Water Supply Engineering

Chapter 6

Water Treatment

Lecture 8 (Week 8)

Water Treatment and Objectives of water treatment, Treatment processes and impurity removal, Screening and its Purpose, Types, Plain Sedimentation and its Purpose, Theory of settlement, Derivation of Stoke's law, Temperature effect on settlement, Ideal sedimentation tank, Types and Design of sedimentation tank, Numerical on theory and design of sedimentation tank

Lecturer: Asst. Prof. Sunil Rakhal

Learning Objectives:

- Understand the purpose and processes of water treatment.
- Learn how different impurities are removed through treatment stages.

Learning Objectives continue:

- Know the function and types of screens in preliminary treatment.
- Comprehend the principles of plain sedimentation and Stoke's Law.
- Analyze the effects of temperature on sedimentation.
- Identify ideal sedimentation tank characteristics and various types.
- Understand the design principles of sedimentation tanks.
- Solve numerical problems related to sedimentation theory and design.

6.Water Treatment

- **Water treatment** refers to the process of improving water quality so that it becomes fit for its intended use. This is achieved by reducing or removing impurities present in the water.

- It's important to note that treatment doesn’t eliminate all impurities completely- instead, it reduces them to levels that are considered safe and acceptable according to water quality standards.

- After undergoing treatment, water should meet certain desirable qualities: it should be safe to consume, have no unpleasant taste or smell, appear clear and colorless, be moderately soft, non-corrosive, and have minimal organic matter.

6.1 Objectives of water treatment

The objective of water treatment are:

1. To remove colour, dissolved gas and murkiness of water.
2. To remove objectionable taste and odour.
3. To make water fit for domestic use as cooking and washing.
4. To kill all the pathogenic germs, which are harmful to human health.
5. To remove disease producing micro-organisms.
6. To remove hardness of water and make it suitable for wide variety of industrial works.
7. To eliminate the tuberculating and corrosive properties of water.

6.2 Treatment processes and impurity removal

S.N.	Treatment Process	Impurities Removed
1	**Screening**	Large suspended and floating matter such as leaves, fish, and branches
2	**Plain Sedimentation**	Coarse and heavy suspended particles like silt, sand, and clay
3	**Sedimentation with Coagulation**	Fine suspended solids and colloidal particles
4	**Filtration**	Microorganisms, very fine suspended particles, and colloidal matter

5	**Disinfection**	Disease-causing microorganisms (pathogens)
6	**Softening**	Hardness-causing minerals
7	**Aeration**	Unpleasant colour, odour, taste, iron, and manganese
8	**Removal of Iron and Manganese**	Iron and manganese
9	**Removal of Colour, Odour and Taste**	Color, odor, and taste-related impurities

6.3 Screening

- Screening is a process of removing suspended matter from water that may range from floating debris such as sticks, branches, leaves, etc. by passing water through screens.
- It works as a protective device for successive treatment plants and increases the working efficiency of plants.
- Screen may be located at the intake structure, raw water pumping station, or the water treatment plant itself
- Two types based on size of the materials removed as follows:

1. Bar screens: (Coarse and medium)
2. Fine Screens

6.3.1 Purpose

Screening is the first step in water treatment where large suspended and floating materials like leaves, sticks, plastics, fish, and other debris are removed from raw water using screens or mesh.

Purpose of Screening:

- To **protect pumps and pipes** from clogging or damage.
- To **prevent blockages** in downstream treatment units.
- To **improve the efficiency** of the entire treatment process by removing bulky waste early on.

6.3.2 Coarse, medium and fine screens

Bar screens

- Bar screens are intended to intercept only grosser floating materials . Generally it is placed in front of fine screen.
- The circular bars are generally of 25 mm size in diameter and rectangular bars are generally 10mm* 50mm and are placed with larger dimension parallel to flow.
- The screens may be course or medium size depending upon the opening space between the bars.
- 50 to 150 mm openings for coarse and 20 to 50 mm openings for medium.

Fine Screen

- Used to remove small suspended matters.
- Fine screens are used at surface water intakes and is generally made of wire mesh.
- The size of wire mesh should be more than 6mm.

- Generally not used as it is frequently clogged and create difficulty in its operation and maintenance.
- Velocity through screens are much higher than approach velocity V. Hence approach velocity V is generally neglected.
- The head loss through the unobstructed screens depends on the nature of their constructions as well as the approach velocity.
- $h = ß(\frac{w}{B})^{\frac{4}{3}} h_v \sin \boldsymbol{\theta}$
- Where h = head loss
- h_v = approach velocity head
- w = maximum c/s width of the bars facing direction of flow
- B =minimum clear opening between pairs of bars.
- **θ** = angle of the rack with horizontal; and

- ß = a shape factor(1.79 for circular rod and 2.42 for sharp edged rectangular bars (Dr. B.C Punmia, Er.Ashok Kumar Jain, Dr. Arun K.Jain, 2013)

6.4 Plain Sedimentation

- Plain sedimentation is a method where water is held in a basin or tank, allowing suspended solids to settle naturally due to gravity, without the use of any chemical agents.
- This technique is most effective when the water has a high concentration of relatively large suspended particles.
- The process helps reduce operational costs by lowering the frequency of cleaning and minimizing the burden on both the distribution system and the subsequent treatment stages.

- It is particularly efficient in settling particles with a specific gravity of 1.2 or higher.
- Additionally, it contributes to the improvement of water quality by helping eliminate turbidity, unpleasant taste, odor, and color that are linked to these suspended solids.
- Two types of suspended particles in water:
    1. Inorganic solids having specific gravity of about 2.65
    2. Organic solids having specific gravity of 1.0 to1.4
- The time for which water is retained in a sedimentation tank is known as detention period or retention period.
- The particles which are settled in the bottom of the sedimentation tank are known as sludge.

6.4.1 Purpose

The purpose of a sedimentation tank in a water supply system is to remove suspended solids from water by allowing them to settle naturally under the influence of gravity. This process improves water quality and reduces the load on subsequent treatment units like filtration and disinfection.

Main Purposes of a Sedimentation Tank:

1. **Removal of Suspended Solids**

- Helps in settling down heavier particles such as silt, sand, and clay without adding chemicals.

2. **Improves Efficiency of Further Treatment**

- Reduces turbidity, making filtration easier and more effective.

3. **Minimizes Cost and Wear**

- Decreases wear and tear on pumps and pipes caused by abrasive solids.
- Reduces chemical usage and energy cost in later stages.

4. **Protects Public Health**

- By reducing particulate matter that may shield harmful microorganisms, it enhances the effectiveness of disinfection.

5. **Enhances Aesthetic Qualities of Water**

- Leads to clearer, cleaner, and better-smelling water by removing floating and settleable debris.

6.4.2 Theory of settlement

- All the particles having more specific gravity than liquid will move vertically downward due to gravitational force.
- Hydraulic subsidence is the phenomenon of settling down of particles at the bottom of sedimentation tank.
- Sedimentation works on a simple principle: when water is kept still or allowed to flow very slowly for a certain duration, the suspended particles gradually settle at the bottom under the influence of gravity. These settled particles are referred to as *sludge*, while any materials that float to the surface are called *scum*—both of which can be removed easily.
- The tank or basin where this settling process occurs is known by various names such as a *sedimentation tank*, *settling basin*, or *clarifier*.

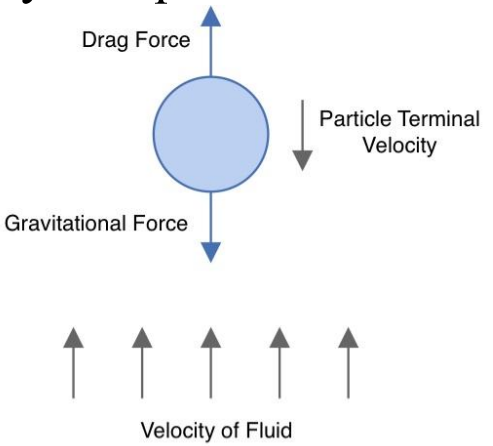
- The length of time, water is held in the tank for this process is known as the *retention time* or *detention period*.

Settling of particles in tank is affected by following factors:

- Velocity of flow of water
- Specific gravity of particles
- Size and shape of particles
- Surface overflow rate
- Detention period
- Viscosity of water
- Inlet and outlet arrangements
- Effective depth of settling zone

6.4.2.1 Derivation of Stoke's law

- A discrete particle maintains its shape, size, and weight while moving in a fluid. If its specific gravity is higher than the fluid, it sinks due to gravity. As it falls in still fluid, its speed increases until drag (frictional resistance) equals gravitational forces acting upon particle. Then, it moves at a constant rate called settling velocity, driven by its effective weight in the fluid.
- The impelling or driving force at the uniform velocity is equals to the effective weight of the particle in fluid.



Mathematically

$$F = (\rho_s\text{-}\rho)gV = \frac{\pi d^3}{6}(\rho_s\text{-}\rho)g \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where,

F = impelling or driving force;

ρ_s and ρ is mass density of particle and water respectively.

V = volume of spherical particles of diameter' d '

Again as per Newtons law or frictional resistance or drag, the force is given by;

$F_d = \frac{1}{2} C_d \rho A v^2$ 2

Where,

C_d = Drag coefficient depends upon Reynold's numbers' R '

A= Project area of the particle = $\frac{\pi d^2}{4}$ for spherical particle

At uniform settling velocity 'v' ; F = F_d. Then from considering equation 1 & 2

$\frac{\pi d^3}{6}(\rho_s - \rho)g = \frac{1}{2} C_d \rho A v^2$

Or $\frac{\pi d^3}{6}(\rho_s - \rho)g = C_d \frac{\pi d^2}{4} \frac{\rho v^2}{2}$

Or v = $\sqrt{\frac{4g\ d(\rho_s-\rho)}{3C_d\rho}}$ = $\sqrt{\frac{4g\ d(S-1)}{3C_d}}$ where S = specific gravity of particle

This is called Hazen's equation and applicable for particle diameter 'd' = 0.1 to 1 mm and Reynold's number 'R'_e = 1 to 1000.

The nature of settling is called transition settling

Here,

$C_d = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34$ and $R_e = \frac{\rho v d}{\mu}$ where μ = dynamics viscosity of water depends upon temperature = ρϑ ; ϑ = kinematic viscosity of water.

Hazen further indicated that for particles having diameter 'd' ≤ 0.1 mm and $R_e \leq 1$, Stoke's law is applicable. Mathematically

F_d = 3 π μ v d ……3

Now,

From equation 2 & 3;

$3\pi\mu vd = \frac{1}{2} C_d \rho A v^2$ and projected area $A = \frac{\pi d^2}{4}$ for spherical particle.

We get,

$3 \pi \mu v d = \frac{1}{2} C_d \rho A v^2$ or, $C_d = \frac{24}{\rho v d/\mu} = \frac{24}{R_e}$

Now putting this value in equation above we get,

$$V = \sqrt{\frac{4gd}{3\left(\frac{24}{R_e}\right)}(s-1)}$$

Or $V^2 = \frac{gd}{18} R_e (S-1)$

Or $V^2 = \frac{gd}{18} \frac{\rho V d}{\mu} (S-1)$

[$\therefore v = \frac{g}{18}\frac{d^2}{\vartheta}(S-1)$]

[1 centistokes= 1mm^2/sec]

This is Stoke's equation. Since kinematic viscosity 'ϑ' of water depends on temperature. Alternatively, if temperature' T' is introduced in place of ϑ, it can be expressed as,

$V = 418(S\text{-}1)d^2 \frac{3T+70}{100}$ mm/sec.

Where, d is diameter of particle in mm and T is temperature of water in °C

These equations are valid for d $\leqq$ 0.1 mm and $R_e \leqq 1$. In this range settling of particle is laminar so it is termed as laminar settling of particles.

If the nature of settling of particle is turbulent, (i.e. $1000 < R_e < 10000$) and 'd'> 1 mm' the value of $C_d \approxeq 0.4$, then Hazen's equation becomes.

$v^2 = \frac{4g(S-1)d}{3\ X\ 0.4}$ or v = $\sqrt{3.33gd(S-1)}$, this equation is called Newton's Equation.

6.4.2.2 Temperature effect on settlement

If temperature increase, decreases the kinematic viscosity of water and by relation increases the settling velocity of the particle's so Settling velocity is directly proportional to temperature and viscosity is inversely proportional to temperature.

Settling velocity can be expressed in terms of temperature as:

$$Vs = 418(S-1)d^2\left(\frac{3T+70}{100}\right)$$

Vs = settling velocity of particle in mm/s

d = diameter of particle in mm

T = temperature of water in Celsius

S = specific gravity of particle

6.4.3 Ideal sedimentation tank

An **ideal sedimentation tank** is designed to maintain uniform horizontal flow velocity throughout every vertical section of the settling zone, ensuring that the **horizontal velocity of water (V_h)** equals the **settling velocity of particles (V_s)**. This balance promotes efficient and predictable particle removal.

The tank is typically divided into **four functional zones**, each with a specific purpose:

1. **Inlet Zone**

   This section ensures that incoming water is **evenly distributed across the entire cross-sectional area** of the tank. It is carefully designed to **minimize turbulence**, so that the movement of settling particles remains undisturbed.

2. **Settling Zone**

   Also called the sedimentation or clarification zone, this is where the **actual settling of suspended solids** takes place.

Water flows in a **steady, uniform manner**, and particles are expected to settle **vertically** while being **evenly spread across the width and depth** of the tank.

3. **Sludge Zone**

   Located at the bottom of the tank, this area is meant for the **accumulation and storage of settled solids**. It's assumed that all particles reaching this zone are successfully removed from the flow.

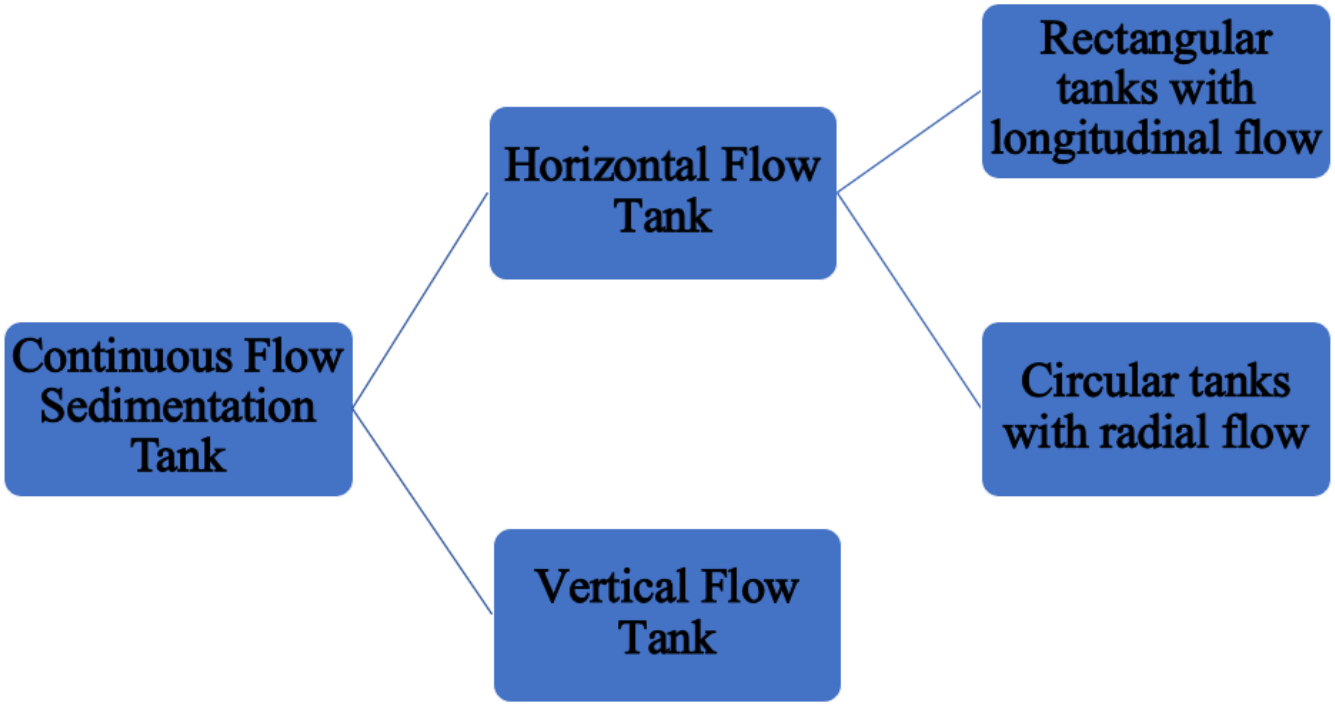
4. **Outlet Zone**

   This part of the tank is designed to **collect the clarified (clean) water** and allow it to exit through outlet channels.

   Any remaining unsettled particles near the surface are also removed at this stage.

(Kansakar, 2015)

6.4.4 Types of sedimentation tank



6.4.5 Design of sedimentation tank

1. Flow velocity

- The velocity of flow of water in sedimentation tanks should be sufficient enough to cause hydraulic subsidence of suspended impurities.
- It should remain uniform throughout the tank and it is generally =20 cm/min to 40 cm/min. Generally, 30cm/min.
- it is essential that when once the particle has settled and reached the sludge zone, it should not be scoured or lifted up by the velocity of flow of water over the bed.
- Camp has given the following expression for the displacement velocity (non scouring)
- $V=\sqrt{\frac{8\beta g(s-1)d}{f}}$

- where, β = 0.04 for unigranular sand ; and 0.06 or more for non- uniform

(interlocking) sticky materials

f = Weishbach- Darcy friction factor = 0.025 to 0.03 for setting tanks

2. Detention Period

- Detention time is the theoretical time taken by a particle of water to pass between entry and exit of a settling tank.
- If V = volume of the basin, Q = discharge rate and t_0 is the detention period, we have

$$t_0 = \frac{V}{Q} = \frac{LBH}{Q}$$

- The value of detention period depends upon the type of suspended impurities in water, and vary from 4 to 8 hours.

3. *Flowing through Period*

- It is the average time required for a batch of water to pass through the settling tank
- Theoretically, flowing through period= detention time but It is always less than the detention period due to short circuit effects.
- How close this will approximate the detention period will depend upon the design of the tank
- The flowing through period of an existing tank can be determined by placing sodium chloride in the influent and testing for the chloride content of the effluent.

4. *Surface overflow rate*

- The quantity of water passing per unit (or per day) per unit horizontal area is known as the overflow rate or surface loading or hydraulic loading and expressed in terms of m3/m2/day.

- The increase in surface area of a sedimentation tank will increase in the settling or removal efficiency of the tank.
- The settling of particles indicates that all the particle having settling velocity Vs equal or grater than SOR will be settle or removed.
- Commonly adopted value of SOR for plain sedimentation tank is 15 to 30 m3/m2/day.

➢ ***Tank Dimension***

➢ The surface area of the basin is determined on the basis of the overflow rate or surface loading rate.

$$A = \frac{Volume\ of\ water\ in\ liters\ hour}{Surface\ loading\ rate\ in\ litres\ per\ hour/m2}$$

- The $\frac{length}{width}$ =3:1 to 5:1. The depth of basin is kept between 2.5 to 4 m, (preferred 3 m), inclusive of the allowance for sludge storage
- The cross-section area is such as to provide a horizontal velocity of flow 20 to 40 cm per min, and normally above 30 cm per minute.
- Bottom slopes may range from 1 % in rectangular tanks to about 8 % in circular tanks.
- The slopes of sludge hoppers range from 1.2: 1 to 2 :1 (vertical horizontal

6. Inlet and outlet structure

- Inlets shall be designed to distribute the water equally and at uniform velocities.
- A baffle should be constructed across the basin close to the inlet and should project several feet below the water surface to dissipate inlet velocities and provide uniform flow.

- Outlet weirs or submerged orifices shall be designed to maintain velocities suitable for settling in the basin and to minimize short-circuiting.

7. Sludge Zone:

- The zone in the bottom of the tank in which sludge is retained before being removed is called sludge zone.
- The depth of the sludge zone depends upon the quantity of sediments in the raw water and the de-sludging period.
- Depth of sludge zone is taken as 0.5 to 1.0 m

(Kansakar, 2015)

Design Criteria of Sedimentation Tank/Design Details

- **Detention Period**: For plain sedimentation: 4 to 8 hours, and for coagulate sedimentation: 1 to 4 hours
- **Velocity of Flow**: Not greater than 30 cm/min (horizontal flow) (generally 15 – 30 cm/min)
- **Tank Dimensions:** L:B = 3 to 5:1. Generally L = 30 m (common); maximum 100 m. Breadth = 6 to 10 m.
- Circular: Diameter not greater than 60 m. Generally, 20 to 40 m.
- **Effective depth** 2.5 to 4.0 m (3 m).
- **SOR**: For plain sedimentation: 15 to 30 m3/d/m2 tank area; for thoroughly flocculated water: 30 to 40 m3/d/m2 tank area.

6.4.6 Numerical on theory and design of sedimentation tank

Q. Compute the dimensions of continuous flow sedimentation tank for a population of 30000 person with a daily per capita demand of 100litre. Assume detention period to be 6 hours.

Here,

Flow, Q =30000*100 =3000000 l/d =3000m^3 /d =125m^3 /hr

Detention period, t= 6 hr

Capacity, C= Q*t =125*6 =750 m^3

Assume Surface Overflow Rate, SOR = 15 m^3 /m^2 /d

The SOR should be 15-30 m^3 /m^2 /d.

Surface area, $A_s = \frac{Q}{SOR} = \frac{30000}{15}$ =200 m^2

Depth, $H = \frac{C(vol)}{As} = \frac{750}{200} = 3.75$ m

Assume $\frac{L}{B} = 4$. (The $\frac{L}{B}$ ratio should be 3 – 5.)

$A_s = L*B = 4B*B = 4B^2 = 200$ m

$B = \sqrt{\frac{200}{4}} = 7.07$ m, say 7.10 m.

Length, $L = 4B = 4*7.1 = 28.4$ m.

Assume free board = 0.5 m. Free board should be 0.5 – 1.0 m.

Assume sludge depth = 0.75 m. Sludge depth should be 0.5 – 1.0 m.

Total depth = 3.75+0.5+0.75 = 5.0 m

Provide sedimentation tank of overall dimension

28.4m*7.1m*5.0m

Works Cited

1.Dr. B.C Punmia, Er.Ashok Kumar Jain, Dr. Arun K.Jain. (2013). *Water Supply Engineering.* New Delhi: Laxmi Publications (P) LTD.

2.Kansakar, D. B. (2015). *water supply engineering.* kathmandu: Prakash Man Shakya.

Thank You!!!