CHAPTER: 10

Sedimentation

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**Sedimentation**

separation of unstable and destabilized suspended solids from a suspension by the force of gravity

**Applications in Water Treatment:**
1. settling of coagulated and flocculated waters prior to filtration
2. settling of coagulated and flocculated waters in a softening plant
3. settling of treated waters in an iron and manganese removal plant

**Applications in Wastewater Treatment:**
1. grit removal
2. suspended solids removal in primary clarifier
3. biological floc removal in activated sludge
Sedimentation

Settling of particles from suspension depends on:

**Characteristics of the Particles**

- **DISCRETE PARTICLES**: particles whose size, shape and specific gravity do not change with time.
- **FLOCCULATING PARTICLES**: particles whose surface properties are such that they aggregate upon contact. Thus, changing in size, shape, and perhaps specific gravity with each contact.

**Concentration of Particles in Suspension**

- **DILUTE SUSPENSIONS**: suspensions in which the conc. of particles is not sufficient to cause significant displacement of water as they settle or in which the particles will not be close enough for velocity field interference to occur.
- **CONCENTRATED SUSPENSIONS**: suspensions in which the conc. of particles is too great to meet the conditions mentioned for dilute suspensions.
| TYPE 1 (discrete particle settling) | settling of discrete particles in dilute suspensions  
|                                      | particles have no tendency to flocculate  
|                                      | they settle as individual entities and there is no significant interaction with neighboring particles  
| **Example:** | removal of grit and sand in wastewater treatment |
| TYPE 2 (flocculant settling) | settling of flocculant particles in dilute suspensions  
|                                      | as particles settle and coalesce with other particles, the sizes of particles and their settling velocity increases  
| **Examples:** | removal of SS in primary sedimentation tanks of WWTP  
|                                      | settling of chemically coagulated waters |
| TYPE 3 (hindered settling) or (zone settling) | settling of intermediate concentration of flocculant particles  
|                                      | particles are so close together that interparticle forces are able to hold them in fixed positions relative to each other and the mass of particles settles as a zone at a constant velocity  
| **Example:** | biological floc removal in secondary settling basins of WWTP |
| TYPE 4 (compression settling) | settling of particles that are of such a high concentration that the particles touch each other and settling can occur only by compression which takes place from the weight of particles  
| **Examples:** | occurs in the bottom of deep secondary clarifiers  
|                                      | in sludge thickening facilities |
Type 1 – Discrete Settling

If a particle is suspended in water, it initially has 2 forces acting upon it.

1. The forces of gravity
   \[ f = \rho_p g \forall_p \]

2. The buoyant force quantified by Archimedes.
   \[ f_b = \rho_w g \forall_p \]

Once motion has been initiated, a third force is created due to viscous friction

1. Drag force
   \[ f_D = C_D A_p \rho_w \left( \frac{v_s}{2} \right)^2 \]

\( \rho_p = \) density of particle
\( \forall_p = \) volume of particle
\( \rho_w = \) density of water
\( \forall_p = \) volume of particle
\( C_D = \) drag coeff.
\( A_p = \) cross sectional area of particle perpendicular to the direction of movement
\( \rho_w = \) density of water
\( v_s = \) settling velocity of particle
Force balance for a discrete particle that is settling

\[ m_p \frac{d\dot{v}_s}{dt} = F_G - F_B - F_D \]

Downward acceleration of particle

After an initial transient period, the acceleration \( \frac{d\dot{v}_s}{dt} \) becomes zero and the settling velocity becomes constant.

\[ m_p \frac{d\dot{v}_s}{dt} = 0 = F_G - F_B - F_D \]

\[ 0 = (\rho_p g \forall_p) - (\rho_w g \forall_p) - \left( C_D A_p \rho_w \frac{\dot{v}_s^2}{2} \right) \]
\[ 0 = g \forall_p \left( \rho_p - \rho_w \right) - \left( C_D A_p \rho_w \frac{\vartheta_s^2}{2} \right) \]

\[ g \forall_p \left( \rho_p - \rho_w \right) = \left( C_D A_p \rho_w \frac{\vartheta_s^2}{2} \right) \]

\[
\vartheta_s = \sqrt{\frac{2g(\rho_p - \rho_w)\forall_p}{C_D \rho_w A_p}}
\]

SETTLING VELOCITY OF DISCRETE PARTICLE IN ANY SHAPE
(Eqn. 1)

For spherical particle;
\[
\forall_p = \frac{4}{3} \pi r^3
\]
\[
A_p = \pi r^2
\]

\[
\frac{\forall_p}{A_p} = \frac{\frac{4}{3} \pi r^3}{\pi r^2} = \frac{4}{3} r
\]

Substitute into Eqn.1

\[
= \frac{4}{3} d \frac{3}{2}
\]
\[ \vartheta_s = \sqrt{\frac{2g(\rho_p - \rho_w)4d}{C_D\rho_w}} \]

\[ \vartheta_s = \sqrt{\frac{4(\rho_p - \rho_w)gd}{3C_D\rho_w}} \]

**SETTLING VELOCITY OF SPHERICAL DISCRETE PARTICLE**
(Eqn 2)

**Newton’s drag coefficient \((C_D)\) is a function of:**

- Flow regime around the particle
- Particle shape

\[
\begin{align*}
R_e < 1 \\
1 < R_e < 10^4 \\
R_e > 10^4 \\
R_e = \frac{\vartheta_s D}{v} = \frac{\mu}{\rho_w} \quad \text{(kinetic visc.)} \\
R_e = \frac{\vartheta_s D}{v} \quad \text{(for nonspherical particles)}
\end{align*}
\]
Drag coefficient ($C_o$) for spheres:

\[
C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34
\]

For laminar flow $\rightarrow R_e < 1$ negligible

\[
C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34
\]

\[
C_D = \frac{24}{R_e}
\]

where

\[
R_e = \frac{\varrho_s d}{\nu} = \frac{\varrho_s d \rho}{\mu}
\]

\[
C_D = \frac{24 \mu}{\varrho_s d \rho_w}
\]

For laminar flow

\[
\varrho_s = \frac{g}{18 \mu} \left( \rho_p - \rho_w \right) d^2
\]

Settling velocity of spherical discrete particles under laminar flow conditions (STOKE’S LAW) (Eqn. 3)
For turbulent flow $\Rightarrow R_e > 10^4$

$C_D = 0.34 - 0.4$ commonly used

Substitute into Eqn.2

Settling velocity of spherical discrete particles under turbulent flow conditions

$$\delta_s = \sqrt{\frac{10 g (\rho_p - \rho_w) d}{3 \rho_w}}$$
Example 1: Find the terminal settling velocity of a spherical discrete particle with diameter 0.5 mm and specific gravity of 2.65 settling through water at 20°C

\[ \rho_w = 998.2 \text{kg/m}^3 \]

\[ \mu = 1.002 \times 10^{-3} \text{Ns/m}^2 \]
→ Particles move horizontally with the fluid (all particles have the same horizontal velocity)

→ Particles move vertically with terminal settling velocity
  (different for particles with different size, shape and density)

All particles with $V_s > V_c \rightarrow$ will be completely settled.

Particle with $V_s < V_c \rightarrow$ will be removed in the ratio $\frac{V_p}{V_c}$
\[ V_c = \text{critical velocity} = \frac{\text{tank depth}}{\text{detention time}} = \frac{\text{depth}}{\frac{\text{tank volume}}{\text{flowrate}}} \]

\[ = \frac{\text{depth}}{(\text{depth} \cdot \text{area})/\text{flowrate}} \]

\[ = \frac{\text{flowrate}}{\text{area}} = \frac{Q}{A} \]

(Settling velocity of the slowest-settling particles that are 100% removed)

In a typical suspension of discrete particles → a large variation in particle size

To determine the overall removal for a given design settling velocity (or overflow rate) → the settling velocity distribution for the suspension must be determined

**Experimental analysis**

use of a settling column

use of sieve analysis and hydrometer tests.
The critical settling velocity is
\[ v_{sc} = \frac{H}{\delta_m} = \frac{H}{\pi Q} \]
but \( A_s = WL \)
Thus \( v_{sc} = \frac{Q}{A_s} \)

The critical settling velocity is
\[ v_{sc} = \frac{H}{\delta_m} \]
but \( \delta_m = \int_{R_1}^{R_2} \frac{dr}{r} \)
Where \( \nu_r = \frac{Q}{2\pi rH} \)
\[ \delta_m = \frac{2\pi H}{Q} \int_{R_1}^{R_2} r \, dr \]
\[ = \frac{\pi (R_2^2 - R_1^2)}{2} \]
Thus \( v_{sc} = \frac{Q}{A_s} \)

The minimum upflow velocity is
\[ v_u = \frac{Q}{A_s} \]
The limiting case for particle removal occurs when
\[ v_{sc} = v_u \]
Thus \( v_{sc} = \frac{Q}{A_s} \)

FIGURE 12.16
Definition sketch for idealized settling in (a) a rectangular horizontal-flow, (b) a circular radial-flow, and (c) an upflow sedimentation tank. Source: Adapted from Ref. [12.4].
Batch Settling Column Test for Type 1 Settling

Depth of column \( \rightarrow \) is not a factor in the analysis (about 2 m)
Diameter of column \( \rightarrow \) about 200 mm

Procedure:

1. Height of the port is measured

2. Suspension to be tested is placed in the column
   Mixed completely to ensure uniform distribution of particles

3. At time=0, a portion of the sample is removed from the port
   TSS analysis is carried out in order to determine the initial TSS concentration

4. The suspension is allowed to settle

5. Intermittent samples are removed at appropriate time intervals
   For each sample withdrawn,
   TSS analysis must be performed in order to determine the fraction remaining in suspension at each time interval

6. Settling velocity at each time interval \( V' = H/t'; V'' = H/t''; V''' = H/t''' \ldots \)
   fraction with settling velocity less than stated vs terminal settling velocity
Fraction removed = \((1 - X_C) + \int \frac{V_P}{V_C} \, dx\)

- Fraction particles with velocity greater than \(V_c\)
- Fraction particles with removed with velocity less than \(V_c\)
Sieve Analysis for Type 1 Settling

1. Particle Size vs Weight fraction greater than size (%) are determined

2. Settling velocity for each particle size is calculated

3. Cumulative distribution curve (fraction with settling velocity less than stated vs terminal settling velocity) is drawn

\[
\text{Fraction removed} = (1 - X_C) + \int \frac{V_P}{V_C} \, dx
\]

- Fraction particles with velocity greater than \( V_C \)
- Fraction particles with removed with velocity less than \( V_C \)
Type 2 – Flocculent Settling  
(settling of flocculent particles in dilute suspension)

Chemical precipitates formed in coagulation and other destabilization processes tend to agglomerate while settling as a result of interparticle collisions.

As a result:
→ their sizes change continually (increases)

→ their shapes change continually

→ their specific gravity change  
  (as a result of entrapment of water in interstitial spaces)
### Example 2:

<table>
<thead>
<tr>
<th>Particle Type</th>
<th>Weight Fraction $W_i$</th>
<th>Settling Velocity, $V_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>0.2 m/sec</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
<td>0.1 m/sec</td>
</tr>
<tr>
<td>3</td>
<td>0.2</td>
<td>0.3 m/sec</td>
</tr>
<tr>
<td>4</td>
<td>0.4</td>
<td>0.15 m/sec</td>
</tr>
</tbody>
</table>

If $V_c = 0.16$ m/sec for a given settling tank, what is the % of all solids removed?
**Example 3:** A settling analysis is run on a Type 1 suspension in a laboratory column with a port 1.8m below the suspension surface. The data obtained are shown below.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>TSS (conc, mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>220</td>
</tr>
<tr>
<td>3</td>
<td>116</td>
</tr>
<tr>
<td>5</td>
<td>98</td>
</tr>
<tr>
<td>10</td>
<td>75</td>
</tr>
<tr>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>60</td>
<td>2</td>
</tr>
</tbody>
</table>

What will be the theoretical removal efficiency in a settling basin for an overflow of 432 m²/m.day?
Solution of Example 2:

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>TSS (conc, mg/L)</th>
<th>Mass Fraction Remaining</th>
<th>Vs (m/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>116</td>
<td>0.58</td>
<td>1.8/3=0.6</td>
</tr>
<tr>
<td>5</td>
<td>98</td>
<td>0.49</td>
<td>1.8/5=0.36</td>
</tr>
<tr>
<td>10</td>
<td>75</td>
<td>0.38</td>
<td>1.8/10=0.18</td>
</tr>
<tr>
<td>20</td>
<td>35</td>
<td>0.18</td>
<td>1.8/20=0.09</td>
</tr>
<tr>
<td>40</td>
<td>10</td>
<td>0.05</td>
<td>1.8/40=0.045</td>
</tr>
<tr>
<td>60</td>
<td>2</td>
<td>0.01</td>
<td>1.8/60=0.03</td>
</tr>
</tbody>
</table>
Overflow rate \( V_c = 432 \text{ m}^2 \text{ m.d} \frac{1 \text{ d}}{24 \text{ hr}} \frac{1 \text{ hr}}{60 \text{ min}} = 0.3 \text{ m/min} \)

\[ X_c = 0.46 \]

Total removal \[ = \left( 1 - X_c \right) + \frac{1}{V_c} \int_0^{x_c} V \text{d}x \]

\[ = 0.54 + \frac{1}{0.3} \left( 0.0143 + 0.0158 + 0.01266 + 0.0077 + 0.0044 \right) \]

\[ = 0.54 + \frac{0.05486}{0.3} \]

\[ = 0.72 \]

\[ = 72\% \]
**Example 4:** A settling basin is designed to have a surface overflow rate of 32.6 m/d. Determine the overall removal obtained for a suspension with the size distribution given in the table below. The specific gravity of the particles is 1.2 and water temperature is 20°C.

( $\mu = 1.0087 \times 10^{-3} \text{ Ns/m}^2, \rho = 998.23 \text{ kg/m}^3$ )

<table>
<thead>
<tr>
<th>Particle Size, mm</th>
<th>Weight Fraction Greater Than Size, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>0.08</td>
<td>15</td>
</tr>
<tr>
<td>0.07</td>
<td>40</td>
</tr>
<tr>
<td>0.06</td>
<td>70</td>
</tr>
<tr>
<td>0.04</td>
<td>93</td>
</tr>
<tr>
<td>0.02</td>
<td>99</td>
</tr>
<tr>
<td>0.01</td>
<td>100</td>
</tr>
</tbody>
</table>
Solution of Example 3:

\[
\begin{array}{|c|c|c|}
\hline
dx & V & V \cdot dx \\
\hline
0.027 & 0.35 & 0.00945 \\
0.04 & 0.32 & 0.0128 \\
0.04 & 0.29 & 0.0116 \\
0.04 & 0.25 & 0.010 \\
0.04 & 0.20 & 0.008 \\
0.04 & 0.15 & 0.006 \\
0.04 & 0.065 & 0.0026 \\
\hline
\end{array}
\]

\( X_c = 0.267 \)

Total removal \( = (1 - X_c) + \frac{1}{V} \int_0^{X_c} V \, dx \)

\[
= 0.733 + \frac{1}{0.37} (0.00945 + 0.0128 + 0.0116 + 0.01 + 0.008 + 0.006 + 0.0026)
\]

\( = 0.89 \)

\( = 89\% \)
Type 2 – Flocculent Settling
(settling of flocculent particles in dilute suspension)

Chemical precipitates formed in coagulation and other destabilization processes tend to agglomerate while settling as a result of interparticle collisions

→ sizes change

→ shape change

→ specific gravity change (as a result of entrapment of water in interstitial spaces)
Type 2 – Flocculent Settling (Continue)

As their size increases, they settle at a faster velocity \( \rightarrow \) STOKE’s law
\( \text{not applicable} \)

\( \rightarrow \) impossible to develop a general formula for determining settling velocities of flocculant particles.

To determine the settling characteristics \( \rightarrow \) batch settling column test must be performed
Batch Settling Column Test For Type 2 Settling

Min. Diameter of column → about 150 - 200 mm (to minimize sidewall effects)

Height of column → depth of the proposed tank

Sampling ports → are provided at equal intervals in height
**Procedure:**

1. Suspension to be tested is placed in the column
   Mixed completely to ensure uniform distribution of particles

3. At time=0, a portion of the sample is in order to determine the initial TSS concentration

4. The suspension is allowed to settle

5. At periodic time intervals, samples are removed through the ports located in different heights.
   
   For each sample withdrawn at each depth and for each time,
   TSS analysis must be performed in order to determine the fraction remaining in suspension at each time interval

6. Percent removals
   
   \[ X_{ij} = \text{mass fraction removed (at } i^{\text{th}} \text{ depth at } j^{\text{th}} \text{ time interval)} = (1 - C_{ij}/C_0) \times 100 \]

7. Percent removal lines (**isoremoval lines**) are drawn by interpolation.
Figure 4-7 Isoremoval lines from settling analysis.
To find the total removal at any chosen time:

% removal of completely removed fraction

% removal of partially removed fraction

are found

Initially:
a vertical line from the chosen time is projected upward.

% removal of completely removed fraction

% read at chosen time → % of particles that are completely removed.

% read at chosen time → % of particles having

<table>
<thead>
<tr>
<th>Average settling velocity ≥ Design settling velocity</th>
</tr>
</thead>
</table>

30
To determine the % removal of partially removed fractions

particles having settling velocity < design settling velocity will be removed in the ratio of average settling velocity of fraction

\( \frac{\text{ave depth reached in chosen time}}{\text{chosen time}} \)

design settling velocity (total depth / chosen time)

Median lines are drawn between the percent removal lines

Ave. depth reached \( \rightarrow \) read from the intersection point of vertical line and drawn median line

\[
\text{% partially removed} = \frac{\text{average depth reached by fraction}}{\text{total depth}} \times \text{Fraction}
\]
Example 5 (Type 2 Settling):
A column analysis of a flocculating suspension is run in the apparatus shown below. The initial solids concentration is 250 mg/L. The resulting matrix is shown below. What will be the overall removal efficiency of a settling basin which is 3 m deep with a detention time of 1 h and 45 min.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Time of sampling, min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td>0.5</td>
<td>133</td>
</tr>
<tr>
<td>1</td>
<td>180</td>
</tr>
<tr>
<td>1.5</td>
<td>203</td>
</tr>
<tr>
<td>2</td>
<td>213</td>
</tr>
<tr>
<td>2.5</td>
<td>220</td>
</tr>
<tr>
<td>3</td>
<td>225</td>
</tr>
</tbody>
</table>
**SOLUTION:**

Removal at each depth and time:

\[
X_{ij} = \left(1 - \frac{C_{ij}}{C_0}\right) \times 100
\]

<table>
<thead>
<tr>
<th>Depth</th>
<th>Time of sampling, min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td>m</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>47</td>
</tr>
<tr>
<td>1</td>
<td>28</td>
</tr>
<tr>
<td>1.5</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>2.5</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
</tr>
</tbody>
</table>

→ Plot isoremoval lines by interpolation
Detention time = 1hr 45 min = 105 min
Draw a vertical line from 105 min

% removal of completely removed fraction at t=105 min = 43%
(from graph, by interpolation)

% removal of partially removed fraction:

bw 43-50% → fraction 7%, ave. depth reached by fraction 2.6
\[ \frac{2.6}{3} \times 7\% = 6.06\% \]

bw 50-60% → fraction 10%, ave. depth reached by fraction 1.8
\[ \frac{1.8}{3} \times 10\% = 6\% \]

bw 60-70% → fraction 10%, ave. depth reached by fraction 1.2
\[ \frac{1.2}{3} \times 10\% = 6\% \]

bw 70-80% → fraction 10%, ave. depth reached by fraction 0.8
\[ \frac{0.8}{3} \times 10\% = 2.66\% \]

bw 80-90% → fraction 10%, ave. depth reached by fraction 0.45
\[ \frac{0.45}{3} \times 10\% = 1.5\% \]

bw 90-100% → fraction 10%, ave. depth reached by fraction 0.15
\[ \frac{0.15}{3} \times 10\% = 0.5\% \]

Total % removal of partially removed particles at time=105 min = 6.06 + 6 + 4 + 2.66 + 1.5 + 0.5 = 20.72%
Total removal at time=105min = completely removed % + partially removed %
= 43 % + 20.72 %
= 63.72 %

NOTE: In applying isoremoval curves to design a tank, scale – up factors of

0.65 → the overflow rate
1.75 → for the detention time

are used to compensate for the side wall effects of the batch settling column.
### TABLE 12.3
Typical Overflow Rates Used for the Design of Sedimentation Tanks in Water and Wastewater Treatment Plants

<table>
<thead>
<tr>
<th>TYPE OF OPERATION</th>
<th>OVERFLOW RATE, m/d</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Typical*</td>
</tr>
<tr>
<td>Water treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alum coagulation</td>
<td>40–60</td>
<td>48</td>
</tr>
<tr>
<td>Turbidity removal</td>
<td>35–45</td>
<td>40</td>
</tr>
<tr>
<td>Color removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lime softening</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low magnesium</td>
<td>60–110</td>
<td>80</td>
</tr>
<tr>
<td>High magnesium</td>
<td>50–90</td>
<td>65</td>
</tr>
<tr>
<td>Wastewater treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary only</td>
<td>30–60</td>
<td>40</td>
</tr>
<tr>
<td>Primary with waste activated sludge return</td>
<td>22–40</td>
<td>30</td>
</tr>
<tr>
<td>Secondary treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activated sludge (excluding extended aeration)</td>
<td>16–32</td>
<td>24</td>
</tr>
<tr>
<td>Activated sludge (following extended aeration)</td>
<td>10–24</td>
<td>16</td>
</tr>
<tr>
<td>Trickling filter</td>
<td>16–30</td>
<td>24</td>
</tr>
</tbody>
</table>

*The typical value is based on average plant flow; for peak flow use twice the typical value.*
<table>
<thead>
<tr>
<th>Description</th>
<th>Conventional-Type Sedimentation Basin</th>
<th>Sedimentation Basin for High-Rate Filters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface loading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For alum floc</td>
<td>18–36</td>
<td>30–60</td>
</tr>
<tr>
<td>m³/m² · d</td>
<td>0.3–0.6</td>
<td>0.5–1.0</td>
</tr>
<tr>
<td>gpm/ft²</td>
<td></td>
<td>60–150³</td>
</tr>
<tr>
<td>For heavy flocs</td>
<td>30–60</td>
<td>45–75</td>
</tr>
<tr>
<td>m³/m² · d</td>
<td>0.5–1.0</td>
<td>0.75–1.25</td>
</tr>
<tr>
<td>gpm/ft²</td>
<td></td>
<td>1.5–3³</td>
</tr>
<tr>
<td>Mean horizontal velocity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>m/min</td>
<td>0.15–0.9</td>
<td>0.3–1.2</td>
</tr>
<tr>
<td>fpm</td>
<td>0.5–3</td>
<td>1–4</td>
</tr>
<tr>
<td>Water depth, m</td>
<td>3–5</td>
<td>3–5</td>
</tr>
<tr>
<td>Detention time, min</td>
<td>120–240</td>
<td>60–120</td>
</tr>
<tr>
<td>Weir loading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>m³/d · m</td>
<td>140–270</td>
<td>210–330</td>
</tr>
<tr>
<td>gpm/ft</td>
<td>8–15</td>
<td>12–18</td>
</tr>
</tbody>
</table>

* (1) High settler modules are commonly installed in the basin to cover up to 75 percent of basin surface area. (2) Cold weather regions generally use a conservative design criteria. (3) Weir loading requirements are somewhat questionable since some recent studies have shown that the long launder often do not yield better tank performance.

³ These figures are for the surface loading of the settler module not the basin.

� These figures vary depending on the kind of settler selected.
### TABLE 11.6 Clarifiers in Water Treatment

(Compiled, 1987)

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rectangular and Circular Clarifiers</strong></td>
<td></td>
</tr>
<tr>
<td>Depth, m (ft)</td>
<td>2.4–4.9 (8–16)</td>
</tr>
<tr>
<td>Overflow rate, m³/m²/d (gal/ft²/d)</td>
<td>20–70 (490–1720)</td>
</tr>
<tr>
<td>Weir loading rate, m³/m (gal/ft/d)</td>
<td>Less than 1 250 (100 000)</td>
</tr>
<tr>
<td>Maximum length of rectangular basin, m (ft)</td>
<td>70–75 (230–250)</td>
</tr>
<tr>
<td>Circular basin maximum diameter, m (ft)</td>
<td>38 (125)</td>
</tr>
<tr>
<td><strong>Upflow Solids Contact Clarifiers</strong></td>
<td></td>
</tr>
<tr>
<td>Depth, m (ft)</td>
<td>2.5–3 (8–10)</td>
</tr>
<tr>
<td>Overflow rate, m³/m²/d (gal/ft²/d)</td>
<td>24–550 (590–13 500)</td>
</tr>
<tr>
<td><strong>Inclined Tube or Lamella Clarifiers</strong></td>
<td></td>
</tr>
<tr>
<td>Inclined length, m (ft)</td>
<td>1–2 (3.3–6.6)</td>
</tr>
<tr>
<td>Angle of inclination (°)</td>
<td>7–60</td>
</tr>
<tr>
<td>Tube diameter or plate spacing, cm (in)</td>
<td>Near 5 (2)</td>
</tr>
<tr>
<td>Overflow rates based on plan area, m³/m²/d (gal/ft²/d)</td>
<td>2–8 times rate for conventional clarifiers, 88–178 (2 160–4 370)</td>
</tr>
<tr>
<td>Depth, m (ft)</td>
<td>6–7 (20–23)</td>
</tr>
</tbody>
</table>

*a* Compiled from Gregory and Zabel (1990), ASCE and AWWA (1990), AWWA (1971), Culp and Culp (1974).
<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Clarifiers</strong>&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Overflow rate, m³/m²/d (gal/ft²/d)</td>
<td></td>
</tr>
<tr>
<td>For average dry weather flow rate</td>
<td>32–49 (785–1 200)</td>
</tr>
<tr>
<td>For peak flow condition</td>
<td>49–122 (1 200–3 000)</td>
</tr>
<tr>
<td>Sidewater depth, m (ft)</td>
<td>2.1–5 (6.9–16.4)</td>
</tr>
<tr>
<td>Weir loading rate&lt;sup&gt;c&lt;/sup&gt;, m³/m²/d (gal/ft²/d)</td>
<td>125–500 (10 000–40 000)</td>
</tr>
<tr>
<td><strong>Secondary Clarifiers</strong></td>
<td></td>
</tr>
<tr>
<td>Overflow rate&lt;sup&gt;d&lt;/sup&gt;, m³/m²/d (gal/ft²/d)</td>
<td></td>
</tr>
<tr>
<td>For average dry weather flow rate</td>
<td>16–29 (393–712)</td>
</tr>
<tr>
<td>For peak flow condition</td>
<td>41–65 (1 006–1 595)</td>
</tr>
<tr>
<td>Sidewater depth, m (ft)</td>
<td>3.0–5.5 (9.8–18)</td>
</tr>
<tr>
<td>Floor slope</td>
<td>Nearly flat to 1:12</td>
</tr>
<tr>
<td>Maximum diameter, m (ft)</td>
<td>46 (150)</td>
</tr>
</tbody>
</table>

<sup>a</sup>From WEF and ASCE (1992), *Design of Municipal Wastewater Treatment Plants*, vol. 1. WEF, © WEF 1992.

<sup>b</sup>Criteria are based on the maximum ranges specified by a number of firms and agencies reported in WEF and ASCE (1992).

<sup>c</sup>Generally for average flow conditions.

<sup>d</sup>For circular or rectangular tanks.
Example 6:

A city must treat about 15000 m$^3$/day of water. Flocculation particles are produced by coagulation and a column analysis indicates that an overflow rate of 20 m/day will produce satisfactory removal at a depth of 3.5m. Determine the size of

a) the required rectangular settling tanks

b) the required circular settling tanks
EXAMPLE 6:

Design circular primary sedimentation tanks for a domestic wastewater treatment plant having $Q_{\text{avg}} = 70000\, \text{m}^3/\text{d}$ and $Q_{\text{peak}} = 105000\, \text{m}^3/\text{day}$. 
Sedimentation Basin Design

Settling basins \( \rightarrow \) rectangular (horizontal view)

- square (occasionally used)
- circular (radial flow)

in plan view

A single rectangular basin will cost \( \rightarrow \) more than a circular basin of the same size

However;

if numerous tanks are required \( \rightarrow \) rectangular tanks can be constructed with common walls and be the most economical.

NOTE: a minimum of two basins should be provided in order to be able to inspect, repair, periodically clean and maintain one basin at a time while the other basin is in operation.
Sedimentation tanks can be divided into 4 different functional zones;

1. Inlet zone
2. Settling zone
3. Sludge zone
4. Outlet zone
Inlet Structures

- should dissipate influent energy
- distribute the flow
- mitigate density currents
- minimize sludge blanket disturbance

→ are designed to uniformly distribute the influent suspension over the cross section of the settling zone.

For Rectangular Basins

**full width inlet channels** → effective spreading of flow introduce a vertical velocity component into sludge happen that may resuspend sludge.

**inlet channels with submerged orifices**

For sedimentation tank followed by flocculation → width of flocculation basin − width of settling tank (depths are different)

Depth of inlet channel = depth of flocculator basin
Pipe connection between flocculation unit & sedimentation

- Low velocity in pipe → settling of floc
- High velocity in pipe → breakage of floc

Permissible flow velocity to maintain floc suspension → 0.15 – 0.6 m/sec

If sedimentation tank does not adjoin a flocculator

→ inlet channels with submerged orifices do not extend down the full depth of the tank
FIGURE 9.29 *Inlet and Outlet Details for a Rectangular Settling Tank with Orifice Flume Outlet Preceded by Flocculation*
FIGURE 9.44  Inlet and Outlet Details for a Rectangular Tank
Figure 9-16 (Metcalf & Eddy, 1991)

Typical rectangular primary sedimentation tank.
Inlet Structures (continue)

For circular tanks

circular tanks → radial flow

to achieve a radial flow pattern influent is introduced → in the center of the tank
or
around the periphery of the tank

Central feed → water enters a circular well designed to distribute
the flow equally in all directions

D of feed well = 15-20 % of tank diameter

Depth = 1-2.5m

Velocity through the orificies on feed well
0.075-0.15 m/sec

entrance pipe → suspended from bridge OR encased in concrete beneath the tank floor
For peripheral feed (not as uniform as central feed)

orifice channel around periphery of the tank

from the channel the flow discharges through the orifices into sedimentation tank
FIGURE 21-22. Flow patterns in sedimentation tanks: (a) Rectangular settling tank; (b) center feed, source flow; (c) peripheral feed, spiral flow; (d) peripheral feed, radial flow; (e) square, radial flow. (Reprinted from Water Treatment Plant Design. Copyright 1969, American Water Works Association, Inc.)
**Figure 5-43**

Typical energy-dissipating and flow distribution inlet for a center-feed sedimentation tank. The inner ring is used to create a tangential flow pattern. (Randall, et al., 1992.)
**Figure 5-41**

Typical circular primary sedimentation tanks:
(a) center feed and
(b) peripheral feed.
(Crites and Tchobanoglous, 1998.)

**Figure 5-42**

Typical circular primary sedimentation tank.
Figure 3-14  Circular clarifier design. (Courtesy of Walker Process equipment.)
FIGURE 9.32  Inlet and Outlet Details for Circular Tanks
(Center Feed)
FIGURE 9.33  Circular Settling Tank (Center Feed by Pipe through Wall)

(a) Plan

(b) Elevation

Courtesy of Infilco Degremont, Inc.
FIGURE 9.34  Circular Settling Tank (Center Feed by Pipe under Tank Bottom)

Courtesy of Infilco Degremont, Inc.

60
FIGURE 9.35  Inlet and Outlet Details for a Circular Tank
(Peripheral Feed)

Şekil 6.21. Çevreden beslenen dairesel çöküürme havuzları
Figure 3.28. Inlet and Outlet Details for Circular Tanks (Center Feed)

(Reynolds, 1982)

(a) Plan

(b) Section, $D < 30$ to 35 ft

(c) Section, $D > 35$ to 35 ft

Effluent Channel

Weir

Inlet Well

Feed

Discharge
A. Suyun giriş bacası ve tahrik ünitesi havuzun ortasındaki iskele tarafından taşınmaktadır.

B. Suyun giriş bacası ve tahrik ünitesi köprü tarafından taşınmaktadır.

C. Cer makinasi çevrede olup çamur toplayıcı merkezdeki iskele tarafından taşınmaktadır.

Şekil 6.20. Dairevi çöktürme havuzu kesitleri
**Settling Zone**

It depends on the following design parameters:

→ Settling characteristics of the suspended matter

→ Surface loading (overflow rate)

→ Width / length ratio OR diameter

→ Detention time
**Sludge Zone**

Rectangular tanks $\rightarrow$ the bottom is slightly sloped to facilitate sludge scraping

- a pair of endless conveyor chains
- bridge – type mechanism

continuously pulls the settled material into a sludge hopper where it is pumped out periodically.

Motion of scraper $\rightarrow$ momentarily resuspend lighter particles a few cm above the scraper blades

Excessive horizontal velocity
(for the case of rectangular basins) $\rightarrow$ move these materials towards outlet zone.

To prevent this,

horizontal velocity $\rightarrow$ $< 9$ m/hr for light flocculant suspensions
\[\approx 36 \text{ m/hr for heavier discrete suspensions}\]
Bridge type mechanism → travels up and down the tank

one or more scraper blades are suspended from the bridge
Figure 5-45
FIGURE 12.19

Typical sedimentation tanks: (a) rectangular (longitudinal section without skimmer)

Source: Courtesy of Walker Process.
FIGURE 9.31  Rectangular Settling Tank
Courtesy of Walker Process Equipment, Division of McNish Corporation.
Figure 3–15  Rectangular clarifier design. (Courtesy of Clow Corporation.)
(Montgomery, 1985)

Sedimentation Facilities

SIDE SECTIONAL ELEVATION

FIGURE 24-25. Traveling Bridge Sludge Collector. (Courtesy Water Process.)
Circular tanks

The bottom of the tank is sloped to form an inverted cone and the sludge is scraped to a relatively small hopper located near the center of the tank.

Velocity or scraper $\rightarrow$ important

Very high velocity $\rightarrow$ resuspension of settled particles ($<5\text{mm/sn}$)

Travelling bridge with sludge suction headers and pumps $\rightarrow$ not very good
FIGURE 12.19

Typical sedimentation tanks: circular radial flow.
FIGURE 7-2
TYPICAL CLARIFIER CONFIGURATIONS
Outlet Zone

weir channels are used

Checked by weir loading \((\text{m}^3/\text{m.day})\) \(\frac{Q}{L}\)

Large weir loading \(\rightarrow\) resuspension of particles settled near to effluent launders

Effluent weirs \(\rightarrow\) placed as far from the inlet as possible
to increase weir length (i.e to decrease weir loading) → double-sided weirs can be used

Typical weirs → 90° V notch metal plates bolted onto the effluent collection through
May be placed

→ at the opposite and of the rectangular basins through the entire width of tank through the length of the tank

if the weir loading causes the required weir length to be greater than tank width the channel may be extended to a length of 1/3 the basin length (Reynolds)

→ around the perimeter of center – feed circular tanks

→ at the center of peripheral feed circular tanks
(a) Section A-A through Tank Showing Orifice Flume

(b) Section B-B through Effluent Channel and Effluent Box

FIGURE 9.45 Sections through Orifice Flume and Effluent Channel
FIGURE 9.31  Rectangular Settling Tank
Courtesy of Walker Process Equipment, Division of McNish Corporation.
FIGURE 21-22. Flow patterns in sedimentation tanks: (a) Rectangular settling tank; (b) center feed, source flow; (c) peripheral feed, spiral flow; (d) peripheral feed, radial flow; (e) square, radial flow. (Reprinted from Water Treatment Plant Design. Copyright 1969, American Water Works Association, Inc.)
Figure 3.31. Inlet and Outlet Details for a Circular Tank (Peripheral Feed)

(Reynolds, 1982)
TABLE 12.4
Typical Dimensions of Sedimentation Tanks

<table>
<thead>
<tr>
<th></th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
</tr>
<tr>
<td>Rectangular</td>
<td></td>
</tr>
<tr>
<td>Depth, m</td>
<td>3−5</td>
</tr>
<tr>
<td>Length, m</td>
<td>15−90</td>
</tr>
<tr>
<td>Width, m</td>
<td>3−24</td>
</tr>
<tr>
<td>Circular</td>
<td></td>
</tr>
<tr>
<td>Depth, m</td>
<td>3−5</td>
</tr>
<tr>
<td>Diameter, m</td>
<td>4−60</td>
</tr>
<tr>
<td>Bottom slope, mm/m</td>
<td>60−160</td>
</tr>
</tbody>
</table>

**FIGURE 12.20**
Nonideal conditions in circular sedimentation tanks: (a) formation of wind-driven circulation cells, (b) thermal stratification, and (c) density currents. To improve the effluent quality, the discharge weir should be placed in the dead zone.