. Objective

On the basis of a sedimentation test with a flocculent suspension of clay particles the fundamentals for the design of a settling tank can be found. For this purpose the changes of the particle concentration in time and with depth should be measured. From these measurements the cumulative frequency distribution of settling velocities at different depths can be calculated.

At fixed time intervals samples are taken from the suspension at different depths. Of these samples the turbidity is measured. With the help of a calibration curve (Figure 2) the turbidity can be transferred into a suspended solids concentration (SS) in mg/l. The determination of the turbidity gives an enormous saving of time compared to direct measurements of SS.

2. Experiment set-up

The test is done in a transparent pipe, 2 m high with a diameter of 19 cm (Figure 1).

The suspension used in this experiment is made of very fine dispersed Gouda clay particles with a density of 1050 kg/m^3.

Alum is used as a coagulant. After mixing the alum with the suspension it is pumped in the settling column. A stirrer in the column guarantees a homogeneous mixture. As soon as the stirrer is switched off flocculation begins, followed by sedimentation of the flocks. Samples are taken at different depths at prescribed time intervals.

3. Theory

3.1 Discrete and flocculent settling

Sedimentation is a treatment process where water is slowly flowing through a reservoir. Because of the low flow velocities particles are able to deposit on the bottom of the reservoir. Distinction should be made between discrete and flocculent settling.

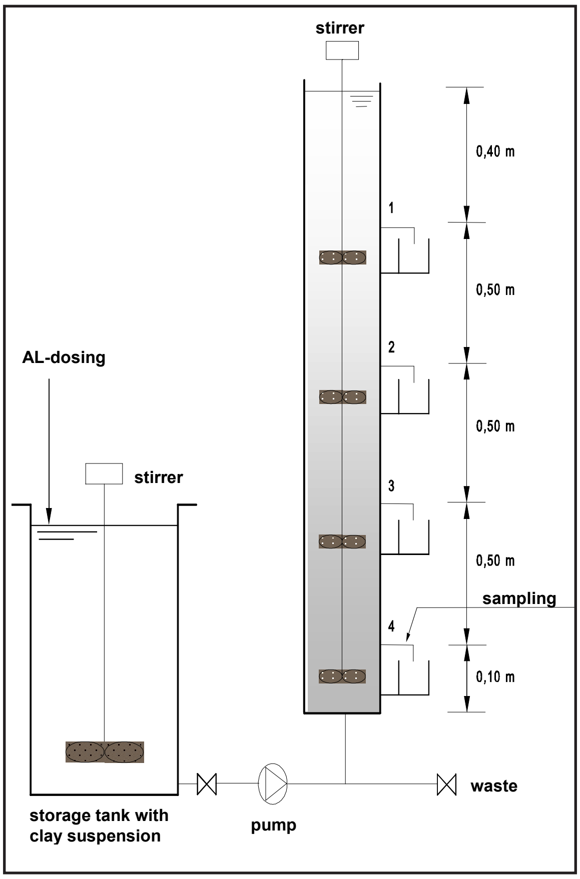

Figure 1 - Experiment set-up flocculent settling

Discrete settling happens with inert particles such as sand grains, but also when the flocculation process is finished. The shape, size and weight of the particles don't change anymore.

With flocculent settling the particles clog together during the settling process, forming bigger flocs that settle faster. This process can be stimulated by adding a coagulant. With increasing time and depth the frequency distribution of the settling velocities will change with flocculent settling.

3.2 Frequency distribution of settling velocities

The cumulative frequency distribution of settling velocities can not be calculated in a theoretical way because the size, shape and mass density of the particles are unknown and even variable with flocculent settling. The frequency distribution is found experimentally by plotting the percentage remaining SS (p) against the settling velocity v_s that can

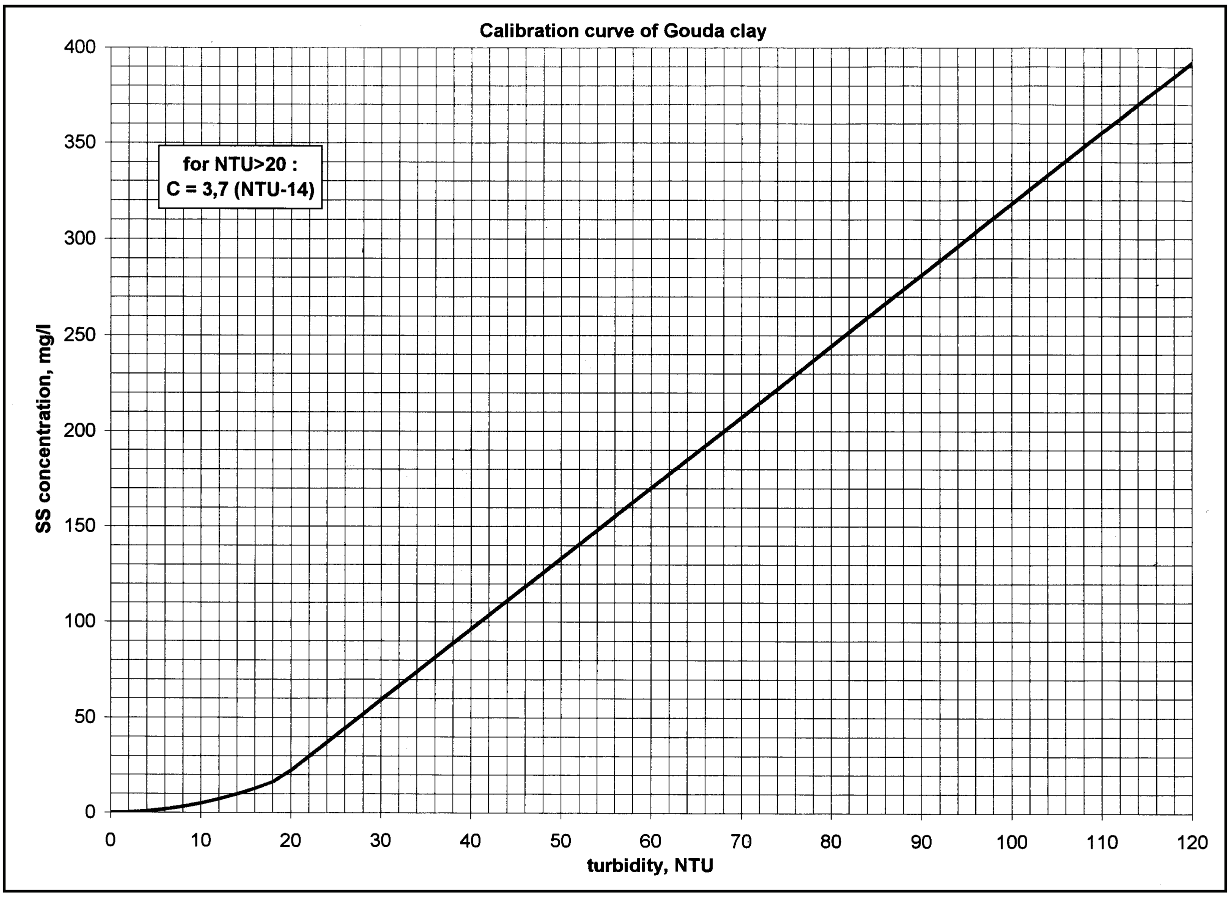

Figure 2 - Calibration curve of Gouda clay

be calculated from the depth of the sampling port under the water surface (H) divided by the elapsed time t.

$p = 100 \times c/c_0$ (%)

$v_s = H/t$ (m/h)

With discrete settling the frequency distributions for all differents depths will coincide into one line and v_s is the real settling velocity. With flocculent settling the frequency distributions don't coincide en v_s is the apparent settling velocity, averaged over the elapsed time.

3.3 Settling efficiency as function of depth and time

Plotting the percentage remaining SS (p) against the depth gives a curve like the one in figure 2. This can be repeated for different times, thus giving a series of curves. These curves can be transferred to efficiency curves as a function of the surface loading (s_0) in a real settling tank.

The original amount of SS in the settling column is represented by the total area of the rectangle (F). After an elapsed time t=x the amount of solids in suspension is reduced to the area (f) below the curve. The efficiency is:

$$r = 100 - \frac{1}{H}\int_0^H p \cdot dh = \frac{F-f}{F} \cdot 100\%$$

H is the depth under consideration. Every value of H can be chosen along the curve and the right border of the surface is bounded by the vertical line through the point h=H. In this experiment the values for H are fixed at 0.5 – 1.0 – 1.5 and 2.0 m. For each of these values a vertical line in figure 2 is drawn and for every curve the value r is determined.

The surface loading s_0 of a settling tank is equal to the apparent settling velocity of the particles and is calculated as:

s_0 = H/t

where t is the time that corresponds to the curves in figure 3.

The relation between r and s_0 can be calculated for any depth. The values can be plotted, resulting in an efficiency graph like figure 4. Such graphs are the basis for the design of a settling tank.

4 Procedure

The experiment should be executed according to the following procedure:

- take 4 dry buckets of 15 l each.
- add 1 full spoon of dry clay powder to each bucket.
- add 10 l water to the clay powder. Mix intensively while adding.
- leave the buckets for about 20 min. to rest. The heavier discrete particles will settle.
- check if the storage tank is clean. If not, remove the remains of the previous experiment.
- check if the valve in the waste line is closed. This valve must be closed!
- transfer the supernatant carefully to the storage tank without any particles that are settled on the bottom of the buckets.
- add cold/hot water to a total volume of 75 l and a temperature equal to the room temperature.
- calculate the amount of coagulant $Al_2(SO_4)_3$ needed to get a final concentration of 2 mg Al^{3+}/l.
- add the coagulant to the storage tank.
- turn on the stirrer in the settling column.
- fill the sedimentation column completely with the clay suspension up to the overflow. Keep stirring the storage tank during the filling process.
- when the water level in the column reaches the overflow (2 m) stop the pump, close the valve and switch off the stirrer in the storage tank.
- measure the water level in the column.
- take the first series of samples from sampling port 1, 2, 3 and 4, just before turning off the stirrer. Rinse the ports before taking a sample.
- switch off the stirrer in the settling column, wait a few minutes until the water volume in the column is quiescent and start the clock: t=0.
- take samples after 3, 6, 9, 15, 21, 30, 45, 60, 75, 90, 120 and 150 minutes (rinse the sampling ports every time before sampling) and note the turbidity of all samples and the water level after each sampling.

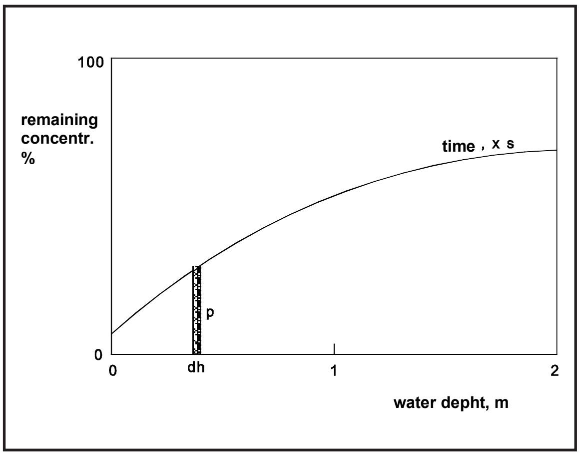

Figure 3 - Percentage remaining concentration as a function of water depth and time

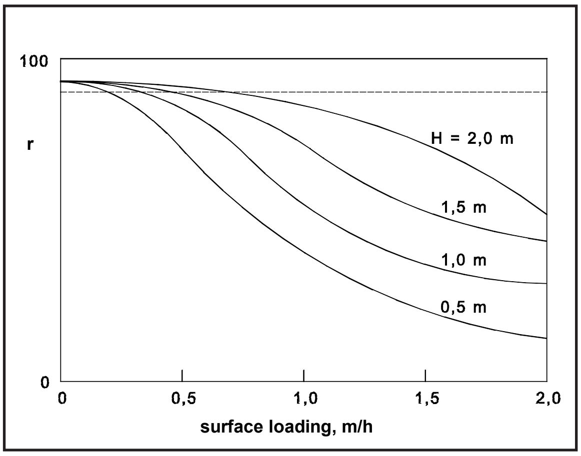

Figure 4 - Settling efficiency against the surface loading

- transform turbidity to SS-concentration with the calibration curve for this specific clay suspension.

Tip: Use the periods between sampling to work out the calculations (see below).

5. Elaboration

Execute the following steps:

- plot SS-concentration of the four sampling ports against time in one graph. Check in this graph if the sedimentation process really began at t=0. If not, correct the time table.
- calculate for each sampling port the depth under the (changing!) water level, the critical settling velocity in m/h and the remaining percentage SS for all sampling times.
- draw in one graph the four frequency distributions of the settling velocities for all sampling ports. Be aware that part of the particles probably stay in suspension.
- plot (on mm-paper) the remaining percentage p against the depth H. Connect the points by a curve and extrapolate up to 2 m depth.
- calculate and plot the removal ratio curves as a function of the overflow rate s_0 for various tank depths (0.5, 1.0, 1.5 and 2.0 m).
- design on the basis of these results a rectangular horizontal flow sedimentation tank(s), given the following data: a flow rate Q of 1500 m^3/h and the highest possible removal efficiency r (to be established by the supervisor), dependent on your experimental results. The tank should have a depth of at least 2.5 meter.
- check your design for turbulence and stability by calculation of the Reynold's and Camp numbers. If necessary, modify the design.
- check your design for resuspension of settled solids.

6. Design

A rectangular horizontal flow settling tank can be designed using the experimental results.

The basic design parameters are the flow rate Q, the required efficiency r and a minimum water depth in the tank. Attention has to be given to some criteria:

1. The horizontal flow velocity should be limited as to prevent resuspension of settled particles. Resuspension is caused by too high flow velocities. The permitted velocity is determined by the settling velocity of the smallest particle that anyhow has to be removed. This normative settling velocity can be calculated with the appropriate equations (see next page).

2. The flow in the tank should be as less turbulent as possible. A measure for turbulency is the Reynolds number Re:

$$Re = \frac{V_0 \cdot R}{\nu}$$

3. The flow in the tank should be stable. To check stability one can use the Camp number C_p:

$$C_p = \frac{v_0^{\,2}}{g} R$$

R = the hydraulic radius.

4. The designer has to choose acceptable dimensions for the tank.

A further tool can be the investment cost, according to Huisman proportional to A1.5 x H .

Resuspension of settled solids

The smallest particles that can be removed in the tank should not be resuspended by a too high water velocity.

The settling velocity of non-spherical flocculent particles is given by the Newton equation (a modified Stokes equation):

$$v_s = \sqrt{\frac{4g}{3C_d\Phi}\frac{\rho_s - \rho_w}{\rho_w}d_p}$$

in which:

C_d = drag coefficient (-)
Φ = coefficient for non-spherical particles (-)
ρ_s = density of particles (flocs) (kg/m^3)
ρ_w = density of water (kg/m^3)
d_p = particle diameter (m)

The magnitude of C_d can be approximated by

$$C_d = \frac{24}{Re_p} + \frac{3}{\sqrt{Re_p}} + 0{,}34$$

where $Re_p = \frac{\Phi v_s d_p}{\nu}$

Φ = 1,0 for spherical particles, 2,0 for sand grains and ± 20 for very loose aggregates of flocks (like activated sludge).

The scouring velocity according to Camp is

$$v_s = \sqrt{\frac{8k}{f}\frac{\rho_s - \rho_w}{\rho_w}gd_p}$$

in which:

k = 0.04 for uniform particles; 0.06 for flocculent particles
f = Friction factor of Darcy-Weisbach, ± 0.03

Data form

Group number: Date

Results turbidity measurements

Time (min)	Turbidity Sampling port (NTU)				Water height (cm)
	1	2	3	4	
0					
3					
6					
9					
15					
21					
30					
45					
60					
75					
90					
120					
150					

Temperature (°C) begin: End: