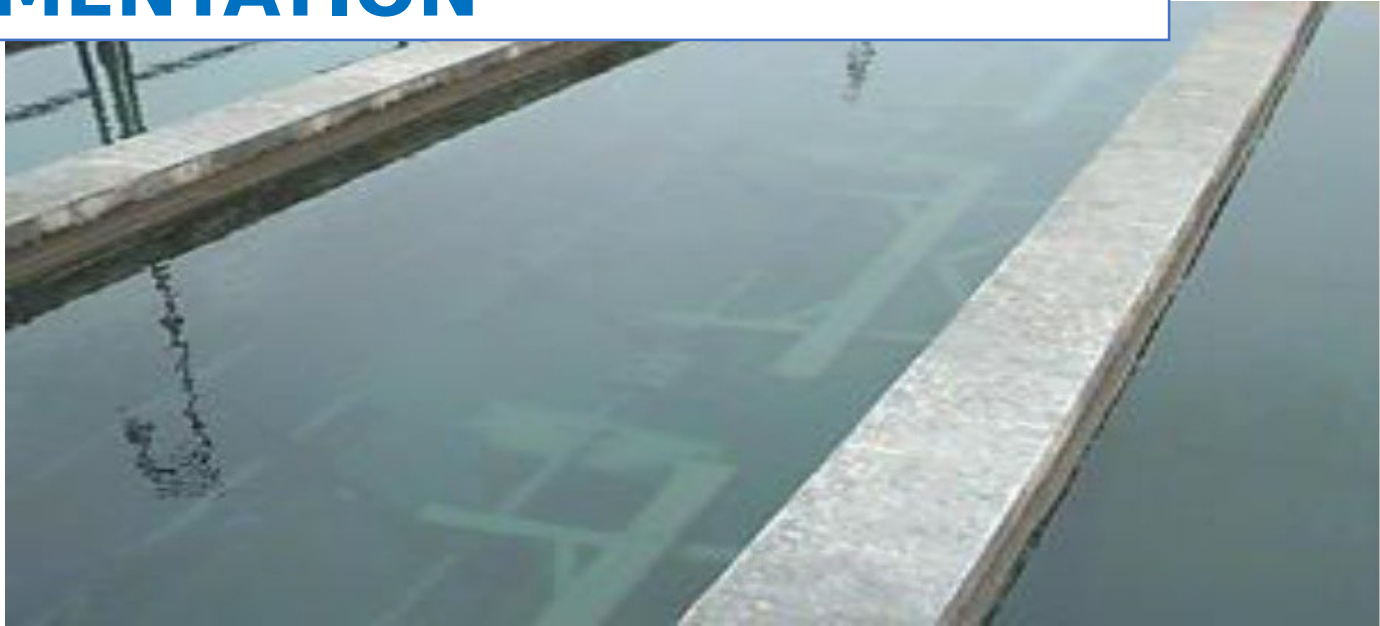


Sedimentation



CHAPTER THREE: SEDIMENTATION



In this lesson we will answer the following questions

- ✚ How does sedimentation fit into the water treatment process?
- ✚ What zones are present in a sedimentation basin?
- ✚ How is sedimentation sludge disposed of?

Sedimentation

- ✚ is a treatment process in which the velocity of the water is lowered below the suspension velocity and the suspended particles settle out of the water due to gravity.
- ✚ The process is also known as **settling** or **clarification**.
- ✚ Most water treatment plants include sedimentation in their treatment processes.
- ✚ However, sedimentation may not be necessary in low turbidity water of less than 10 NTU.
- ✚ In this case, coagulation and flocculation are used to produce pinpoint (very small) floc which is removed from the water in the filters.

Location in the treatment plant

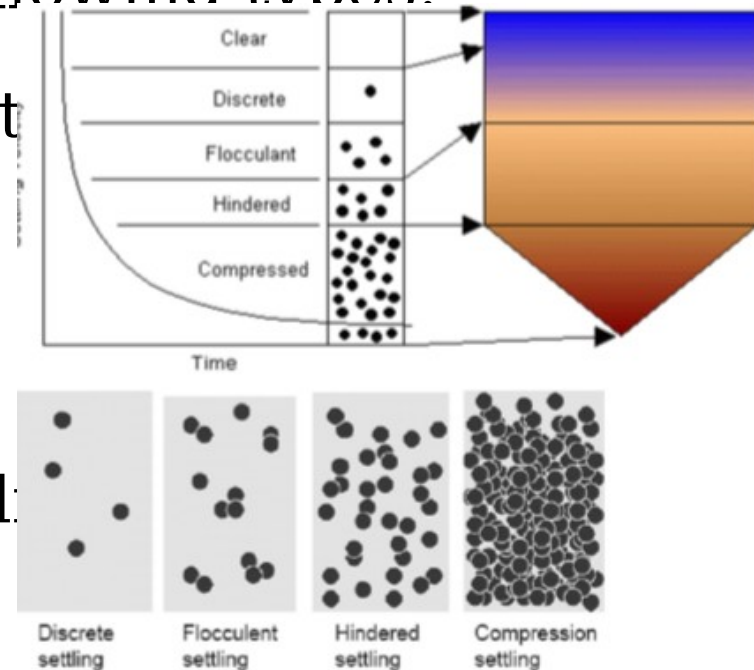
- ✚ The most common form of sedimentation follows coagulation and flocculation and precedes filtration.
- ✚ This type of sedimentation requires chemical addition (in the coagulation/flocculation step) and removes the resulting floc from the water.
- ✚ Sedimentation at this stage in the treatment process should remove 90% of the suspended particles from the water, including bacteria.
- ✚ It can also occur as part of the pretreatment process, where it is known as pre sedimentation .



- ✚ All the particles having more specific gravity than the liquid will move vertically downward due to gravitational force.
- ✚ It will accelerate until the frictional resistance or drag become equal to the gravitational forces acting upon the particle.
- ✚ At such stage the particle will settle at uniform velocity. This uniform velocity is called Settling velocity.
Purpose: To **decrease** the **concentration of suspended particles** in the water, reducing the load on the filters

2. Sedimentation Theory

- Determination of the particle-settling velocity is different for different types of particles
- Settling properties of particles are often categorized into one of the following types:
 - Type-I: Discrete Particle Settling
 - Type-II: Flocculent Settling
 - Type-III: Zone Settling
 - Type-IV: Compression Settling



A. Discrete Particle Settling

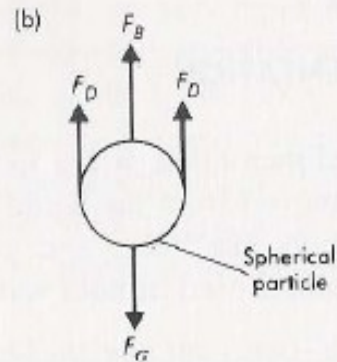
- Any particle which does not alter its **size, shape, and weight** while rising or settling □ discrete particle
- Discrete Particle Settling:-
 - No interaction between particles
 - Settling velocity is constant for individual particles
 - Dilute solid's concentration
- **Examples:-**
 - Pre-sedimentation in water treatment
 - Grit removal in wastewater

Con...

- All the particles having **more specific gravity** than the **liquid move vertically downward** due to gravitation force
- Will accelerate until the **frictional resistance/drag become equal to gravitational forces** acting upon the particle
- At such stage the particle will settle at uniform velocity.
 - Settling velocity

Type 1 – Discrete Settling

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



1. The forces of gravity

$$f_g = \rho_p g V_p$$

2. The buoyant force quantified by Archimedes.

$$f_b = \rho_w g V_p$$

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

1. Drag force

$$f_D = C_D A_p \rho_w \frac{v_s^2}{2}$$

ρ_p = density of particle

V_p = volume of particle

ρ_w = density of water

V_p = volume of particle

C_D = drag coeff.

A_p = cross sectional area
of particle perpendicular
to the direction of
movement

ρ_w = density of water

v_s =settling velocity of particle

From Newton's Law

$$F_D = F_G - F_B$$

$$\frac{C_D v_t^2 \rho A}{2} = \rho_p g V - \rho g V = V g (\rho_p - \rho)$$

$$v_t = \sqrt{\frac{2 V g (\rho_p - \rho)}{C_D \rho A}}$$

For spherical particle;

$$\left. \begin{array}{l} V_p = \frac{4}{3} \pi r^3 \\ A = \pi r^2 \end{array} \right\} \frac{V_p}{A_p} = \frac{\frac{4}{3} \pi r^3}{\pi r^2} = \frac{4}{3} r$$

$$= \frac{4 d}{3} \longrightarrow$$

Substitute into Eqn.1



$$v_s = \sqrt{\frac{2g(\rho_p - \rho_w)d}{C_D \rho_w}}$$

$$v_s = \sqrt{\frac{4(\rho_p - \rho_w)gd}{3 C_D \rho_w}}$$

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

Newton's drag coefficient (C_D) is a function of:

$R_e < 1$, Laminar Flow $\rightarrow$

$$C_D = \frac{24}{R}$$

$1 < R_e < 10^4$, Transitional Flow $\rightarrow$

$R_e > 10^4$, Turbulent Flow $\rightarrow$

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

Where R = Reynolds number

$$C_D = 0.40$$

$$R = \frac{\rho V_s D}{\mu}$$

μ = dynamic viscosity, N.s/m²

Drag coefficient for sphere

Drag coefficient (C_D) for spheres:

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

For laminar flow $\rightarrow R_e < 1$ negligible

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

$$C_D = \frac{24}{R_e} \quad \text{where} \quad R_e = \frac{v_s d}{\nu} = \frac{v_s d \rho}{\mu}$$

$$C_D = \frac{24 \mu}{v_s d \rho_w}$$

For laminar flow

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

For turbulent flow $\rightarrow R_e > 10^4$

$C_D = 0.34 - 0.4$ commonly used

Substitute into Eqn.2

$$v_s = \sqrt{\frac{10}{3} g \frac{(\rho_p - \rho_w) d}{\rho_w}}$$

**Settling velocity of
spherical discrete particles
under turbulent flow
conditions**

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

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

$$\mu = 1.002 \cdot 10^{-3} \text{ Ns / m}^2$$

Con...

Solution

Given

$$D=0.5\text{mm}$$

$$S_g=2.65$$

$$\mu = 1.002 * 10^{-3} \text{Ns} / \text{m}^2,$$

$$\rho_w = 1000 \text{Kg} / \text{m}^3$$

$$S_g = \frac{\rho_p}{\rho_w} \Rightarrow \rho_p = S_g * \rho_w = 998.2 * 2.65$$

$$\approx 2650 \text{Kg} / \text{m}^3$$

Con..

Assume the flow is Laminar

$$V_p = \frac{gd^2[\rho_p - \rho_w]}{18\mu} = \frac{9.81 * [0.5 * 10^{-3}]^2 [2650 - 998.2]}{18 * 1.002 * 10^{-3}} \\ = \underline{0.22 \text{m/sec}}$$

Check the flow is laminar or not

$$CD = \frac{24}{Re}, \quad Re = \frac{\rho_w * V_p * d}{\mu} = \frac{998.2 * 0.22 * 0.5 * 10^{-3}}{1.002 * 10^{-3}} = 112 \quad (Not!)$$

The flow is transitional flow

$$CD = \frac{24}{Re} + \frac{0.3}{\sqrt{Re}} + 0.34 = \frac{24}{112} + \frac{0.3}{\sqrt{112}} + 0.34 = 0.84$$

$$V_p = \sqrt{\frac{4gd}{3CD} * \frac{(\rho_p - \rho_w)}{\rho_w}} = 0.111 \text{m/sec}$$

Check Re

$$Re = \frac{\rho_w * V_p * d}{\mu} = \frac{998.2 * 0.11 * 0.5 * 10^{-3}}{1.002 * 10^{-3}} = 55 \quad (\text{ok!})$$

Therefore $V_p = 0.11 \text{m/sec}$

Con...

Example: 2

Find the diameter of the particle that has a settlement velocity of 0.1m/sec. Density of particle = 2650 and density of water = 1000kg/m³.

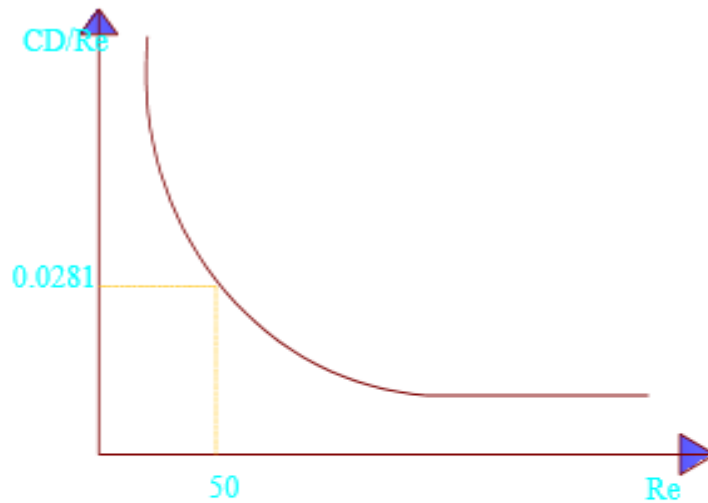
Con...

$$\mu = 1.3 \times 10^{-3} \text{ Ns/m}^2$$

$$\frac{C_D}{R_N} = \frac{4}{3} \frac{1650}{10^6} \frac{9.81 \times 1.3 \times 10^{-3}}{10^{-3}} = 0.0281$$

From the curve $R_N = 50$ for $\frac{C_D}{R_N} = 0.0281$

$$d = \frac{50 \times 1.3 \times 10^{-3}}{0.1 \times 10^3} = 0.65 \times 10^{-3} = 0.65 \text{ mm}$$



Allen's Law at intermediate Reynolds number

$$V_p = \frac{0.153 * g^{0.71} * d^{1.14} (\rho_p - \rho_w)}{\rho_w^{0.29} \mu^{0.43}}$$

B. Flocculent Settling

- Under **quiescent conditions**, suspended particles in many waters exhibit a natural tendency to **agglomerate**
- Particles **collide and adhere** to each other resulting in particle growth
- As particles flocculate, their size and settling velocity will increase
- Ex: - Coagulation/flocculation settling in water treatment and
- Primary sedimentation in wastewater treatment

Con...

Example 2: Estimate the terminal settling velocity in water at a temperature of 15°C ($\mu = 0.00113 \text{Ns/m}^2$) of spherical silicon particles with specific gravity 2.40 and average diameter of (a) 0.05mm and (b) 1.0mm

C. Zone Settling(Hindered settling)

- Particles are so **close together**, movement is restricted
- Solids move **as a block** rather than individual particles
- Fluidic interference causes a **reduction in settling velocity**
- Distinguishable solids **liquid interface**
- Intermediate solids concentration
- Example: Settling of secondary effluents

D. Compression Settling

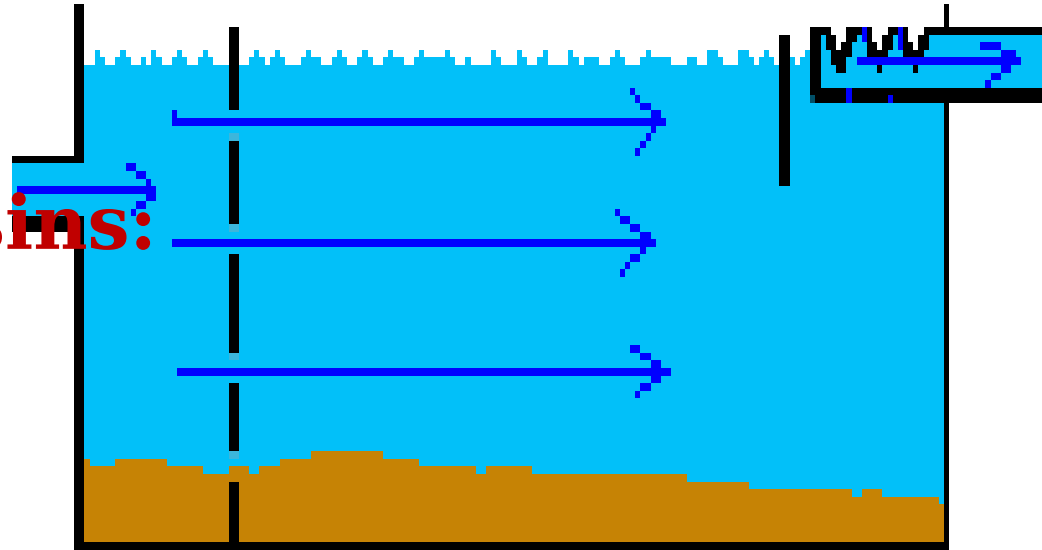
- Particles **physically in contact**
- Water is **squeezed** out of interstitial spaces
- Volume of solids may decrease
- High concentration of solids (**sludges**)

3. SEDIMENTATION TANKS

- The principle involved in these tanks is **reduction of velocity of flow** so that the particles **settle** during the detention period
- Classified as **continuous** flow or **intermittent** flow
- Shape: circular, rectangular, square
- Direction of flow
 - Horizontal flow – Longitudinal and radial flow
 - Vertical flow - Circular (upward flow)

Common Sedimentation basins:

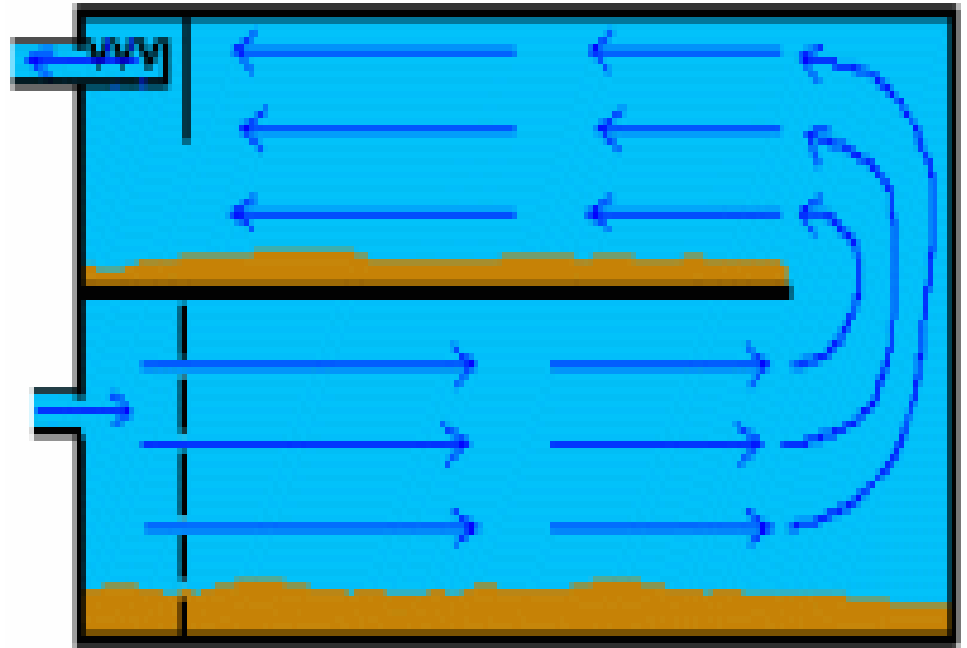
Rectangular basins:



- Found in **large-scale** water treatment plants.
- Predictability and **cost-effectiveness**
- Low **maintenance**
- Least likely to **short-circuit**, especially if the length is at least twice the width
- Disadvantage:
 - ✓ **Large** amount of **land area** required

Common Sedimentation basins:

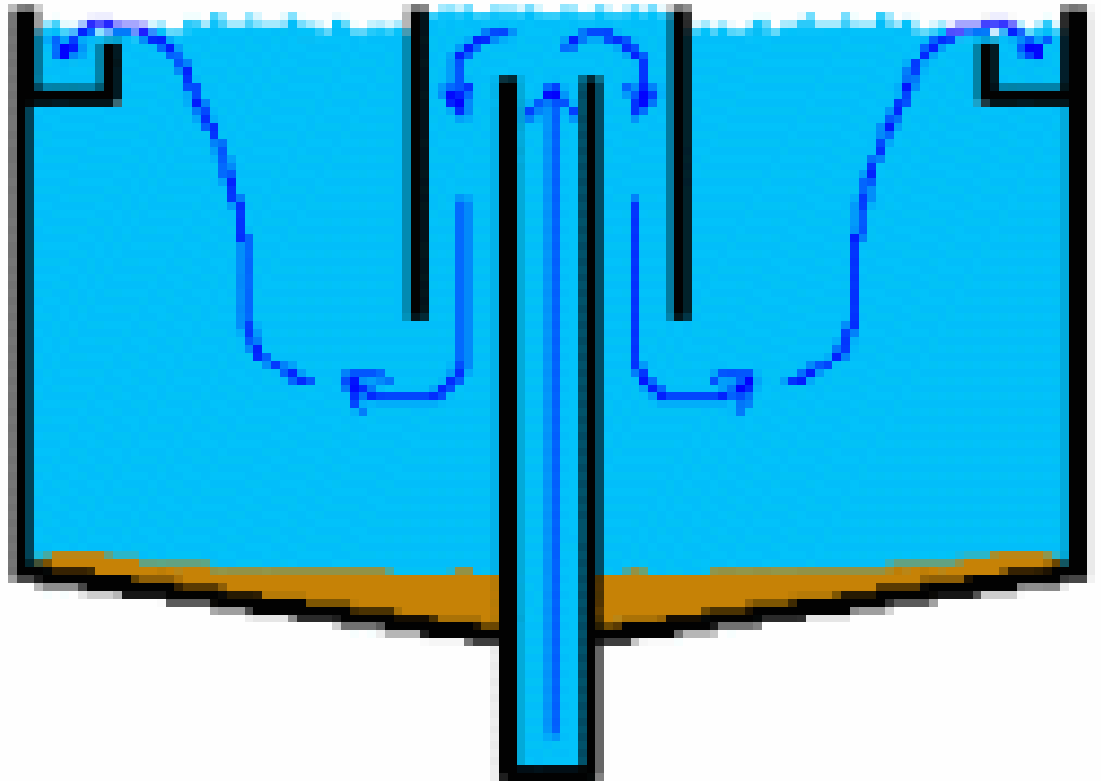
Double-deck Rectangular basins:



- Two rectangular sedimentation basins stacked one at top of the other
- **Conserves land area**, but has higher operation & maintenance costs

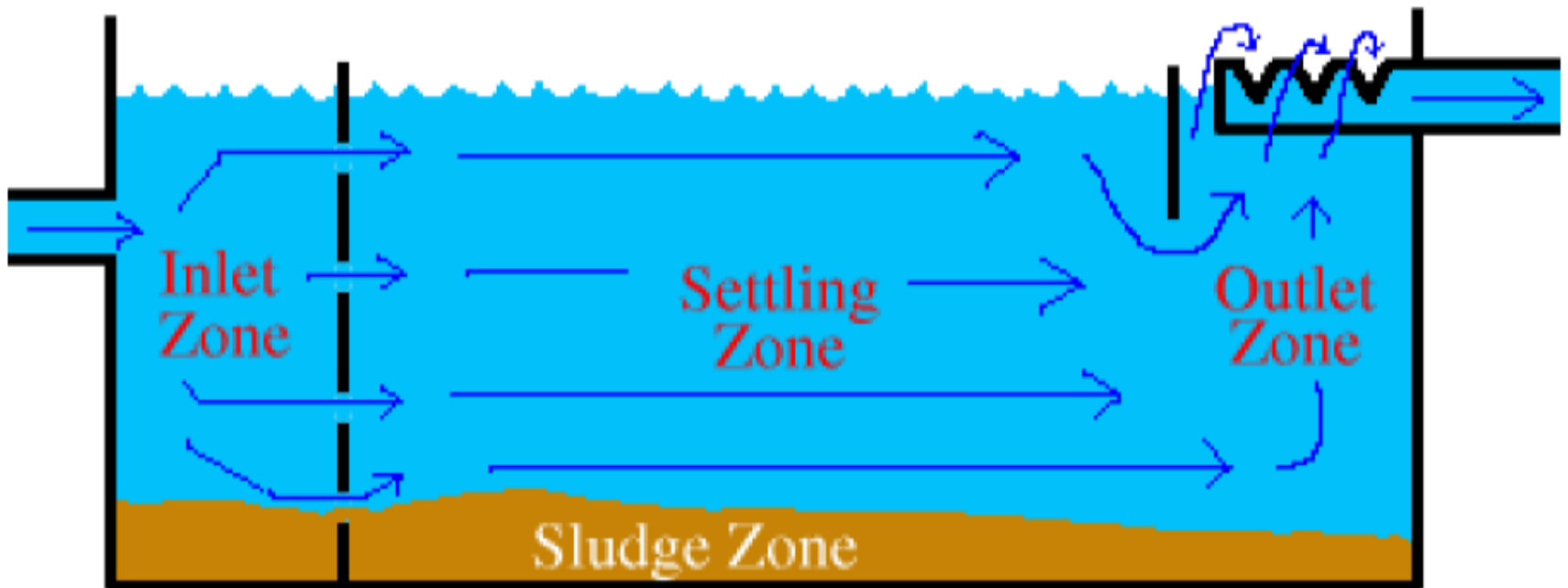
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- **Square or circular** sedimentation basins with horizontal flow are often known as **clarifiers**
- This **basin** is likely to have **short-circuiting** problems



Sedimentation tanks zone

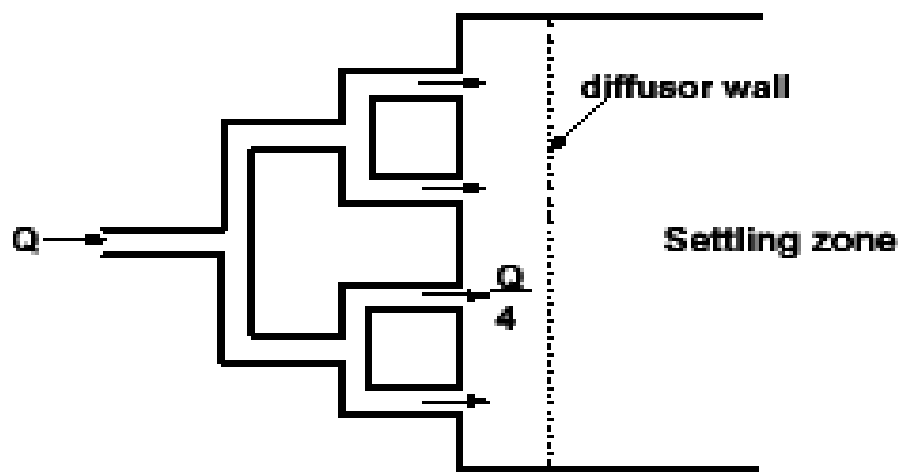
- 1. Inlet zone***
- 2. Settling zone***
- 3. Sludge zone***
- 4. Outlet zone***



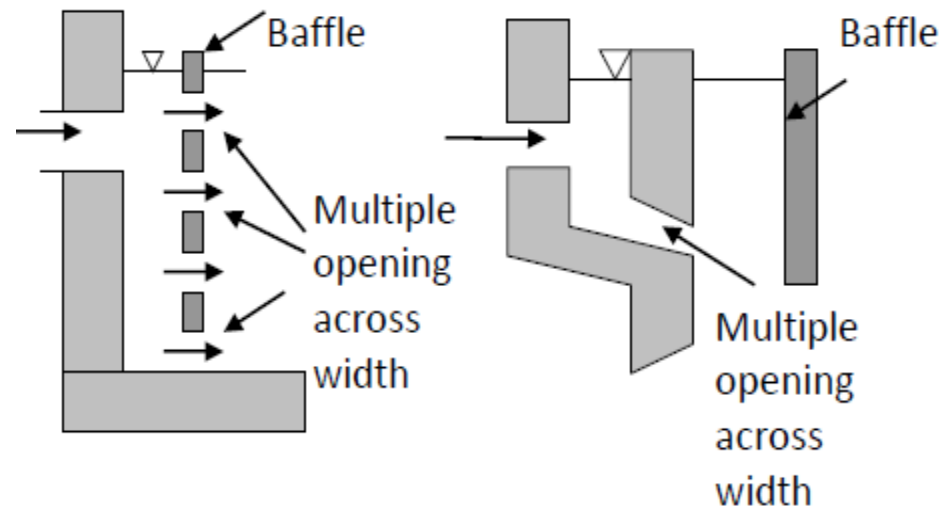
Inlet Zone:

- Primary Purposes:
 - To **distribute** the water and
 - To **control the water's velocity** as it enters the basin

- Designed to **dissipate the momentum** and



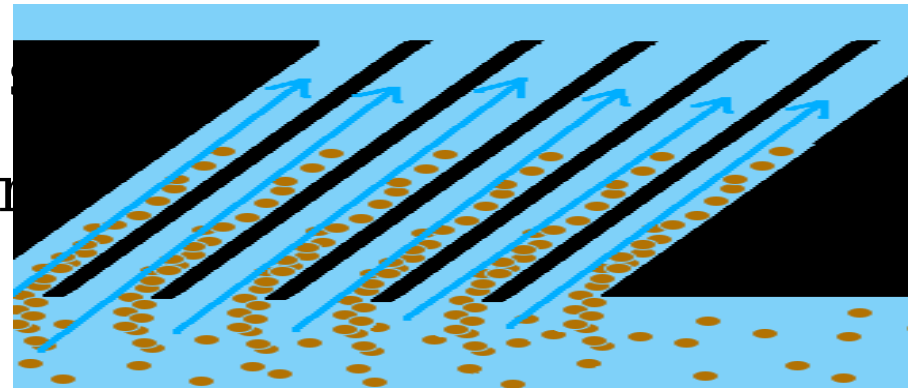
Flow Distribution



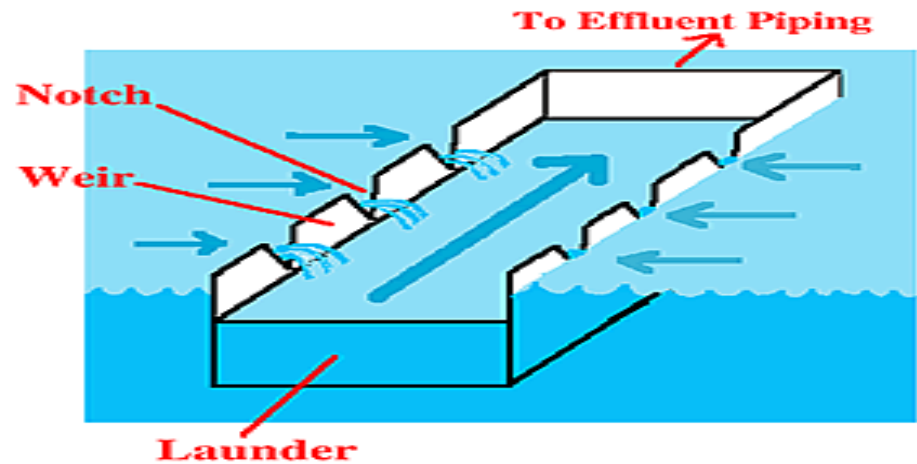
Baffle/diffuser walls

Settling Zone

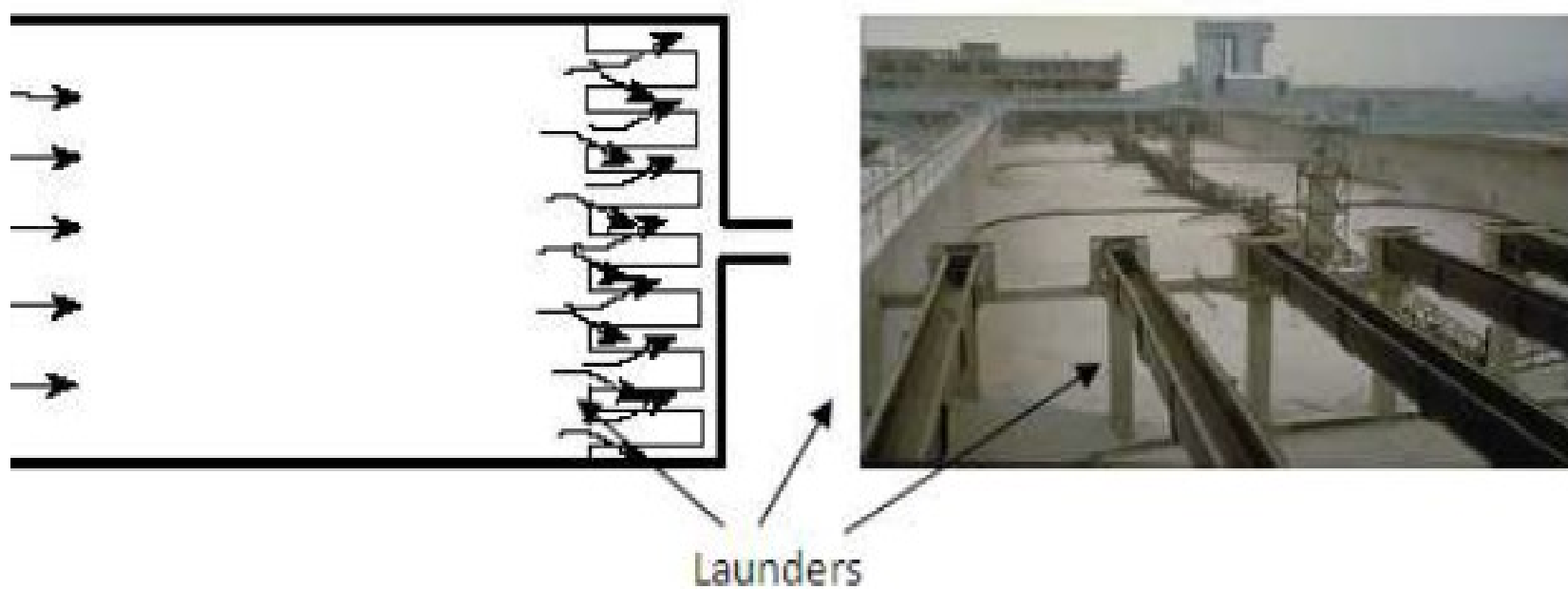
- Large expanse/**spread of open water**
- Suspended particles settle within the flowing water
- Bulk of **floc settling** occurs and **largest volume** of the sedimentation basin
- For optimal performance, requires a **slow, even flow of water**
- But in some cases, tubes
- are included in the settling



Outlet Zone



- The **flow and remaining suspended** particles are carried to the effluent conduit out of the sedimentation basin
- Designed to ensure that the water flowing out of the sedimentation basin has the **minimum amount of floc** suspended in it
- **Control the water level** in the basin



- Consist of an **overflow weir & a receiving channel or launder**
 - **Launder**: to the exit channel or pipe.
- Flow velocity in upward direction has to be limited
- Increase the **length of the overflow** □ overflow weir
- Begins with a **baffle in front** of the effluent
- The **baffle prevents floating material** from escaping the **sedimentation basin** and **clogging the filters**

Sludge Zone

- Found across the bottom of the sedimentation basin where the sludge collects temporarily
- Removed solids **accumulate & withdrawn** as underflow
- Velocity should be **very slow to prevent re-suspension of sludge**
- A drain at the bottom of the basin allows the sludge to be easily removed from the tank
- The tank **bottom should slope toward the drains** to further facilitate sludge removal

Factors Influencing Efficiency of the basin

↘ **Floc Characteristics:**

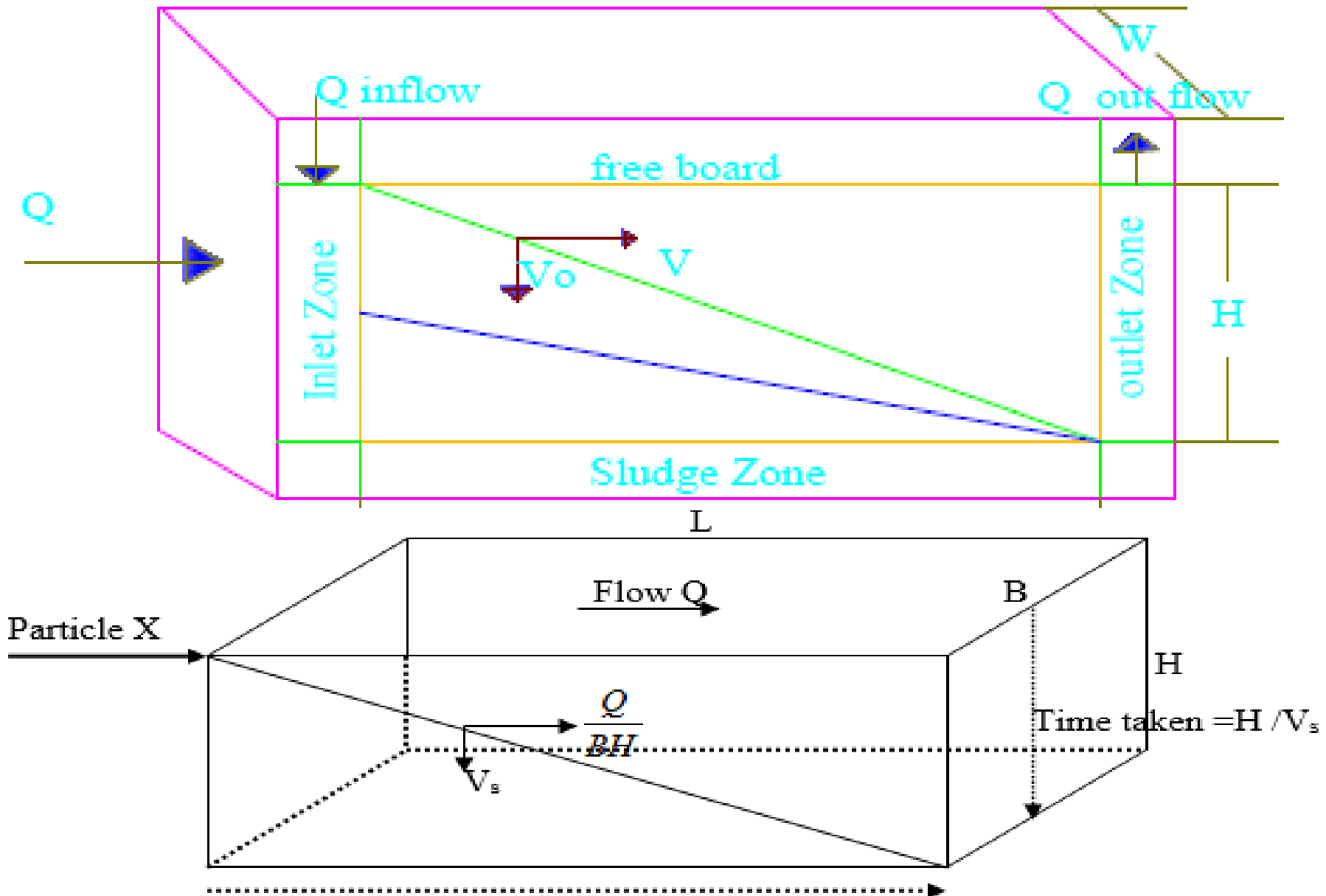
- The **size, shape, and density** of the floc entering the sedimentation basin will all influence how well the floc settles out of the water.
- Floc which is **too small or too large**, is irregularly shaped, or has a low density will not tend to settle out in the sedimentation basin

...

↳ **Short-circuiting:**

- Occurs when **water bypasses the normal flow** path through the basin and reaches the outlet in less than the normal detention time
- Cause of **inefficiency** in the sedimentation basin
- **Floc does not have enough time** to settle out of the water, influencing the plant and the quality of the treated water
- Basin **shape and design** along with the design of the inlet and out-let, can cause short-circuiting
- **Uneven distribution** of flow either at the inlet or out-let can also cause short-circuiting
- Detected if **areas of water in the basin do not appear to be circulating**, or if sludge build up on the bottom of the basin is uneven

4.Design of Rectangular sedimentation tank



➤ Important Parameters and characteristics:

➤ **A. Overflow rate/Surface loading/ Surface overflow rate**

- Settling velocity of the smallest particle which the basin will remove
- Calculated by dividing the **flow by the surface area** of the tank
- Settlement of a particle at the bottom of the tank does not depend on the depth of tank and depends upon the surface area of the tank

B. Capacity of tank:

$$C = Q * T$$

→ T= Detention period theoretical time taken by a particle of water to pass b/n entry & exit of a settling tank, hr

→ C = Capacity of tank

→ Q = Discharge or rate of flow

■ ■ ■

- Particle is moving with a horizontal velocity V and a down ward vertical velocity V_s :

- The horizontal velocity:

$$V = \frac{Q}{BH}$$

- Time of horizontal flow $t_h = \frac{L}{V} = \frac{LHB}{Q}$

- The time for the falling distance:

$$t_v = \frac{H}{V_s}$$

■ ■ ■

- For the particle to reach the bottom before the water leaves the tank the **time of fall must equal the time** of

horizontal flc $\frac{H}{V_s} = \frac{LBH}{Q}$

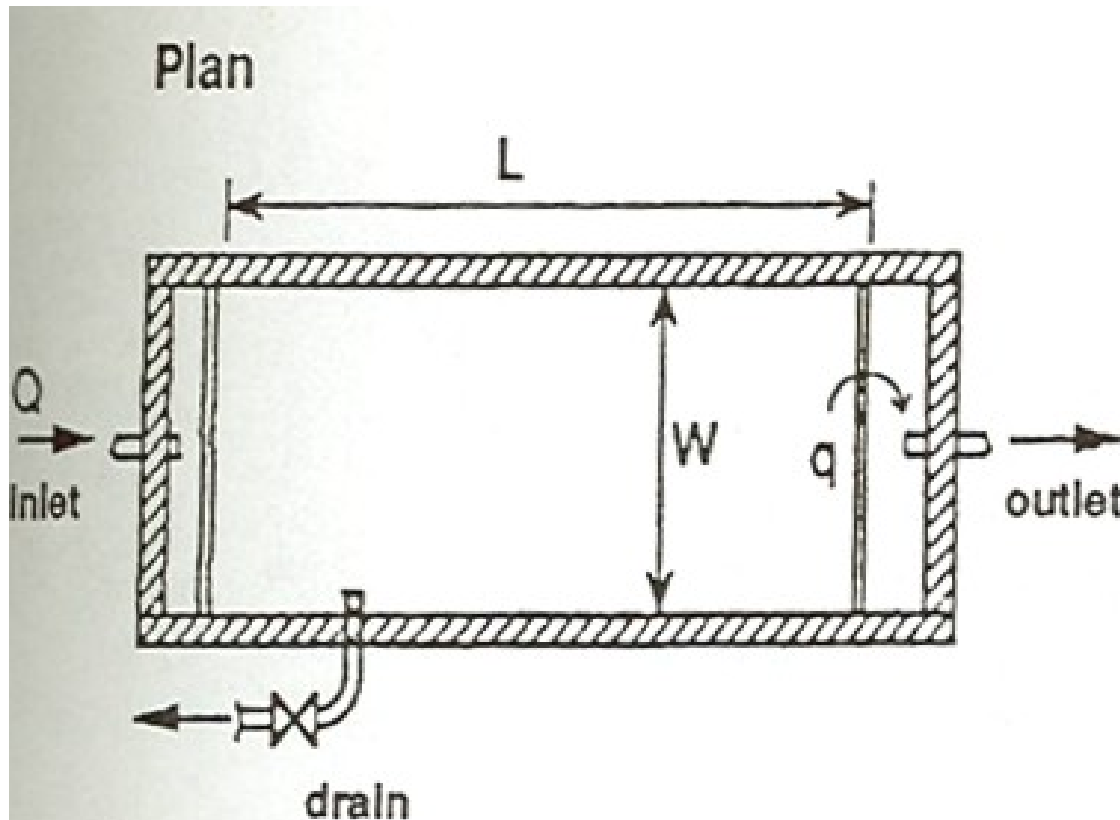
From which

$$V_s = \frac{Q}{LB} = \frac{Q}{A}$$

A = the surface area of
the tank

■ ■ ■

The **detention time** is the time which would be required by the flow of water to fill the tank, if there were no outflows $t = \frac{LHB}{Q}$



List of Symbols

L (m) length

W (m) width

H (m) average depth

Q (m^3/h) flow rate

S_o (m/h) surface loading

T (hr) detention time

q ($\text{l}/\text{s m}$) weir load

Over view of calculations

- Shall be designed for the maximum day demands of stage II and is implemented in two stages
- **Divide flow** in to at least two tanks $Q_c = Q/n$
- Calculate the required **surface area**, **$A = \text{Flow}/\text{Over flow rate}$**
- Calculate the required **volume**, **$V = Q * \text{detention time}$**
- Calculate the tank **depth**, **$d = \text{Volume}/\text{Area}$**
- Calculate the tank **width and length** **$V = L * W * d$ and L/w ratio**
- Check **flow through velocity** **$= Q/A$**
- If velocity is **too high, repeat calculations** with more tanks
- Calculate the weir length, **$Lw = Qc/\text{Weir loading}$**

Design Guide lines

Horizontal Flow setting basin:

No	Design Parameter	Unit	Acceptable range
1	Surface loading rate	m/d	20-60
2	Detention period	Hr	1 ½- 4
3	L/W ratio		> 3
4	Horizontal flow velocity	m/hr	4-36

Source: MoWR Design Guide Line

Con..

The following are the parameters for satisfactory performance of sedimentation tank.

1. Detention period
 - 3 to 4 hours for plain settling
 - 2 to 2.5 hours for floc settling
 - 1 to 1.5 hours for vertical flow type
2. Overflow rate
 - 15 - 30 $\text{m}^3/\text{m}^2/\text{day}$ for plain settling
 - 30 - 40 $\text{m}^3/\text{m}^2/\text{day}$ for horizontal flow
 - 40 - 50 $\text{m}^3/\text{m}^2/\text{day}$ for vertical flow
3. Velocity of flow..... 0.5 to 1.0 cm/sec
4. Weir loading..... 300 $\text{m}^3/\text{m}/\text{day}$
5. L:W 3:1 to 5:1
 - Breadth of tank..... (10 to 12m) to 30 to 50m
6. Depth of tank..... 2.5 to 5m (with a preferred value of 3m)
7. Diameter of circular tank.... up to 60m
8. Solids removal efficiency..... 50%
9. Turbidity of water after sedimentation 15 to 20 NTU
10. Inlet and outlet zones..... 0.75 to 1.0m
11. Free board..... 0.5m
12. Sludge Zone..... 0.5m

Example-1

Find the dimension of a rectangular sedimentation basin for the following data given:-

- ❑ Volume of treated water = 3×10^6 l/d
- ❑ $t_d = 4 \text{ hr} = 240 \text{ min}$
- ❑ Velocity of flow = 10 cm/min

Con....

Solution

length of tank = velocity of flow*td

$$= 0.1 * 240 = 24\text{m}$$

$$\text{Volume of water in 4hr} = \frac{3 * 10^6 * 4}{10^3 * 24} = 500\text{m}^3$$

$$\text{X sectional area (B*H)} = V/L = 500/24 = 20.8\text{m}^2$$

Assuming the working depth = 3m

$$\text{Width of tank} = 20.8/3 = 7\text{m}$$

Provide 1m for sludge storage and 0.5m for free board

$$\text{Total depth} = 3 + 1.5 = 4.5\text{m}$$

Provide the inlet zone = out-let zone = 3m

$$\text{Total length} = 24 + 6 = 30\text{m}$$

$$\text{Provide the Sedimentation tank} = 30 * 7 * 4.5$$

Example-2

Design a sedimentation basin for the following data:-

- Flow rate:-
 - Max flow rate = $10,000\text{m}^3/\text{day}$
 - Average flow rate = $5790\text{m}^3/\text{day}$
- Design parameters:-
 - $t_d = 4\text{hr}$
 - $L/W = 2$
 - Surface over loading rate = $10\text{m}^3/\text{m}^2/\text{d}$
 - Design flow rate to be 25% of maximum flow rate

Con...

Solution

Determine the number of tanks

$$\text{No. of tanks} = 100/25 = 4$$

$$Q_{\text{single}} = 10,000/4 = 2500 \text{m}^3/\text{day}$$

Determine the area of the sedimentation tank

$$\text{Area} = \text{maximum flow rate}/\text{SOR}$$

$$= 2500/10$$

$$= 250 \text{m}^2$$

$$A = 1 \cdot w = 2w^2$$

$$W = 11.18 \text{m} = 11 \text{m}$$

$$L = A/W = 23 \text{m}$$

Determine the effective height (H)

$$H = \text{SOR} \cdot t_d$$

$$= 1.67 \text{m}$$

Provide the sludge and the free board zone of 0.5m

$$H_t = 2 + 0.5 + 0.5 = 3 \text{m}$$

Assume the inlet and out-let zone to be equal to the effective depth of the tank.

Con...

Example 2: A water treatment plant has four clarifiers treating $0.175 \text{ m}^3/\text{s}$ of water. Each clarifier is 4.88m wide, 24.4m long and 4.57m deep. Determine: (a) the detention time, (b) overflow rate, (c) horizontal velocity, and (d) weir loading rate assuming the weir length is 2.5 times the basin width.

Con...

Review

Sedimentation basin efficiency is influenced by floc characteristics, water temperature, short-circuiting, and gases in the water, algal growth on tank walls, intermittent tank operation, surface loading, and weir loading. To insure optimal performance, the operator should test turbidity and temperature of the water and should visually survey the basin

Design of a sedimentation basin involves the following steps:

- ✱ Divide flow in to at least two tanks.
- ✱ Calculate the required surface area.
- ✱ Calculate the required volume.
- ✱ Calculate the tank depth.