SETTLING TANKS

- THEORY
- OPERATION
- DESIGN

THEORY

- Also referred as 'SEDIMENTATION TANKS'.
- **Settling-** process by which particulates settle to the bottom of a liquid and form a sediment.
- Particles experience a force, either due to gravity or due to centrifugal motion; tend to move in a uniform manner in the direction exerted by that force.
- Gravity settling- the particles will tend to fall to the bottom of the vessel, forming a slurry at the vessel base.
- For dilute particle solutions, two main forces enacting upon particle. Primary force is an applied force, such as gravity, and a drag force that is due to the motion of the particle through the fluid. The applied force is not affected by the particle's velocity; the drag force is a function of the particle velocity.

Settling or Sedimentation

- Settling- a unit operation in which solids are drawn toward a source of attraction. The particular type of settling that will be discussed in this section is gravitational settling. It should be noted that settling is different from sedimentation.

- Sedimentation- The condition whereby the solids are already at the bottom and in the process of sedimenting. Settling is not yet sedimenting, but the particles are falling down the water column in response to gravity. Of course, as soon as the solids reach the bottom, they begin sedimenting. In the physical treatment of water and wastewater, settling is normally carried out in settling or sedimentation basins.

Removal Mechanisms

Gravity separation

- Settling tanks, tube settlers and hydro cyclones

Filtration

- Screen, Granular media, or porous media filter

Flotation

- Foam Fractionation

$$V_s = \frac{g(\rho_p - \rho)D_p^2}{18\mu}$$

Settling Basins

Advantages

- Simplest technologies
- Little energy input
- Relatively inexpensive to install and operate
- No specialized operational skills
- Easily incorporated into new or existing facilities

Disadvantages

- Low hydraulic loading rates
- Poor removal of small suspended solids
- Large floor space requirements
- Re-suspension of solids and leeching

Solids Physical Characteristics

- particle specific gravity

- particle size distribution

DESIGN

In specifying a water and wastewater sedimentation tank size, the major features to be considered are:

- tank cross sectional area,
- tank depth,
and type of cleaning mechanism used.

In specifying a design basis for water and wastewater sedimentation tanks; three conditions are commonly considered:

- solid handling capacity (kg/day),
-   overflow rate (lpm/m2),
-   detention time.

Additional design data required to ascertain mechanical construction, specific gravity of solids, size distribution of solids, underflow construction, operating temperature, and geographical location. Typical dimensions of sedimentation tanks are given in Table 1.

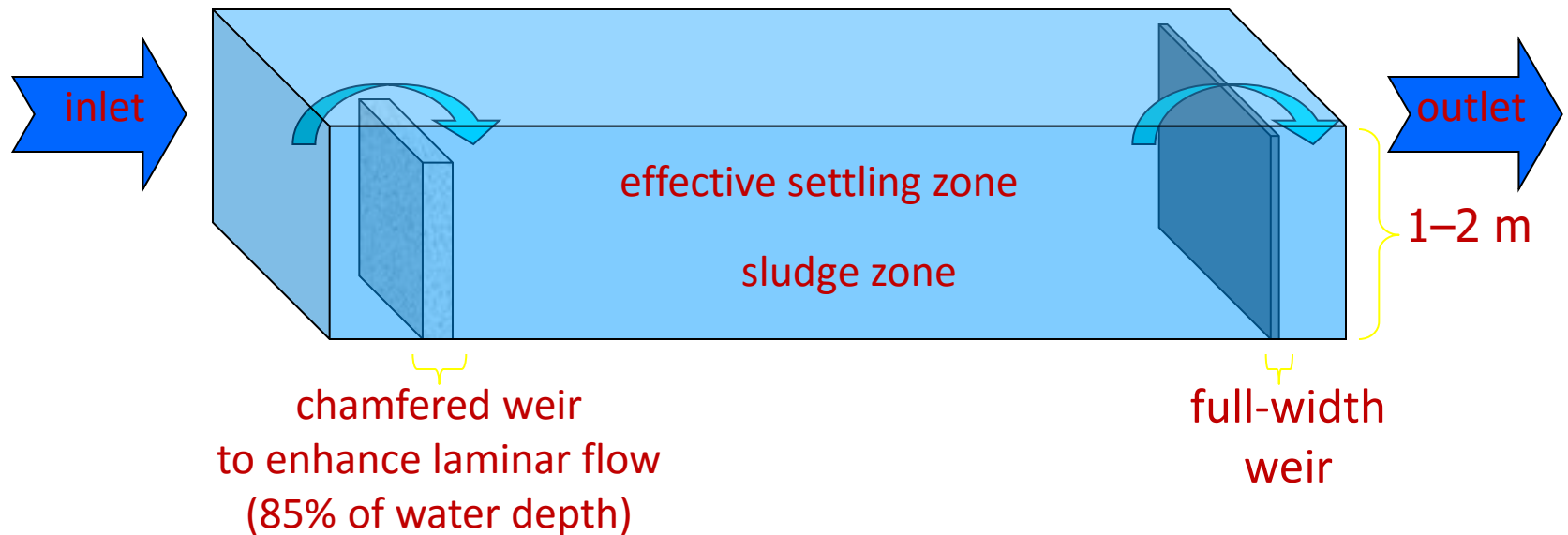$V_s = \dfrac{g(\rho_p - \rho)D_p^2}{18\mu}$

Sedimentation

$$V_s = \frac{g(\rho_p - \rho)D_p^2}{18\mu}$$

Stokes Law

- Denser and large particles have a higher settling velocity
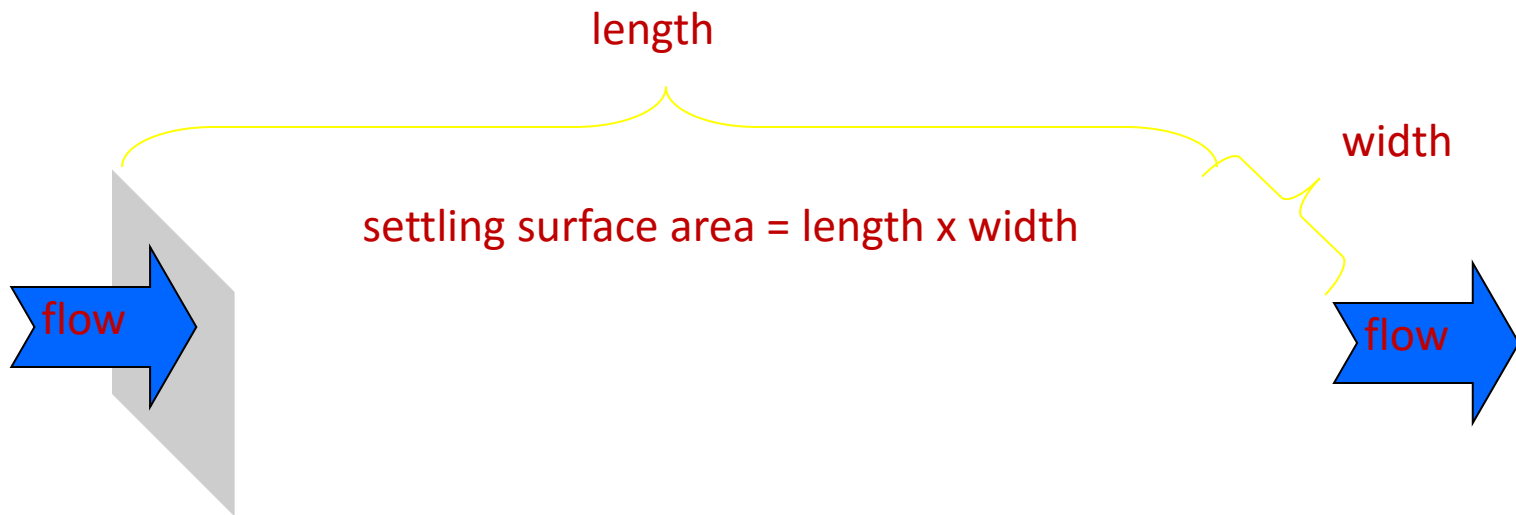
Settling Basins

- Design to minimize turbulence:

inlet

outlet

effective settling zone

sludge zone

1–2 m

chamfered weir
to enhance laminar flow
(85% of water depth)

full-width
weir

Settling Basins

- Overflow rates are used for design: V_o

$$Overflow\,Rate = \frac{Flow\,Rate\,(m^3/s)}{settling\;\;surface\;\;area\,(m^2)}$$

length

width

settling surface area = length x width

flow

flow

Settling Basin Design

"Rule of Thumb"
Settling Basin Design

- basin floor area of 41 Lpm per m^2 of flow.

- 250 to 410 Lpm per m width of weir for outflow.

- submerge inlet weir 15% of basin water depth.

- use 25 cm wide weirs and use rounded edges .

- maximize length of settling chamber as much as possible.

Settling (Sedimentation)

Paddle flocculators Baffles Overflow channels

Rapid mixer

Flocculation Sedimentation
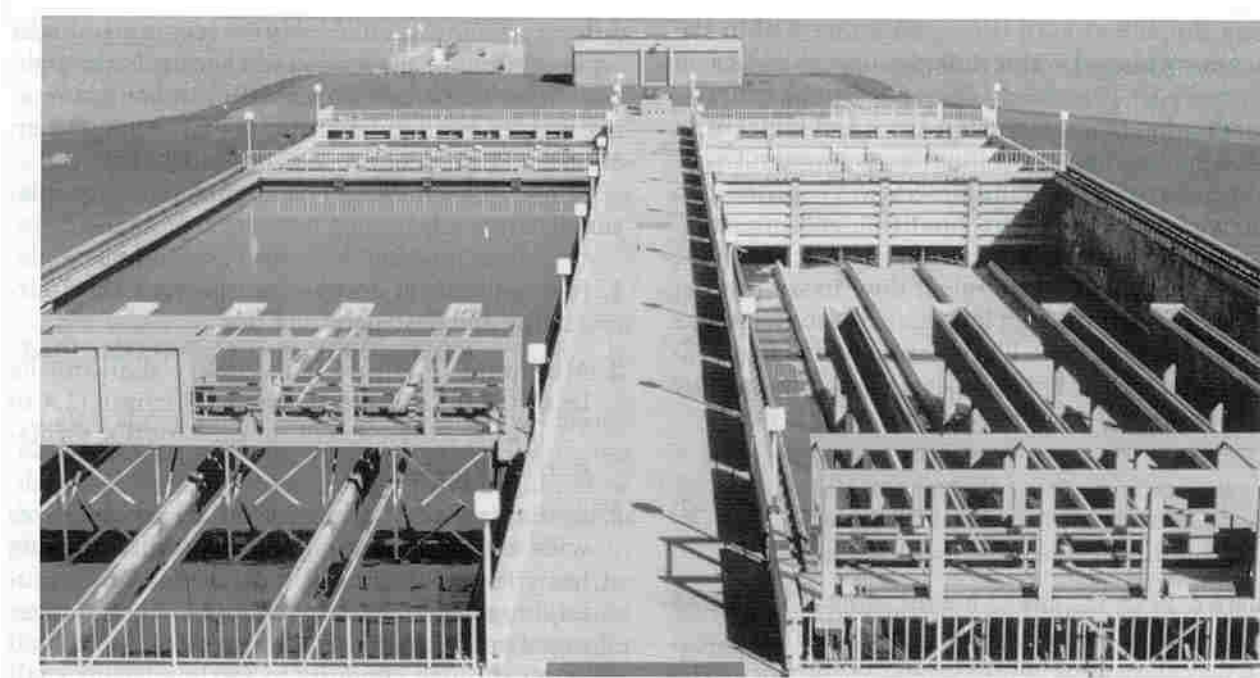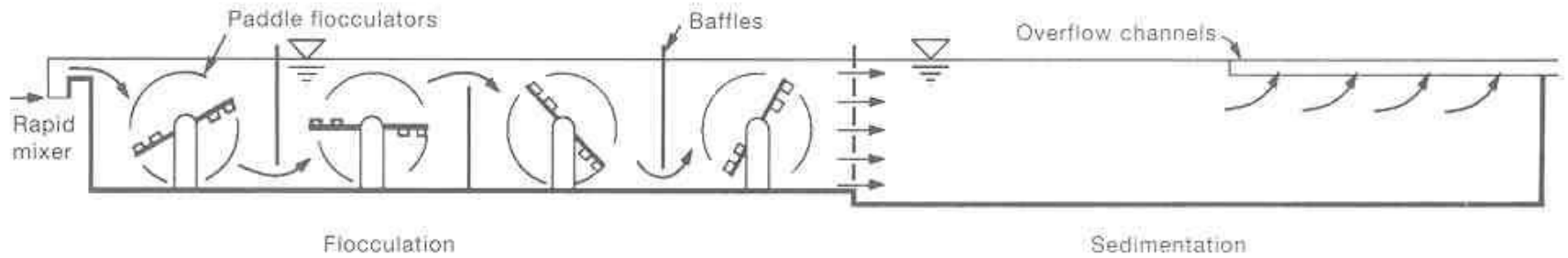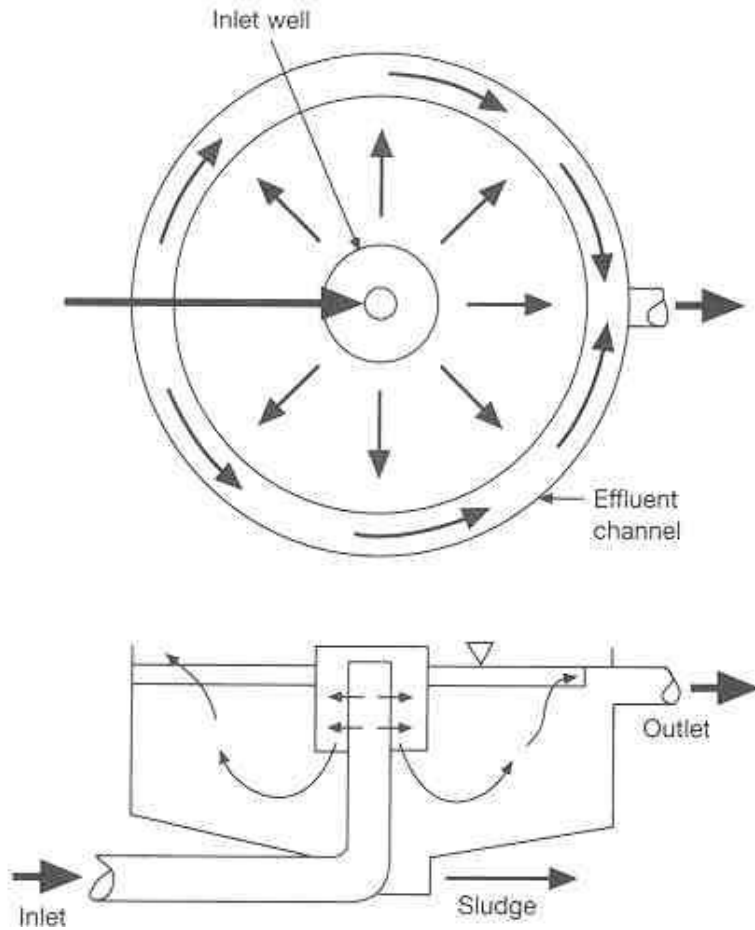
Settling Tanks, Basins, or Clarifiers

Generally, two types of sedimentation basins (also called tanks, or clarifiers) are used:
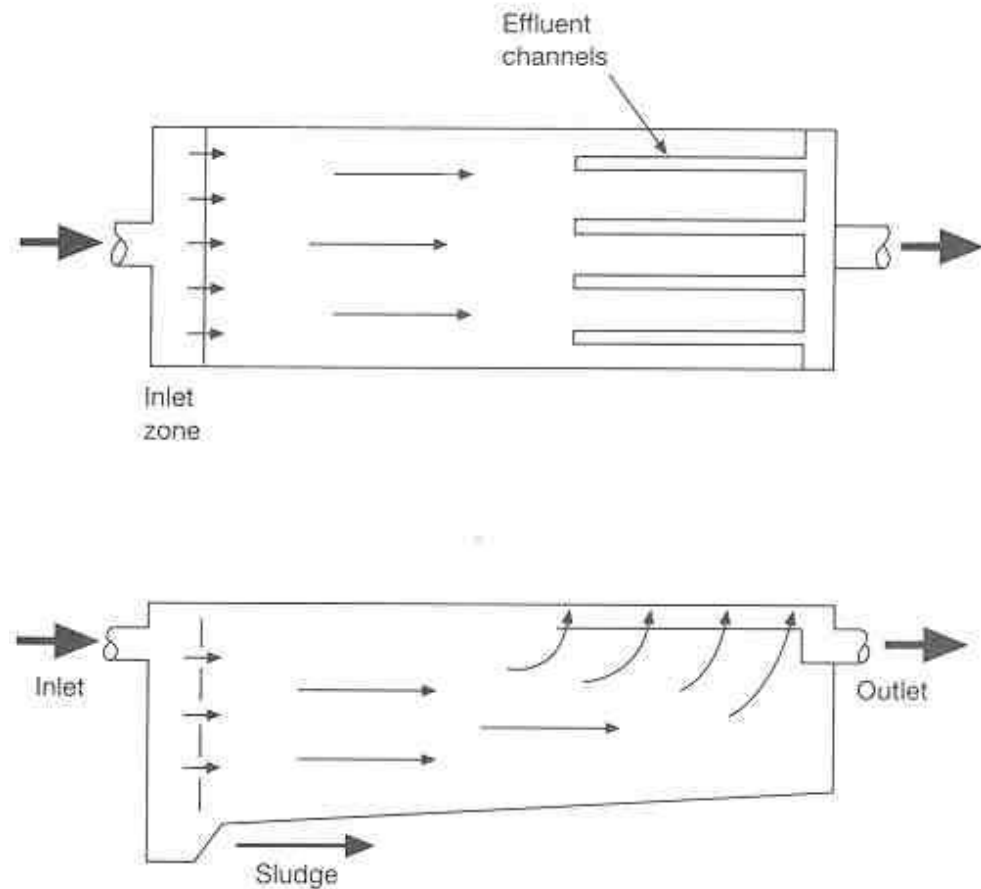
Rectangular and
Circular.

Rectangular settling, basins or clarifiers, are basins that are rectangular in plans and cross sections. In plan, the length may vary from two to four times the width.

The length may also vary from ten to 20 times the depth. The depth of the basin may vary from 2 to 6 m. The influent is introduced at one end and allowed to flow through the length of the clarifier toward the other end.
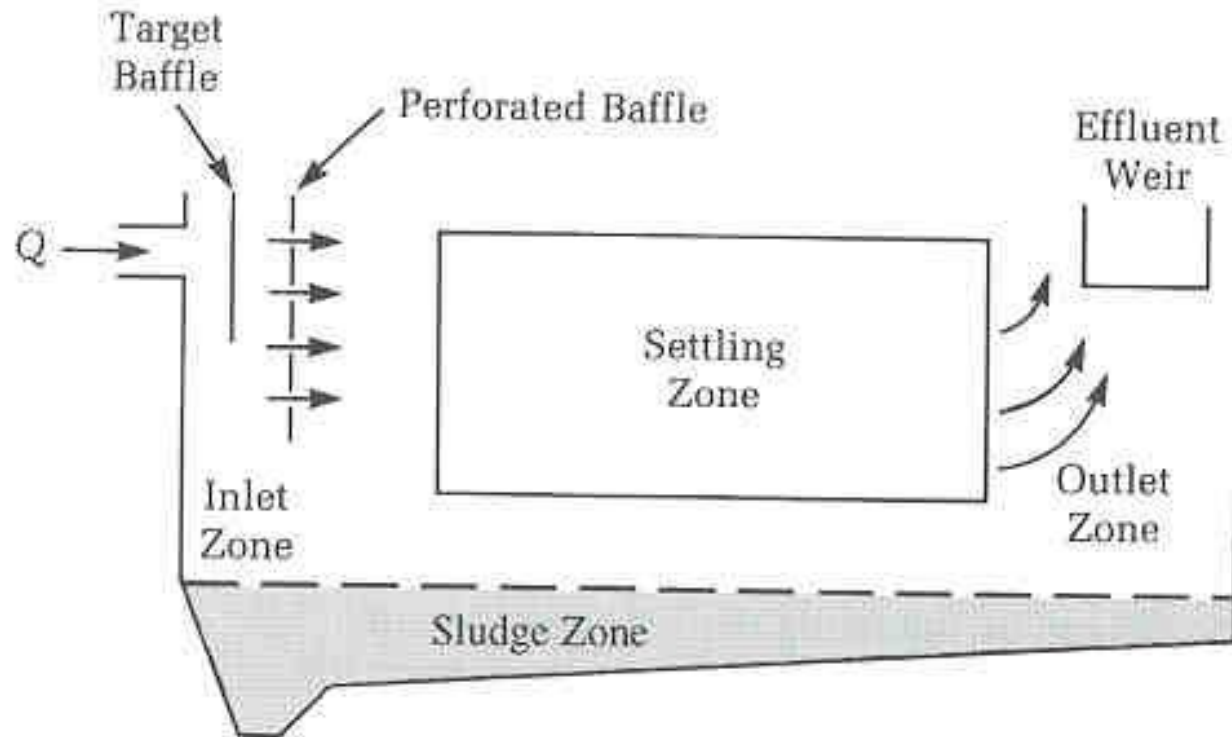
Circular Basin

Rectangular Basin

Circular Basin (top): Inlet well, Effluent channel

Circular Basin (bottom): Outlet, Inlet, Sludge

Rectangular Basin (top): Effluent channels, Inlet zone

Rectangular Basin (bottom): Inlet, Outlet, Sludge
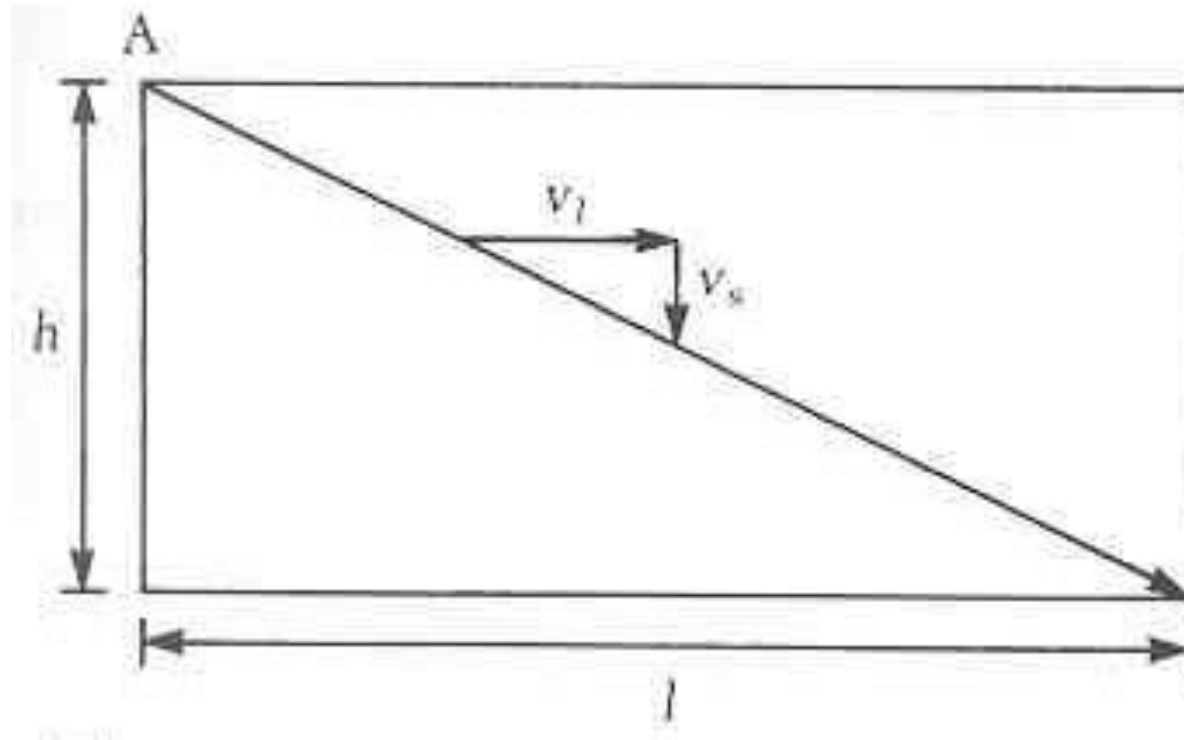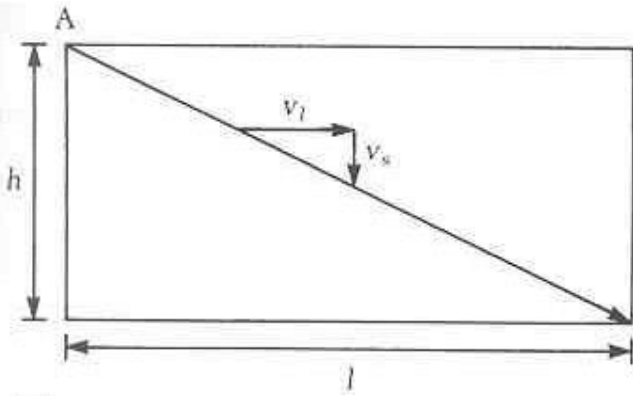
Basin Model

Settling Model

V_s = settling velocity of the particle
V_l = horizontal velocity of liquid flow

A particle that is just removed has a settling velocity v_0.

This trajectory represents a particle which has a settling velocity v_0
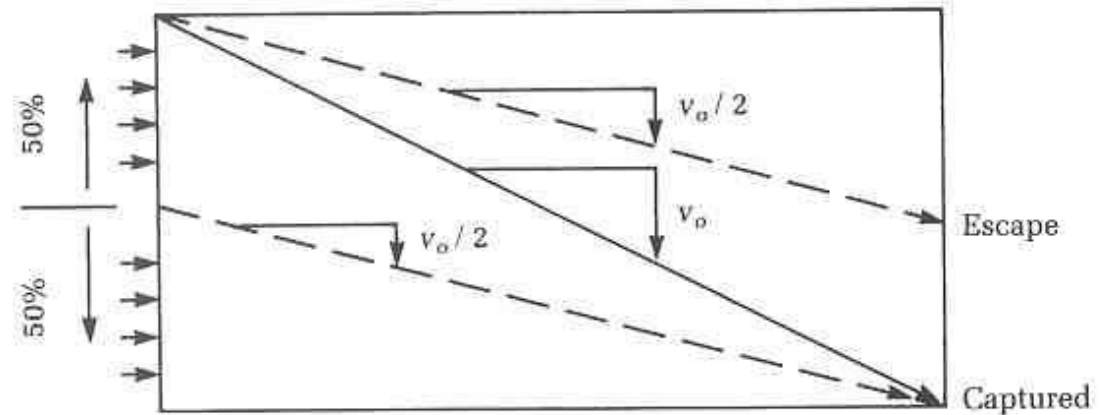
$$v_0 = h / t = Q / A$$

Where: $t = V/Q$

A = surface area of the basin

Critical Settling Velocity and Overflow Rate

v_0 expressed in units of velocity (ft/s) is the critical settling velocity

Critical settling velocity is the settling velocity of particles which are 100% removed in the basin

v_0 expressed in units of flow per unit area is called the **Overflow rate**

As you can see the only difference between the critical settling velocity and the overflow rate is the type of unit used to express the number

The critical settling velocity and the overflow rate are the same number, but proper units should be used to express each

Since smaller particles have lower settling velocities, if you want to remove smaller particles in the settling basin you have to have a lower overflow rate.

Since $v_0 = Q/A$, to have a smaller v_0 you have to have a larger area (a bigger basin removes smaller particles)

Table 1 Typical Dimensions of Sedimentation Tanks

Description	Dimensions	
	Range	Typical
Rectangular		
Depth, m	3-5	3.5
Length, m	15-90	25-40
Width, m	3-24	6-10
Circular		
Diameter, m	4-60	12-45
Depth, m	3-5	4.5
Bottom Slope, mm/m	60-160	80

Example 1

A water treatment plant has a flow rate of 0.6 m³/sec. The settling basin at the plant has an effective settling volume that is 20 m long, 3 m tall and 6 m wide. Will particles that have a settling velocity of 0.004 m/sec be completely removed? If not, what percent of the particles will be removed?

$$v_0 = Q/A = 0.6 \text{ m/sec} \ / \ (20 \text{ m x } 6 \text{ m}) = 0.005 \text{ m/sec}$$

Since v_0 is greater than the settling velocity of the particle of interest, they will <u>not</u> be completely removed.

The percent of particles which will be removed may be found using the following formula:

$$\text{Percent removed} = (v_p \ / \ v_0) \ 100$$

$$= (0.004/0.005) \ 100 = 80 \ \%$$

Example 2

How big would the basin need to be to remove 100% of the particles that have a settling velocity of 0.004 m/sec?

$$v_0 = Q / A$$

$$0.004 = 0.6 / A$$

$$A = 150 \text{ m}^3$$

If the basin keeps the same width (6 m):

$$A = 150 \text{ m}^3 = 6m \times L$$

$$L = 25 \text{ m}$$

Example 3

Determine the terminal settling velocity for a sand particle with an average diameter of 0.5 mm and a density of 2600 kg/m³ settling in water at 20°C. Density and viscosity values may be found in Appendix C.

SOLUTION:

1. Determine the terminal settling velocity using Stokes' law, Eq. (12.28).

$$v_s = \frac{g(\rho_p - \rho_w)d_p^2}{18\mu}$$

$$= \frac{9.81 \text{ m/s}^2(2600 - 998.2)\text{kg/m}^3(5 \times 10^{-4} \text{ m})^2}{18 \times 1.002 \times 10^{-3} \text{ N} \cdot \text{s/m}^2}$$

$$= 0.22 \text{ m/s}$$

2. Check the Reynolds number.

$$N_R = \frac{\phi v_s d_p \rho_w}{\mu}$$

where ϕ is a shape factor to account for the irregularities of the sand. Using a value of 0.85 for ϕ the Reynolds number is:

$$N_R = \frac{0.85(0.22 \text{ m/s})(5 \times 10^{-4} \text{ m})(998.2 \text{ kg/m}^3)}{1.002 \times 10^{-3} \text{ N} \cdot \text{s/m}^2}$$

$$= 93.2$$

3. Because the Reynolds number computed in step 2 is greater than 0.3, Eq. (12.27) must be used to solve for the settling velocity.

   a. Solve for the coefficient of drag using Eq. (12.25) and the above value as the first estimate of N_R.

   $$C_D = \frac{24}{N_R} + \frac{3}{\sqrt{N_R}} + 0.34$$

   $$= \frac{24}{93.2} + \frac{3}{\sqrt{93.2}} + 0.34$$

   $$= 0.91$$

   b. Solve for the velocity using Eq. (12.27).

   $$v_s^2 = \frac{(4/3)(9.81 \text{ m/s}^2)(2600 - 998.2)\text{kg/m}^3(5 \times 10^{-4} \text{ m})}{0.91(998.2 \text{ kg/m}^3)}$$

   $$v_s = 0.11 \text{ m/s}$$

4. Repeat steps 2 and 3 to check the accuracy of the velocity computed in step 3b.

a. Use the velocity computed in step 3b to estimate the new Reynolds number:

$$N_R = \frac{0.85(0.11)(5 \times 10^{-4})(998.2)}{1.002 \times 10^{-3}}$$

$$= 46.5$$

b. Compute the new C_D value:

$$C_D = \frac{24}{46.5} + \frac{3}{\sqrt{46.5}} + 0.34$$

$$= 1.30$$

c. Compute the new velocity:

$$v_s^2 = \frac{(4/3)(9.81)(2600 - 998.2)(5 \times 10^{-4})}{1.30(998.2)}$$

$$= 0.0081 \text{ m}^2/\text{s}^2$$

$$v_s = 0.09 \text{ m/s}$$

5. Repeating steps 2 and 3 using the data from step 4 yields

$N_R = 38.1$

$C_D = 1.46$

$v_s = 0.085$ m/s

6. Repeating steps 2 and 3 using the data from step 5 yields

$N_R = 36.0$
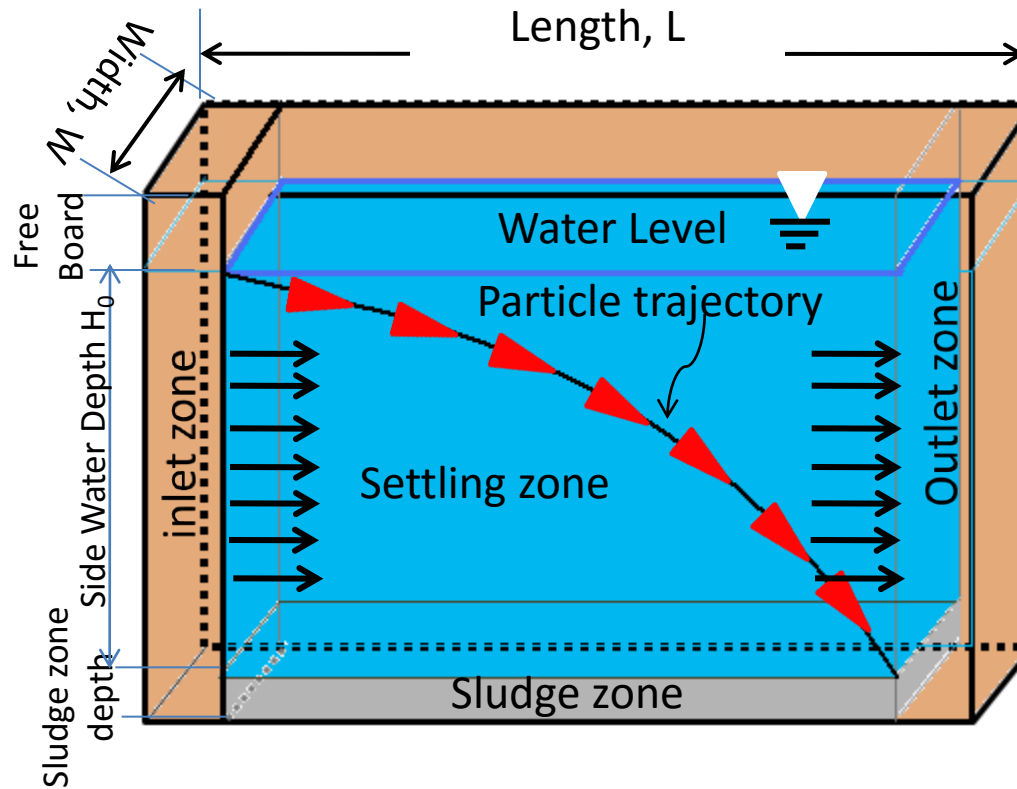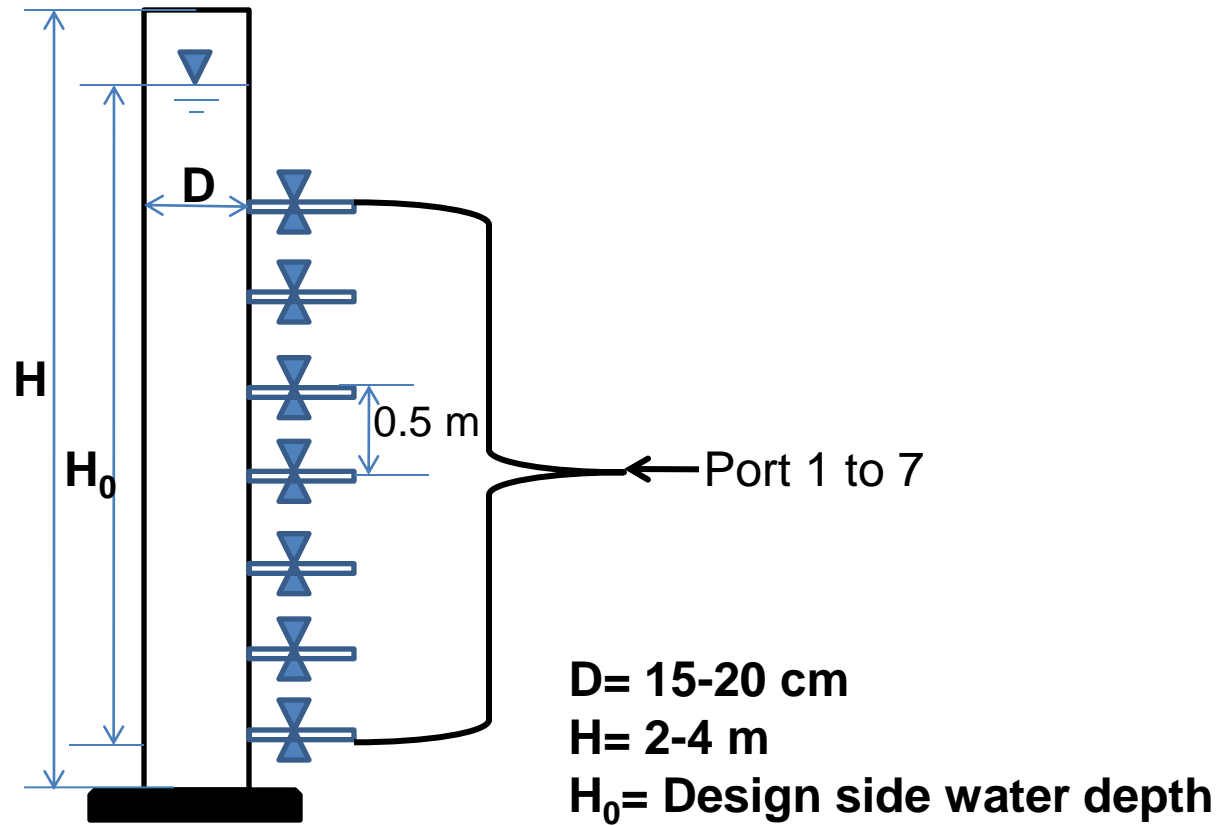
$C_D = 1.51$

$v_s = 0.083$ m/s

The above estimate of the velocity is sufficiently accurate.

Flocculant Settling OR Type II Settling; Particle Trejectory

D = 15-20 cm
H = 2-4 m
H_0 = Design side water depth

Example

- Example Batch Settling test results reduction analysis for sample port no. 1
- Plot a grid showing percent TSS removal at each port at different time intervals
- Draw lines of equal % removal (isoremoval). These lines are drawn similarly to contour lines.
- Draw vertical line at each point an iso removal line intersects the x-axis (3.5 m depth). List the observations

Time, min		TSS removed, mg/l	Removal efficiency, %
0	200	0	?
10	134	66	?
20	75	125	?
30	51	149	?
40	20	180	?

- **Observations**

- **For example, the R=60% isoremoval curve intercept the x-axis at 38 minutes. The 60% settling time t is therefore 38 min.**

- **90% of the particles have settled 0.51 m or more.**

- **80% of the particles have settled 0.72 m or more**

- **Likewise, 70 % and 60% of the particles have settled 1.01 m, and 3.50 m or more respectively.**

Port No.	Depth, m	Sampling time, min								
		10	20	30	40	50	60	70	80	90
1	0.5	33	62	74	90					
2	1.0	21	41	65	71	80	89	90		
3	1.5	16	36	59	67	74	81	86	91	
4	2.0	17	33	56	64	71	78	82	88	91
5	2.5	14	32	54	64	70	78	82	85	88
6	3.0	14	30	52	63	69	75	81	83	85
7	3.5	12	30	51	60	69	74	80	83	84