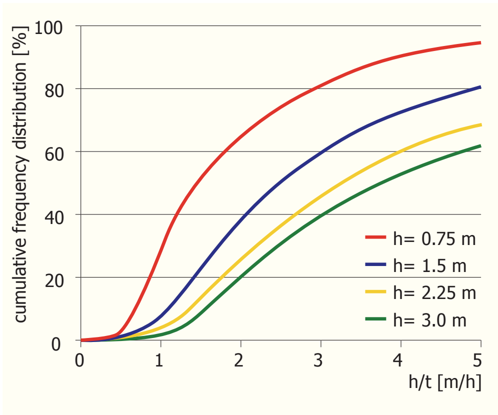
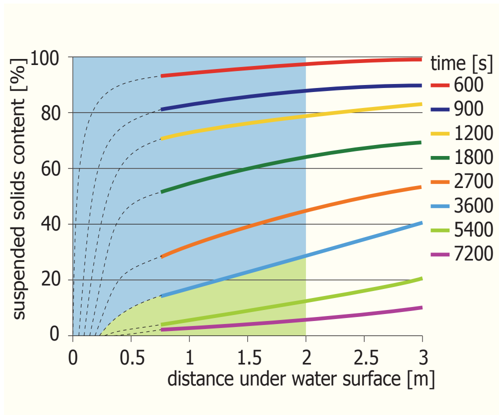
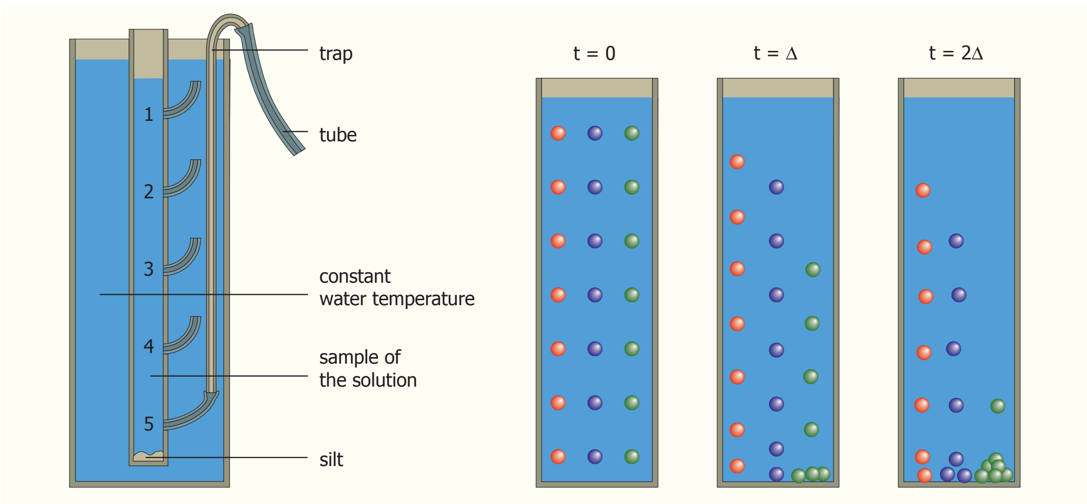
WATER TREATMENT

Sedimentation







Framework

This module represents sedimentation.

Contents

This module has the following contents:

1 Introduction

Sedimentation is a treatment process in which suspended particles, like flocs, sand and clay are re-moved from the water.
Sedimentation can take place naturally in reservoirs or in compact settling installations.
Examples of settling installations are the horizontal flow settling tanks, the tilted plate settlers and the floc blanket installations.

Sedimentation is frequently used in surface water treatment to avoid rapid clogging of sand filters after coagulation and floc formation (Figure 1).
Sedimentation is applied in groundwater treatment installations for backwash water treatment.

In horizontal flow settling tanks (Figure 2) water is uniformly distributed over the cross-sectional area of the tank in the inlet zone.
A stable, non-turbulent, flow in the settling zone takes care of the settling of suspended matter in the settling zone.
The sludge accumulates on the bottom or is continuously removed.
In the outlet zone the settled sludge must be prevented from being re-suspended and washed out with the effluent.

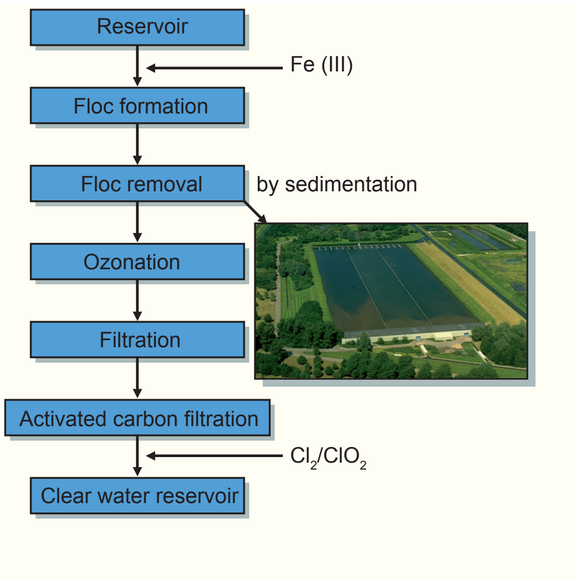


Figure 1 - Process scheme of a surface water treatment plant

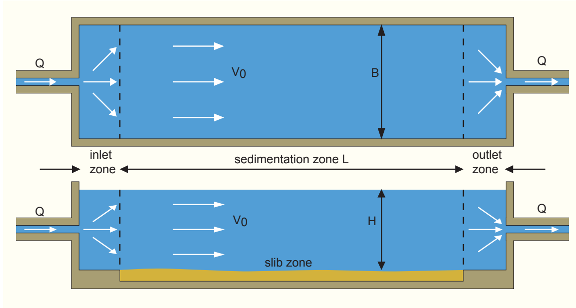


Figure 2 - Horizontal flow settling tank

Sedimentation occurs because of the difference in density between suspended particles and water.
The following factors influence the sedimentation process: density and size of suspended particles, water temperature, turbulence, stability of flow, bottom scour and flocculation:

- density: the greater the density of the particles, the faster the particles settle
- size: the larger the particles are, the faster they settle
- temperature: the lower the temperature of the water is, the higher the viscosity, so the slower the particles settle
- turbulence: the more turbulent the flow is, the slower the particles settle
- stability: instability can result in a short-circuit flow, influencing the settling of particles
- bottom scour: during bottom scour, settled particles are re-suspended and washed out with the effluent
- flocculation: flocculation results in larger particles, increasing the settling velocity.

2 Theory

2.1 Sedimentation of discrete particles

Discrete particles do not change their size, shape or weight during the settling process (and thus do not form aggregates).
A discrete particle in a fluid will settle under the influence of gravity. The particle will accelerate

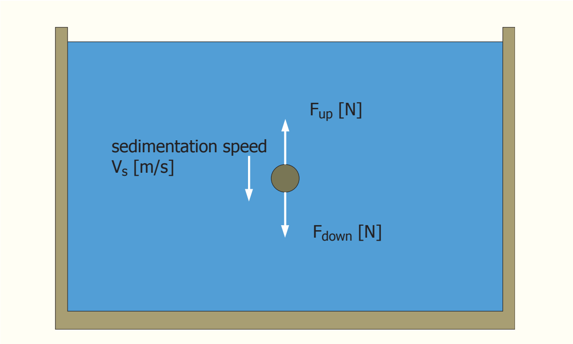


Figure 3 - Forces on a settling particle

until the frictional drag force of the fluid equals the value of the gravitational force, after which the vertical (settling) velocity of the particle will be constant (Figure 3).

The upward directed force on the particle, caused by the frictional drag of the fluid, can be calculated by:

$$F_{up} = c_D \cdot \frac{\rho_w}{2} \cdot v_s^2 \cdot A$$

in which:

F_{up}	=	upward directed force by friction	[N]
c_D	=	drag coefficient	[-]
ρ_w	=	density of water	[kg/m^3]
v_s	=	settling velocity	[m/s]
A	=	projected area of the particle	[m^2]

The downward directed force, caused by the difference in density between the particle and the water, can be calculated by:

$$F_{down} = (\rho_s - \rho_w) \cdot g \cdot V$$

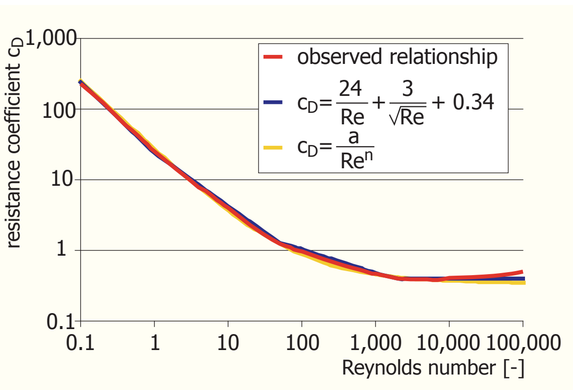


Figure 4 - Relationship between Reynolds number and drag coefficient

in which:

F_{down}	= downward directed flow by gravity	[N]
ρ_s	= specific density of particle	[kg/m^3]
g	= gravity constant	[m/s^2]
V	= volume of particle	[m^3]

Equality of both forces, assuming a spherical particle, gives as the settling velocity:

$$v_s = \sqrt{\frac{4}{3 \cdot c_D} \cdot \frac{\rho_s - \rho_w}{\rho_w} \cdot g \cdot d}$$

in which:

d = diameter of spherical particle [m]

The settling velocity is thus dependent on:

- density of particle and fluid
- diameter (size) of particle
- flow pattern around particle.

The flow pattern around the particle is incorporated in the drag coefficient. The value of the drag coefficient is not constant, but depends on the magnitude of the Reynolds number for settling. For spherical particles the Reynolds number is given by:

$$Re = \frac{v_s \cdot d}{\nu}$$

in which:

ν = kinematic viscosity [m^2/s]

In drinking water treatment practice, laminar settling normally occurs. The Reynolds number for laminar settling of spheres is Re<1, resulting in the following relationship between the Reynolds number and the drag coefficient:

Substitution of this relationship in the equation for the settling velocity gives the Stokes' equation:

$$v_s = \frac{1}{18} \cdot \frac{g}{\nu} \cdot \frac{\rho_s - \rho_w}{\rho_w} \cdot d^2$$

The settling velocity is thus dependent on the viscosity of the fluid and also the temperature.

The relationship between kinematic viscosity and temperature is:

$$\nu = \frac{497 \cdot 10^{-6}}{(T + 42.5)^{1.5}}$$

in which:

T = temperature [°C]

When the Reynolds number Re > 1600, settling is turbulent and when 1<Re<1600, settling is in transition between laminar and turbulent.
In Figure 4 the relationship between the drag coefficient and the Reynolds number is represented.

In Figure 5 the settling velocity as a function of particle size and density is shown.

2.2 *Horizontal flow settling tanks in practice*

In practice, settling occurs in flowing water. An ideal horizontal flow settling tank has the following characteristics:

- at the inlet the suspension has a uniform composition over the cross-section of the tank
- the horizontal velocity v_o is the same in all parts of the tank
- a particle that reaches the bottom is definitively removed from the process.

The flow velocity in a horizontal settling tank is:

$$v_o = \frac{Q}{B \cdot H}$$

in which:

v_o = horizontal flow velocity [m/h]
Q = flow [m^3/h]
B = width of the tank [m]
H = height of the tank [m]

The surface loading of a settling tank is determined by:

$$q = \frac{Q}{B \cdot L}$$

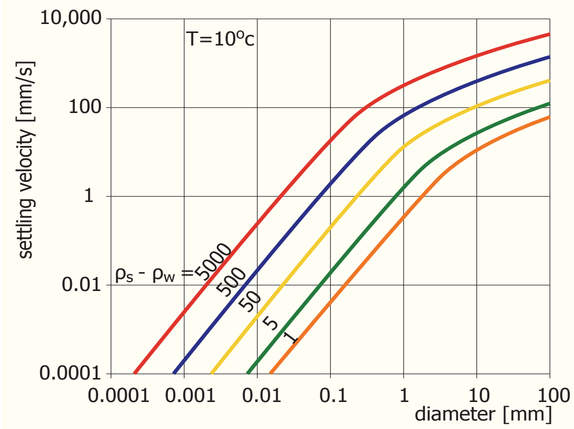


Figure 5 - Settling velocity of discrete spherical particles

in which:

q = surface loading [$m^3/(m^2 \cdot h)$]
L = length of the tank [m]

In Figure 6 the trajectory of a particle is represented. After t_1 the water leaves the tank and after t_2 the particle is settled. The particles will settle, therefore, when $t_2 < t_1$.
The velocity of the particle is divided into horizontal and vertical components and the settling times can be written as:

$$t_2 \le t_1 \Rightarrow \frac{H}{v_s} \le \frac{L}{v_0} \Rightarrow \frac{H}{v_s} \le \frac{B \cdot H \cdot L}{Q}$$

$$\Rightarrow \frac{1}{v_s} \le \frac{1}{q} \Rightarrow v_s \ge q$$

In special cases, when the settling velocity equals the surface loading, the particle reaches the end of the tank. This settling velocity is called the critical velocity v_{so}.
It can be concluded that a particle will only be removed if the settling velocity is greater than or equal to the critical settling velocity (Figure 7).

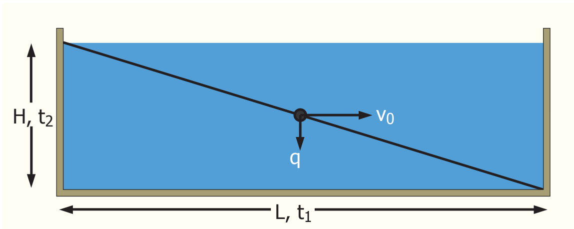


Figure 6 - Settling in a horizontal flow settling tank

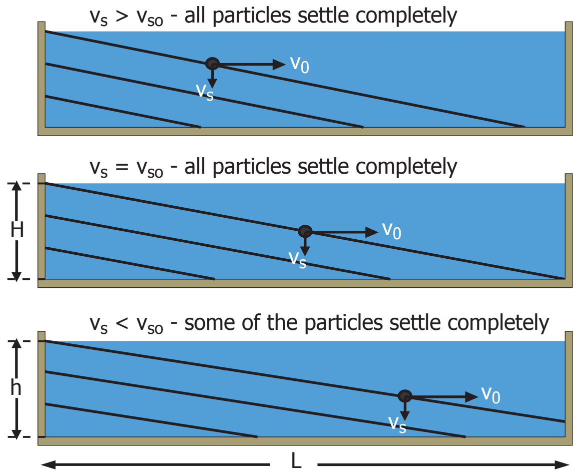


Figure 7 - Settling of a suspension in a horizontal flow

After determining the settling velocity of a particle during a settling test, the surface loading and thus the dimensions of the tank can be determined.
It is remarkable that, in theory, settling in a horizontal flow settling tank is only determined by the flow and the surface area of the tank and is independent on the height of the tank.

The fraction of the particles that settle in case $v_s < v_{so}$ is (Figure 7):

$$\frac{h}{H} = \frac{v_s \cdot T}{v_{so} \cdot T} = \frac{v_s}{v_{so}}$$

in which:
T = residence time of water in the settling tank[s]

The residence time of water in the settling tank is expressed as T and equals t_1 from Figure 6.

2.3 *Settling efficiency of a suspension*

In a suspension the fraction of particles with a settling velocity higher than the surface loading settle completely. The fraction with a lower settling velocity settles partly. The efficiency is determined from the cumulative frequency distribution of settling velocities obtained from a settling test.

The settling test is executed in a cylindrical container (column) filled with a homogeneous sample of the suspension to be tested (Figure 8). At different time intervals samples are taken at different depths and analyzed for suspended solids, turbidity or any other index that can be reduced by settling. The depth is measured with the water surface as reference. In Table 1 the analyses of a settling column test at depth h=1.0 m are represented (Figure 8).

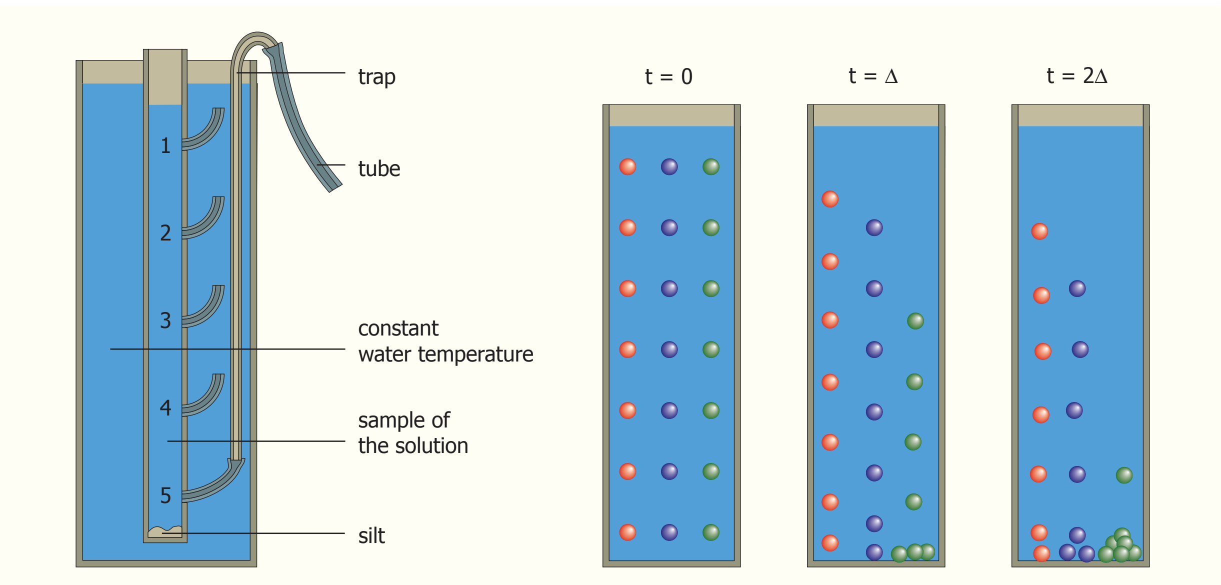


Figure 8 - Settling column and representation of different settling velocities

Table 1 - Particle concentration and relative particle concentration from a settling test at a depth of h = 1.0 m

t (s)	0	666	900	1800	2700	3600	5400	7200
c (ppm)	86	84	79	57	41	29	7	3
p=c/co (%)	100	98	92	66	48	34	8	4

In Figure 9 the cumulative frequency distribution of the settling velocities is represented. The ratio of sampling depth and time is given as a function of the relative solids concentration. The solids with the lowest settling velocity determine the residence time of a settling system.

The particles with a settling velocity higher than the critical settling velocity v_{so} are removed completely. This is represented in Figure 9 by the red arrow. Expressing the relative solids concentration for a settling velocity of v_{so} as p_o, the first part of the settling efficiency is:

$$r_1 = 1 - p_o$$

in which:

r_1 = part of the efficiency caused by complete settling [-]

p_o = relative solids concentration at surface loading s_o [%]

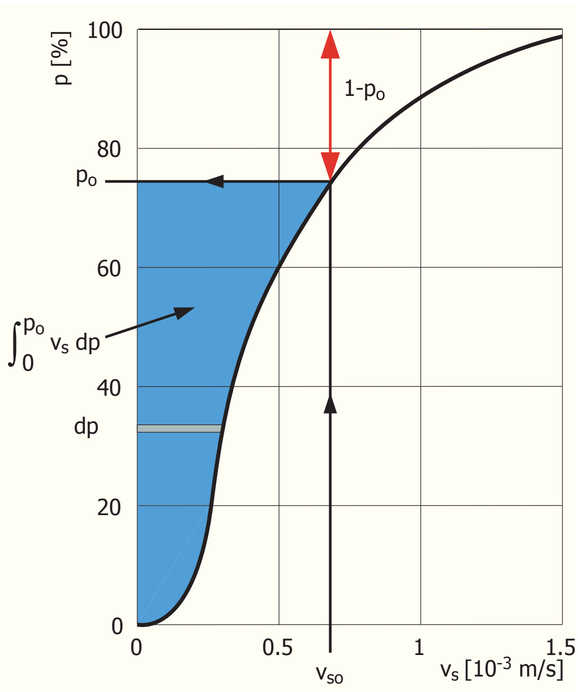


Figure 9 - Cumulative frequency distribution of settling velocities

From the particles with a lower settling velocity than v_{so}, only the particles that enter the tank at a reduced height will be removed.

From the fraction of particles dp with settling velocity v_s, only the fraction h/H or v_s/v_{so} will be removed. This part of the efficiency (partial removal) can be described by:

$$r_2 = \int_0^{p_o} \frac{v_s}{v_{so}} dp = \frac{1}{v_{so}} \int_0^{p_o} v_s dp$$

in which:

r_2 = part of the efficiency caused by partial settling [-]

The efficiency caused by partial settling is represented by the blue surface in Figure 9 divided by the critical settling velocity. Graphically, this part of the total efficiency can be determined as shown in Figure 10.

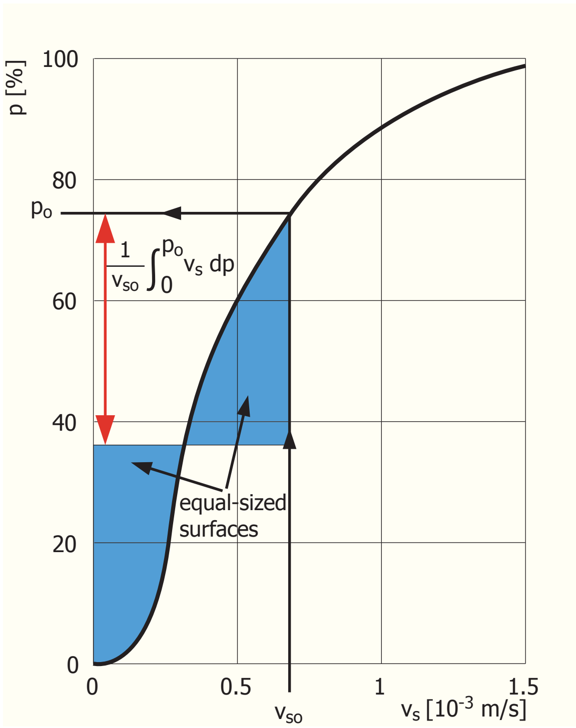


Figure 10 - Efficiency of partial settling

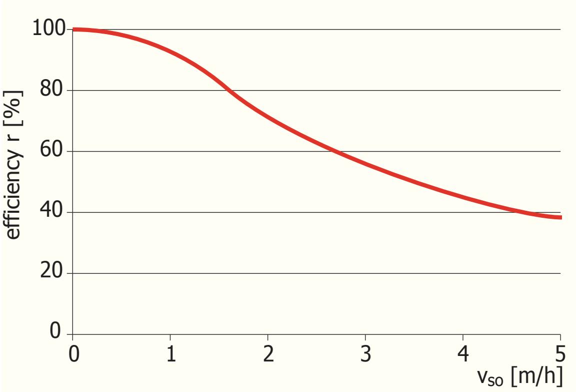


Figure 11 - Removal efficiency in a horizontal flow settling tank

The equation of the total settling efficiency becomes:

$$r = (1 - p_o) + \frac{1}{v_{so}} \int_0^{p_o} v_s \, dp$$

For different values of v_{so} the efficiency is calculated and the results are represented in Figure 11.

It can be concluded that with increasing surface loading of the settling tank (by increasing flow), the settling efficiency decreases.

3 Influences on settling in a horizontal flow tank

In the preceding paragraphs an ideal flow and discrete settling were assumed.

In practice, however, the ideal situation does not exist and the efficiency is influenced by:

- turbulence of flow
- instability of flow
- bottom scour
- flocculation.

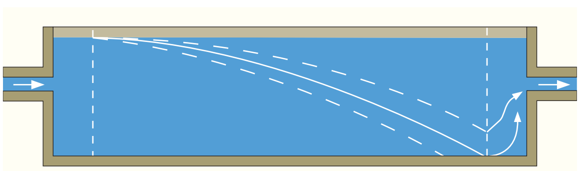


Figure 12 - Influence of turbulence on settling in a horizontal flow settling tank

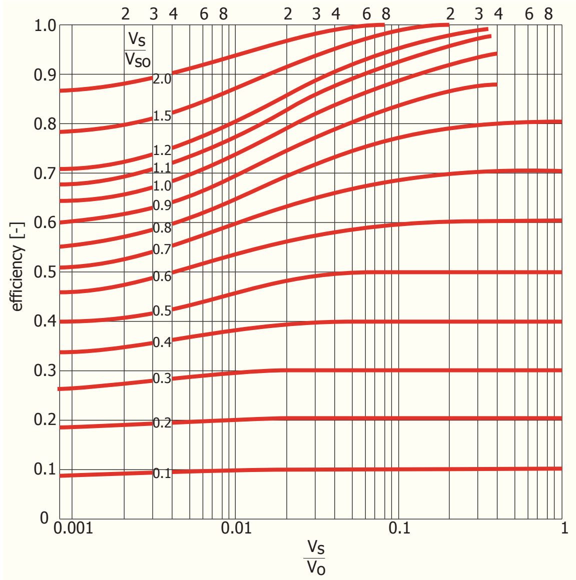


Figure 13 - Influence of turbulence on the efficiency of settling

3.1 Influence of turbulence

In laminar flow in a horizontal flow tank, a particle follows a straight line.

In turbulent flow, eddies will transport particles in a random direction, influencing the settling of the particles (some settle faster and others slower) (Figure 12).

With the Reynolds number the flow characteristics can be determined:

- laminar flow: Re < 2000
- turbulent flow: Re > 2000.

The Reynolds number for flow in a tank can be calculated with:

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

in which:

R = hydraulic radius of a settling tank [m]

The hydraulic radius of a rectangular tank can be calculated with:

$$R = \frac{B \cdot H}{B + 2 \cdot H}$$

With the expression $v_o = Q/(B \cdot H)$ the Reynolds number can be rewritten as:

$$Re = \frac{Q}{\nu} \cdot \frac{1}{B + 2 \cdot H}$$

In Figure 13 the settling efficiency for turbulent flow is represented as a function of v_s/v_{so} and v_s/v_o.

In practice turbulence is not always a disadvantage because, in general, flocculant settling occurs (section 3.4). Turbulence increases the collision frequency of particles, thus increasing the efficiency of the flocculant settling.

3.2 Influence of stability

Flow is called stable when short circuiting does not occur.

In Figure 14 an example of a short-circuit flow caused by wind effects is illustrated. The wind creates a dead zone (or eddy) in the corner of the settling tank. The water flow can then flow, locally, in the opposite direction from the general flow through the tank.

Stability of flow is characterized by the Camp number c_p:

$$c_p = \frac{v_o^2}{g \cdot R}$$

Substituting the equations for vo and R for a rectangular tank, the Camp number becomes:

$$c_p = \frac{Q^2}{g} \cdot \frac{B + 2 \cdot H}{B^3 \cdot H^3}$$

$c_p > 1 \cdot 10^{-5}$ stable flow
$c_p < 1 \cdot 10^{-5}$ unstable flow

In Figure 15 the minimal residence time (T_i) and the average residence time (T_a) of water droplets are represented in comparison with the theoretical residence time (T_o) for different values of the Camp number.

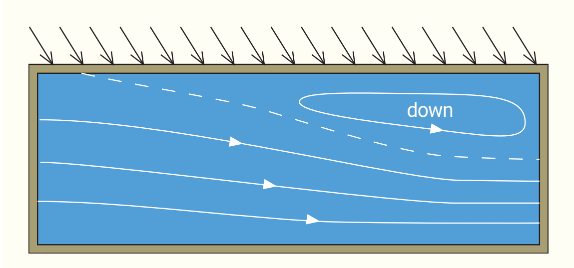


Figure 14 - Short-circuit flow caused by wind

From Figure 15 it can be concluded that the lower the Camp number is (and thus more short-circuit flow occurs), the shorter the minimal and average residence times become. This is due to the decrease in the effective cross-section of the settling tank and, therefore, to an increase in flow velocity.

The efficiency of a settling tank, therefore, will be lower than is the case in a stable flow condition.

3.3 Influence of bottom scour

In theory, a particle is removed from the water when it reaches the bottom of the settling tank.

In practice, however, it is possible that resuspension of already settled particles occurs.

In Figure 16 the forces on particles at the bottom of the tank are shown.

The shear force of water on a spherical particle is:

$$\tau = \frac{\lambda}{8} \cdot \rho_w \cdot v_{sc}^2$$

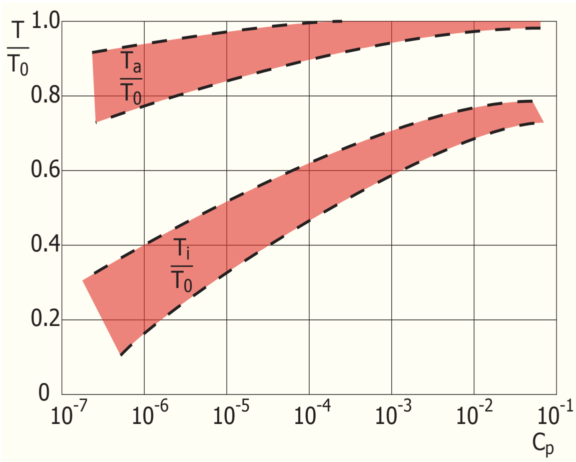


Figure 15 - Short-circuit flow

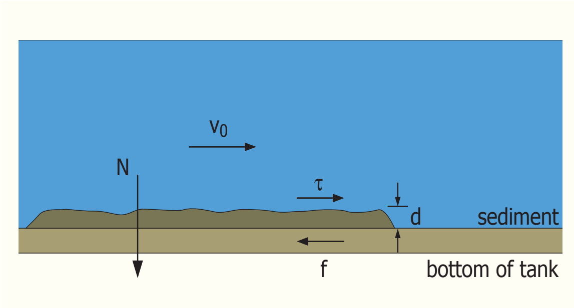


Figure 16 - Bottom scour

in which:

τ = hydraulic shear [N/m^2]

λ = hydraulic friction factor (λ = 0.03) [-]

v_{sc} = critical scour velocity [m/s]

The shear force of particles at the bottom (mechanical friction) is proportional to the submerged weight of the sludge layer:

$$f = \beta . (\rho_s - \rho_w) . g . d$$

in which:

f = mechanical shear [N/m^2]

β = mechanical shear factor (b = 0.05) [-]

In equilibrium the hydraulic shear equals the mechanical shear and the critical scour velocity can be calculated:

$$v_{sc} = \sqrt{\frac{40}{3} \cdot \frac{\rho_s - \rho_w}{\rho_w} \cdot g \cdot d}$$

When the flow velocity in a settling tank is lower than the scour velocity, bottom scour will not occur:

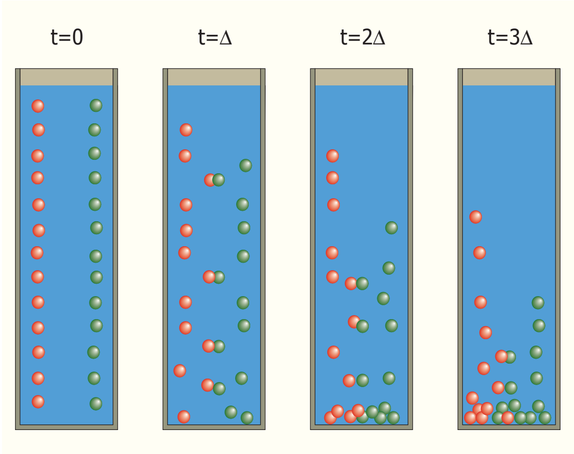


Figure 17 - Flocculant settling

$v_0 <= v_{sc}$ no bottom scour

Given the surface loading, the width and depth of a settling tank can be determined based on this criterion.

3.4 Influence of flocculant settling

During settling, aggregates are formed as a result of collisions between particles, and settling velocities will increase. This phenomenon is called flocculant settling (Figure 17).

In Table 2 the results of a settling test of a flocculant suspension are shown..

In Figure18 the cumulative frequency distribution of settling velocities is given at different tank depths. From the fact that the distributions differ

Table 2 - Relative particle concentration from a settling test

	h = 0.075 m	**h = 1.5 m**	**h = 2.25m**	**h = 3.0 m**
t = 0 s	100	100	100	100
t = 600 s	93	96	98	99
t = 1200 s	81	86	88.5	89.5
t = 1800 s	70.5	77.5	81	83
t = 2700 s	28	38	46.5	53
t = 3600 s	13.5	22	31	40
t = 5400 s	3	8	13.5	20
t = 7200 s	1.5	3	6	9.5

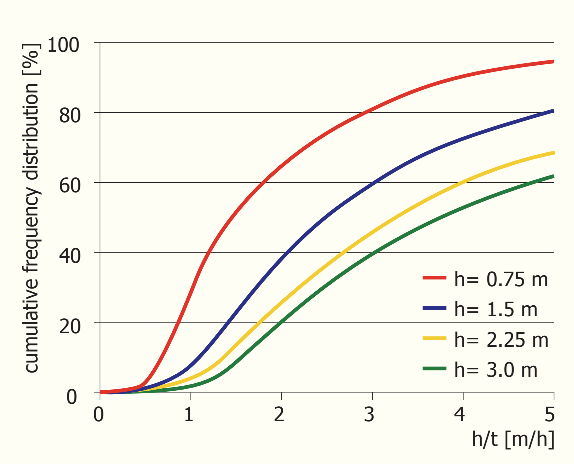


Figure 18 - Cumulative frequency distribution of settling velocities at different tank depths

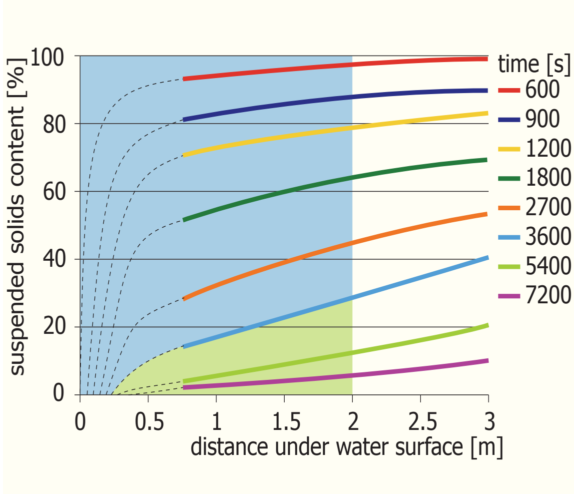


Figure 19 - The relative particle concentration

Example

A horizontal flow settling tank has a height of 2 m, a width of 20 m and a length of 45 m. The flow through the tank is 0.5 m^3/s and the water temperature is 10 ^{0}C

Check if the tank meets the hydraulic requirements.

The horizontal flow velocity and the critical settling velocity are:

$$v_o = \frac{Q}{B \cdot H} = \frac{0.5}{20 \cdot 2} = 12.5 \cdot 10^{-3} m/s$$

$$v_{so} = \frac{Q}{B \cdot L} = \frac{0.5}{20 \cdot 45} = 0.56 \cdot 10^{-3} m/s$$

The hydraulic radius of the tank can be calculated with:

$$R = \frac{B \cdot H}{B + 2 \cdot H} = \frac{20 \cdot 2}{20 + 2 \cdot 2} = 1.67$$

The Reynolds number and the Camp number are:

$$Re = \frac{v_o \cdot R}{\nu} = \frac{12.5 \cdot 10^{-3} \cdot 1.67}{1.31 \cdot 10^{-6}} = 15935$$

$$c_p = \frac{v_o^2}{g \cdot R} = \frac{(12.5 \cdot 10^{-3})^2}{9.81 \cdot 1.67} = 0.954 \cdot 10^{-5}$$

The Reynolds number is higher than 2000 and the flow will be turbulent. The Camp number is about $1 \cdot 10^{-5}$ and no short-circuit flow will occur.

Determine the efficiency of the settling tank considering the suspension from the settling test in Table 2.

In Figure 19 the suspended solids content is represented as a function of water depth at the different sampling times from Table 2. Between 0 and 0.75 meters the progress of the graph is estimated (dotted line). The residence time is:

$$\tau = \frac{B \cdot H \cdot L}{Q} = \frac{20 \cdot 2 \cdot 45}{0.5} = 3600s$$

From Figure 19 the efficiency can be determined, assuming a residence time of 3600 seconds and a height of 2 meters. The blue surface above the line indicates the amount of solids that are settled. The green surface below the line indicates the amount of solids that are still in suspension after 3600 seconds. It can be concluded after measuring the surfaces that the settling efficiency is 80%.

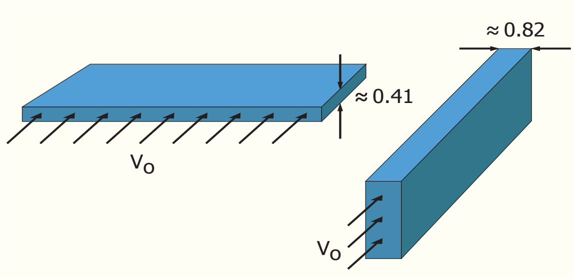


Figure 20 - Settling tanks with laminar and stable flows

over the height of the tank, it can be concluded that flocculant settling occurs.

From Figure 19 it can also be concluded that the efficiency increases with the increasing depth.
For flocculant settling, in contrast to discrete settling, the height of the tank is of importance to the settling efficiency.

4 Practice

4.1 Determination of the dimensions of an ideal settling tank

In ideal settling tanks the flow is stable ($c_p > 10^{-5}$) without turbulence (Re < 2000).
At a temperature of 10°C these conditions are met with a horizontal flow velocity and a hydraulic radius of:
$v_o = 6.4 \cdot 10^{-3}$ m/s
R < 0.41 m

Tanks that meet these conditions are short, wide and shallow or long, narrow and deep (Figure 20).
These constructions, however, are expensive due to the amount of space they occupy.
In practice, a tank will be a compromise between the Reynolds and Camp numbers, on the one hand, and the construction costs, on the other, limiting the length/width/depth ratios.

4.2 Inlet constructions

In the preceding paragraphs it was assumed that the water is uniformly distributed over the cross-section of the tank, but in practice this assumption is not totally accurate.
For an even distribution of the water over the width (and depth) of the tank, inlet constructions are introduced.
In Figure 21 an example of an inlet construction is represented. The inlet velocity is reduced by introducing several inlet channels, followed by a diffuser wall that distributes the water over the entire cross-section of the tank.

A diffuser wall (Figure 22) has openings to distribute the water over the width (and depth) of the tank. At the end of the wall, the flow velocity in the inlet channel is zero and so is the velocity head. The head loss caused by friction, however, is lower than the decrease in velocity head, resulting in an increase in the piezometric level.
The water level at the end of the inlet channel is, thus, higher than the level at the beginning. The result is that at the end of the inlet channel more water enters the tank than at the beginning of the inlet channel. To avoid this uneven distribution, the head loss over the openings in the diffuser wall must be larger than the difference in piezometric level induced by the decrease in flow

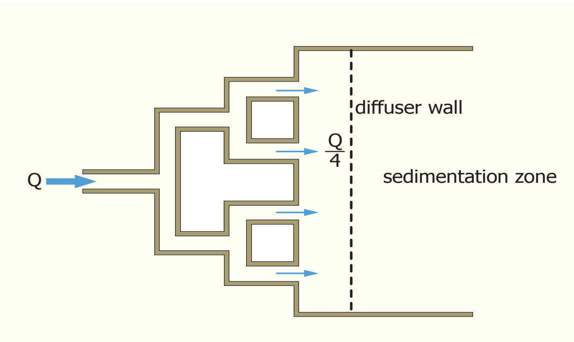


Figure 21 - Inlet construction

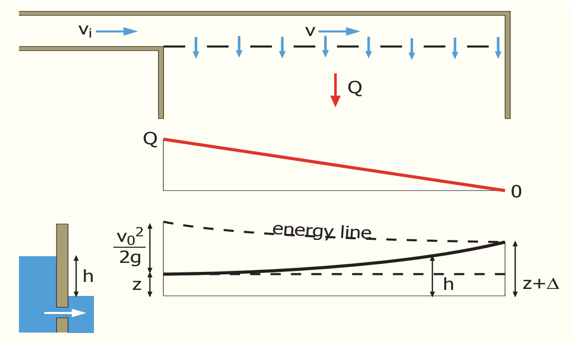


Figure 22 - Diffuser wall

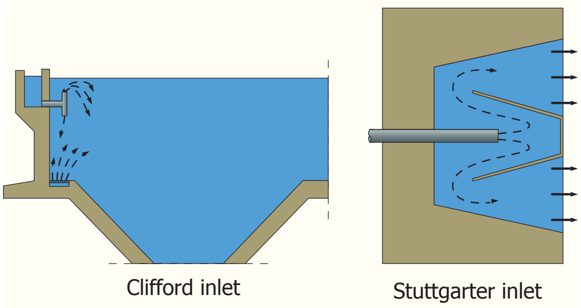


Figure 23 - Clifford and Stuttgarter inlet

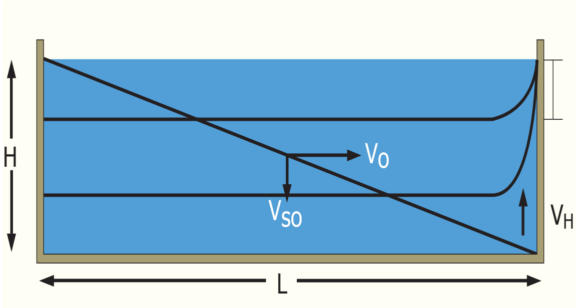


Figure 24 - Upward velocity to overflow weir

velocity.

In practices, more as well as alternative inlet constructions exist, like the Clifford and the Stuttgarter inlet (Figure 23).

4.3 Outlet constructions

The outlet construction is situated at the end of the settling tank and generally consists of an overflow weir.
At the outlet construction, re-suspension of settled solids must be prevented and the flow velocity in an upward direction will thus be limited (Figure 24).

The flow velocity in an upward direction is:

$$v_H = \frac{1}{5} \cdot \frac{Q}{B \cdot H} < v_{so}$$

in which:
v_H =outflow velocity in an upward direction [m/s]

Resulting in:

$$\frac{L}{H} < 5$$

Most horizontal flow settling tank have an L/H>5 and thus:

$$\frac{Q}{n \cdot B} < 5 \cdot H \cdot v_{so}$$

Therefore, the length of the overflow weir must be several times the width of the tank.
To create sufficient length for the overflow weir, several troughs are placed parallel to each other(Figure 25).

4.4 Sludge zone and removal

In the sludge zone the solids are accumulated.
The removal of the sludge can be done hydraulically and mechanically.

Hydraulic sludge removal is done at regular intervals by dewatering the tank and flushing the sludge with pressured water (from hydrants) to a hopper at the bottom of the tank from where it is removed by gravity or by pumping.

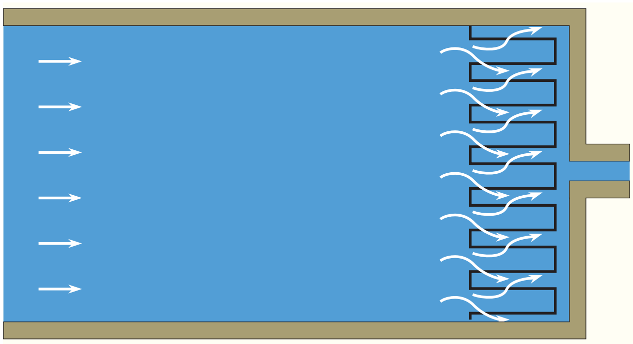


Figure 25 - Overflow weir for effluent discharge

Mechanical sludge removal is frequently applied when sludge volumes are large or the sludge is unstable, resulting in anaerobic decomposition during storage in the sludge zone.
Mechanical sludge removal consists of scrapers that transport the sludge to a hopper in the middle of a round settling tank or near the inlet of a rectangular tank. From the hopper, the sludge is removed.

5 Settling tank alternatives

5.1 Vertical flow settling tank

In vertical flow settling tanks the inlet of the water to be treated is situated at the bottom of the tank and the water flows in an upward direction (Figure 26).
The flow velocity equals, in this case, the surface loading:

$$v_o = \frac{Q}{B \cdot L} = s_o$$

The result is that only particles with a settling velocity higher than the upflow velocity will settle and others will be washed out:

$s >= s_0$ settles completely

$s < s_0$ does not settle

The settling efficiency is entirely determined by the particles that settle completely (see Figure 9):

$$r = 1 - p_o$$

The settling efficiency of discrete particles in vertical flow settling tanks is lower than in horizontal flow tanks, and vertical flow tanks are therefore not used for discrete, totally flocculated, suspensions.
In the case of flocculant settling, vertical flow tanks are used (e.g., in the form of floc blanket clarifiers).

5.2 Floc blanket clarifier

The floc blanket clarifier consists of a (conical) vertical flow tank (Figure 27).
Coagulant is dosed at the inlet of the clarifier and floc formation occurs in the installation. Small, light flocs with a settling velocity lower than the upflow velocity are transported with the water flow in an upward direction and collide with larger, heavier flocs. After attachment, the settling velocity increases until they reach the bottom of the

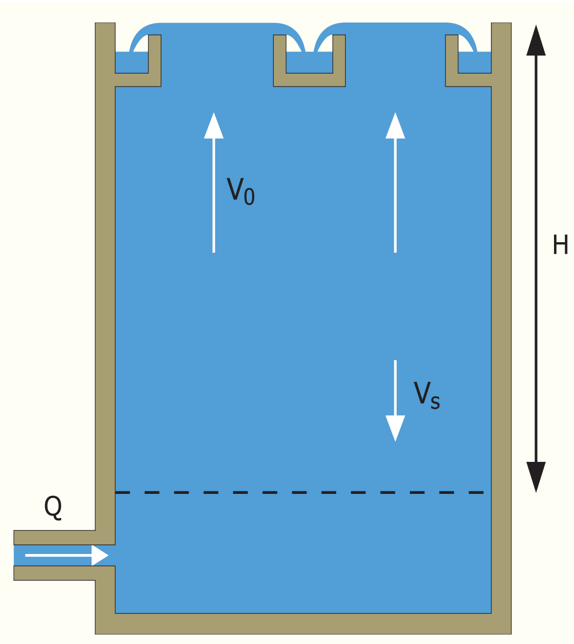


Figure 26 - Vertical flow settling

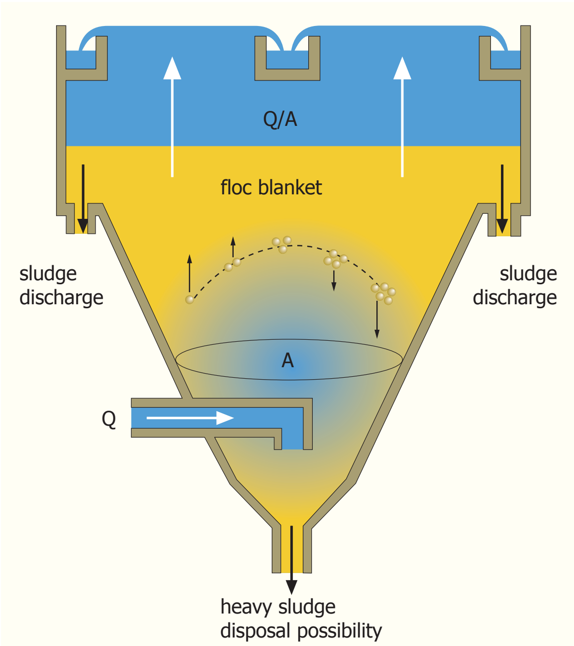


Figure 27 - Floc blanket installation

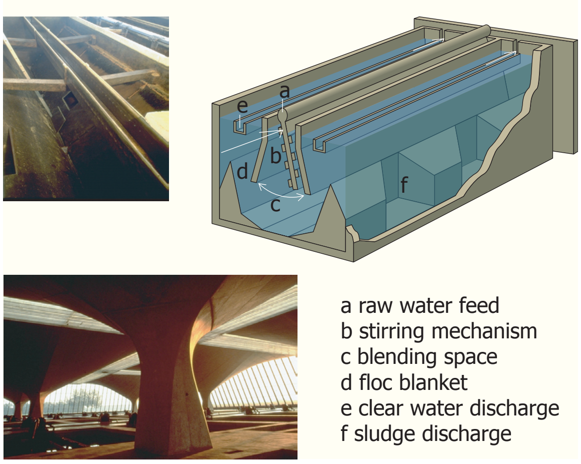


Figure 28 - Floc blanket installation at Berenplaat

tank, where a sludge removal device is installed.

Flocs that do not form aggregates are transported to the top of the installation where the surface area is the largest and the upflow velocity the lowest, and a floc blanket is formed.
The floc blanket is manipulated by a drain at the required thickness. The floc blanket has a filtering effect for even small flocs. Therefore, high efficiencies can be realized with relatively short residence times.

The plant at Berenplaat in Rotterdam is where one of the floc blanket clarifiers in the Netherlands is located (Figure 28). The inlet of the water is at the top of the installation. A stirring device creates turbulence in the floc formation chamber to increase the collision frequency. After leaving the mixing chamber, the flocs form a blanket and the effluent water is drained by troughs.

5.3 Tray settling tanks

The efficiency of discrete settling can be increased by applying horizontal baffles (false floors or trays) (Figure 29).
In section 2.2 it is shown that the settling efficiency for discrete particles is independent of the height of the settling tank. The application of horizontal baffles gives a double surface area and half of the surface loading, resulting in an increase in efficiency.
Horizontal baffles also improve the flow pattern.

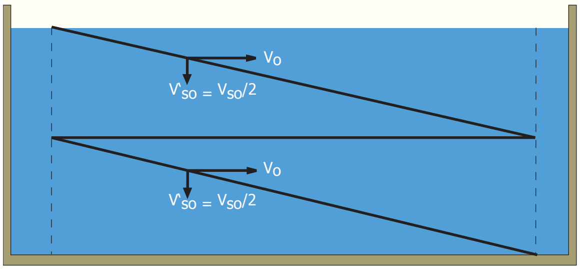


Figure 29 - Tray settling

The Reynolds number decreases and the Camp number increases. The flow becomes less turbulent and more stable.

5.4 Tilted plate settling

In tilted plate settling tanks, water passes baffles that are placed at a steep angle.

In Figure 30 an example is given of a counter-current tilted plate settling tank. The water flows in upward direction and the sludge settles on the plates and slides down. The angle of the plates must be about 55^o to 60^o to secure sludge removal.
In Figure 31 the flow in a counter-current tilted plate settling tank is pictured.
Using geometry the following surface loading can be derived:

$$s_o' = s_o \cdot \frac{w + t}{H \cdot \cos\alpha + w}$$

in which:

s_o'	=	vertical surface loading	[m/h]
w	=	distance between plates	[m]
t	=	thickness of plates	[m]
H	=	height of plates	[m]
α	=	angle of plates with the horizontal	[o]

In a similar way the surface loading for a co-current flow can be derived:

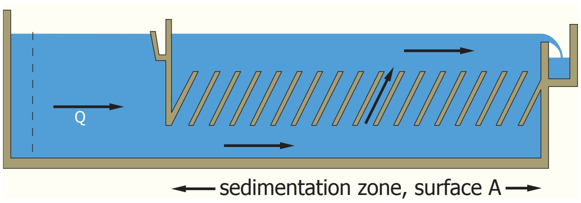


Figure 30 - Counter-current tilted plate settling

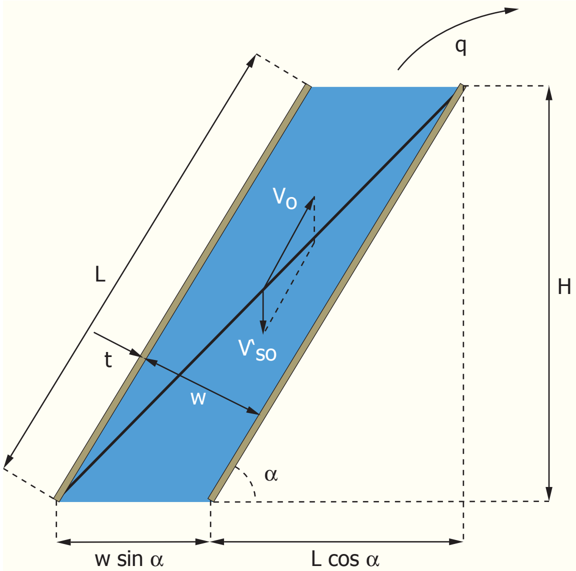


Figure 31 - Flow through a tilted plate settler

$$s_o' = s_o \cdot \frac{w + t}{H \cdot \cos\alpha - w}$$

In Table 3 the design parameters of Figure 31 that are applied in practice are given.
The angle of the plates in co-current systems can be gentler than in counter-current systems without deteriorating the sludge removal.
Substituting the values of Table 3 into the equations for surface loading for both co-current and counter-current systems results in:

$$s_o' \approx \frac{s_o}{20}$$

The space occupied by tilted plate settling tanks is thus a factor 20 smaller than is needed for horizontal flow tanks.

Both the Camp number and the Reynolds number depend on the hydraulic radius and the horizontal flow velocity.

Table 3 - Design parameters

Design parameters	Value
counter-current	55^0 - 60^0
co-current	30^0 - 40^0
H	1 - 3 m
w	3.4 - 8 cm
t	5 mm

In Figure 32 the stability boundary, $c_p > 10^{-5}$, and the turbulence boundary, Re < 2000, are given. In addition, the combinations of hydraulic radius and horizontal flow velocity of horizontal flow and tilted plate tanks applied in practice are shown. From the graph it can be derived that the flow in horizontal flow tanks is turbulent and in some cases instable (and short-circuit flow can occur). The flow in tilted plate tanks, however, is favorable. The Reynolds number is always smaller than 2000, resulting in laminar flow; and the Camp number is always higher than 10^{-5}, resulting in a stable flow without short-circuiting.

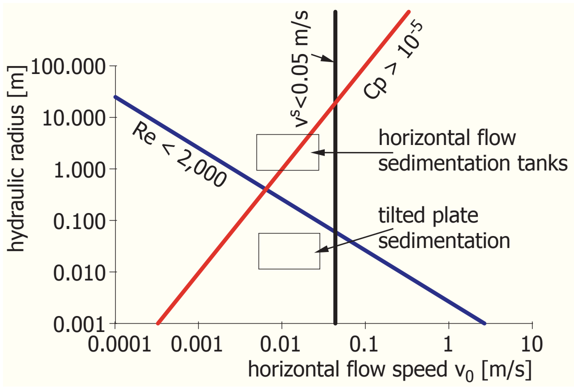


Figure 32 - Hydraulic conditions for optimal settling

Further reading

- Sedimentation and flotation, TU-Delft (2004)
- Water treatment: Principles and design, MWH (2005), (ISBN 0 471 11018 3) (1948 pgs)