

Water Supply Engineering

Chapter 6

Water Treatment

Lecture 9 (Week 9)

Sedimentation with coagulation and its Purpose, Coagulants, Mixing devices (purpose and types), Flocculation tanks, Clarifier, Jar test, Filtration, Purpose, Theory of filtration, Types of filters, Numerical on dimensions and units of filters

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Learning Objectives:

- State the purpose of sedimentation with coagulation.
- Identify common coagulants used in water treatment.
- Explain the purpose and types of mixing devices.
- Perform a jar test to determine coagulant dose.
- purpose of filtration and theory of filtration in water treatment.
- Classify the types of filters used.

6.5 Sedimentation with Coagulation

- Sedimentation with coagulation involves adding specific chemicals known as **coagulants** into the water. These chemicals are mixed thoroughly to encourage the formation of **flocs**—which are sticky, gelatinous, and insoluble clumps.
- This method is particularly effective where **plain sedimentation falls short**, especially when the raw water contains very **fine particles like clay, silt, or light colloidal impurities** that do not settle easily within the normal detention time.
- The flocs that form carry a **positive electrical charge**, which helps them **attract and capture the negatively charged suspended particles**. As these flocs become heavier by trapping more impurities, they settle down to the bottom of the tank.

- Using this process significantly **reduces the turbidity** of the water—typically bringing it down to about **5 to 10 ppm**. Additionally, it helps reduce the burden on filtration systems and can **remove up to 65% of bacteria**, including **about 70% of b-coli organisms**.

6.5.1 Purpose of sedimentation with coagulation

To remove fine suspended and colloidal particles from water that cannot settle naturally, by adding coagulants that cause them to clump together into larger particles (flocs), which then settle more easily during sedimentation.

In essence: It enhances the efficiency of sedimentation by helping tiny particles combine and settle faster.

6.5.2 Coagulants (types and their chemical reactions)

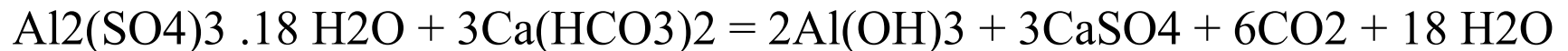
1) Aluminum sulphate(or alum)

➤ $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ called **alum** or **filter alum**, is most widely used

➤ To flocculate, to which the water added shall be **alkaline**

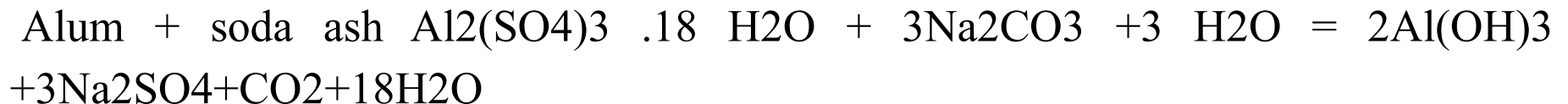
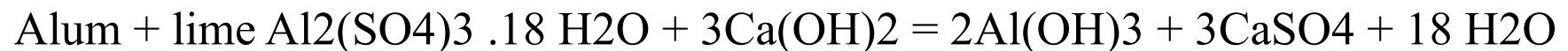
➤ Dosage depend on turbidity and colour and vary from 5 to 30mg/L

➤ **Bicarbonate alkalinity** generally present which gives **insoluble $\text{Al}(\text{OH})_3$** as floc.



➤ Effective pH range **6.5-8.5**

➤ In case little or no alkalinity, lime or soda ash used as



- Forms excellent and strong floc, relatively cheap and easily available in market.
- Only suitable for ph range 6.5 to 8.5, dewater the heavy sludge is major problem.

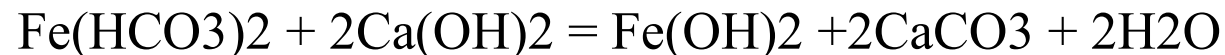
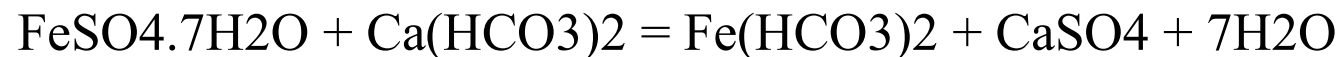
2)Iron Salt

The various iron salts which are used as coagulants are:

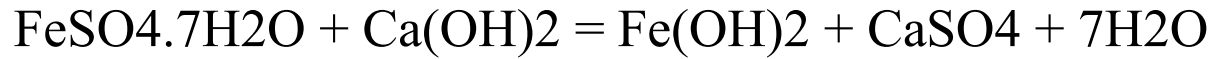
(a) Ferrous sulphate (FeSO₄.7H₂O)

- Also known as copperas and is used as coagulant in coagulation with lime
- Chemical reaction depends upon the order in which chemicals are added to water

(i) When ferrous sulphate is added first



(ii) When lime is added first

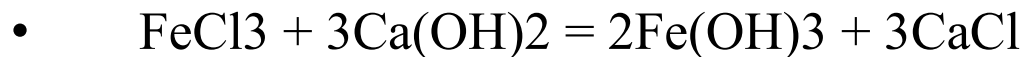


- Finally, $\text{Fe}(\text{OH})_2$ is oxidized to $\text{Fe}(\text{OH})_3$ by dissolved oxygen Floc is gelatinous and effective pH range is 8.5 and above

b) Ferric Chloride (FeCl_3)

- Used with or without lime

- When used with lime, the reaction involved is:



- When used without lime, the reaction involved is:

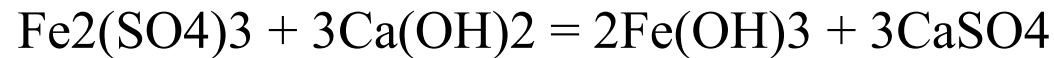


- $\text{Fe}(\text{OH})_3$ formed behave as gelatinous floc

- Effective pH range 3.5 to 6.5.
- Effective in removal of H₂S as well as taste and odour.

(c) Ferric sulphate [Fe₂(SO₄)₃]

- Used in conjunction with lime
- The chemical reaction involved is:



- Fe(OH)₃ formed behave as gelatinous floc
- Effective pH range 4 to 7 and above 9

3.Chlorinated Coppers

- Mixture of ferric chloride and ferric sulphate.

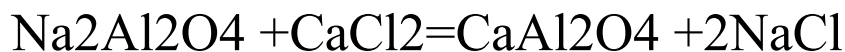
- Prepared by adding chlorine to a solution of ferric sulphate in ratio 1 part of chlorine to 7.8 part of ferrous sulphate.

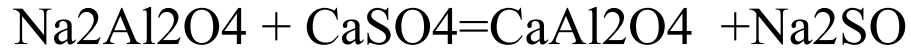


- Forms tough floc which helps in sedimentation.
- Very good coagulant, requires less amount of alkalinity.
- Effective working range of pH 3.5-6.5 and above 8.5

4) Sodium aluminate

- Reacts with salts of calcium and magnesium to form calcium and magnesium aluminate.
- Chemical reaction :





➤ Effective pH range 6-8

- Removes temporary and permanent hardness but very costly and not used in public supply but used to treat boiler water

6.5.3 Mixing devices

- After the addition of coagulants to raw water, they are thoroughly and vigorously mixed so that the coagulants get fully dispersed into the entire mass of water.
- Various mixing devices are as follows but the first two types are common:
 - i. Mixing basin with baffle walls
 - ii. Mixing basin with mechanical means
 - iii. Mixing channels

- iv. Compressed air method
- v. Hydraulic jump method
- vi. Centrifugal pumping method

I. Mixing Basins with Baffle Walls

- Rectangular basins or tanks provided with baffle walls
- Hindrance and disturbance are created by baffles walls causes vigorous agitation of water.
- Results ,Finally through mixing of water with coagulants.
- Baffles walls are placed 60-100 cm apart and velocity is kept 15-30 cm/sec.
- Detention period 20-50 minutes

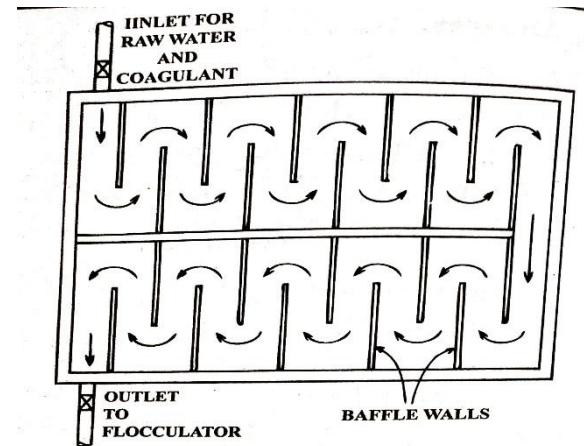
- Clear opening between the end of each baffle and basin wall (roof or floor) be 1.5 times distance between successive walls, minimum value of 0.675 m

Two types:

- a) Horizontal or round the end type
- b) Vertical or over and under type

Horizontal or round end type

- Water with coagulant enter the basin through inlet at one end and mixture moves horizontally for short distance. Due to the presence of baffle wall, it takes a turn and move further with mixing and finally flows out through the other end



*Figure 1: Round the end type mixing basins
Source: (Kansakar, 2015)*

b. Vertical or over and under type

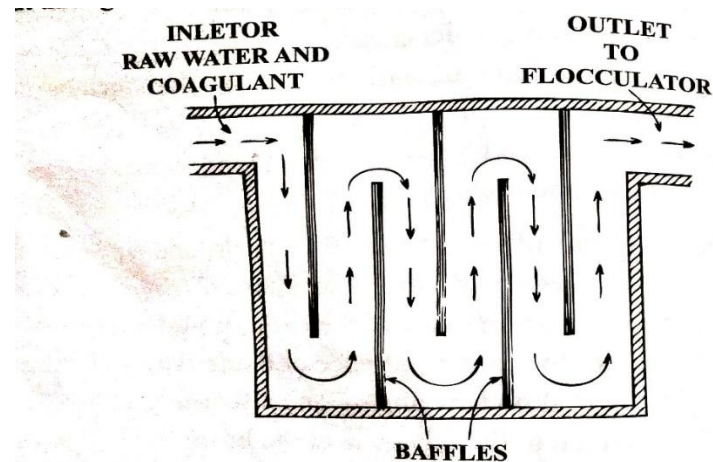


Figure 2: Over and under type mixing basins((Kansakar, 2015)

ii. **Mixing Basins with Mechanically Mean(Flash mixer)**

- Coagulant reach through chemical pipes.
- Flash mixer = mixing basin + mechanically driven impeller or paddle

- Rotating fan mixes coagulants with water which finally goes out from outlet.
- High head loss and variation in velocity occurs in basin.
- Ratio of tank height to diameter ratio is 1:1 to 3:1
- Detention period 0.5 -1 minute

iii. **Mixing channel**

- Narrow mixing channel with vertical baffles projecting in inclined position from both sides of channel.
- Violent agitation.(shakeup, mix)
- Flume if present develops hydraulic jump causing turbulence and measure flow.

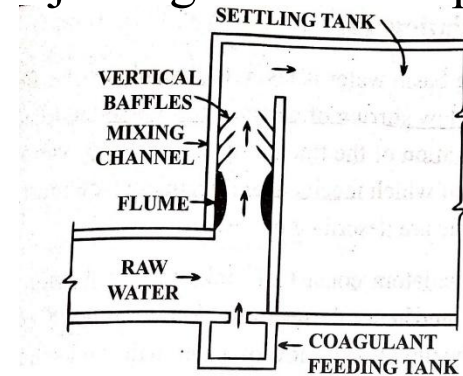


Figure 3: Mixing Channel (Kansakar, 2015)

iv. **Hydraulic Jump Method**

- Utilizes a **flume with a steep slope** where water flows rapidly.
- The sudden change in flow velocity creates a **hydraulic jump**, generating intense turbulence.
- This turbulence effectively mixes the coagulant with water.

v. **Compressed Air Mixing**

- A **constant stream of water pre-dosed with coagulant** is introduced into a mixing basin.
- **Compressed air** is injected from the bottom, and the rising air bubbles induce **vigorous mixing** throughout the basin.
- This method is especially useful when mechanical agitators are not desired.

vi. Centrifugal Pump Mixing

- **Coagulant is introduced into the suction line** of a centrifugal pump.
- As water passes through the **impeller of the pump**, it undergoes thorough agitation.
- This method combines the **pumping and mixing** functions, making it space- and energy-efficient.

6.5.4 Flocculation tanks

Flocculation

- After mixing with coagulants in the mixing basin, water is directed to the **flocculation unit**, where gentle stirring helps the smaller particles combine into larger, settleable flocs.

- The flocculation process involves **slow and uniform agitation**, allowing flocs to grow without breaking apart. Among various types, **mechanical flocculators** are the most widely used due to their efficiency and control.
- These systems typically include a **tank equipped with rotating paddles**, which continuously stir the water. Because of this paddle-based mechanism, they are often referred to as **paddle flocculators**.
- Depending on the **flow pattern** of water, mechanical flocculators are categorized into two main types:

Longitudinal Flow Flocculator:

Features a **rectangular tank** where paddles rotate along a **horizontal shaft**, guiding water in a straight path.

- **Vertical Flow Flocculator:**

- Involves a **circular tank** with paddles mounted on a **vertical shaft**, promoting an upward or downward flow pattern.

These designs are chosen based on space, hydraulic requirements, and operational preferences.

Design Criteria of Flocculators

- Depth of tank 2-4.5 m
- Detention period 10-40 minutes
- Velocity of flow 0.2-0.8 m/min.
- Total area of paddle 10-25% of cross-sectional area of tank
- Outlet flow velocity to outlet channel 0.1-0.25 m/s

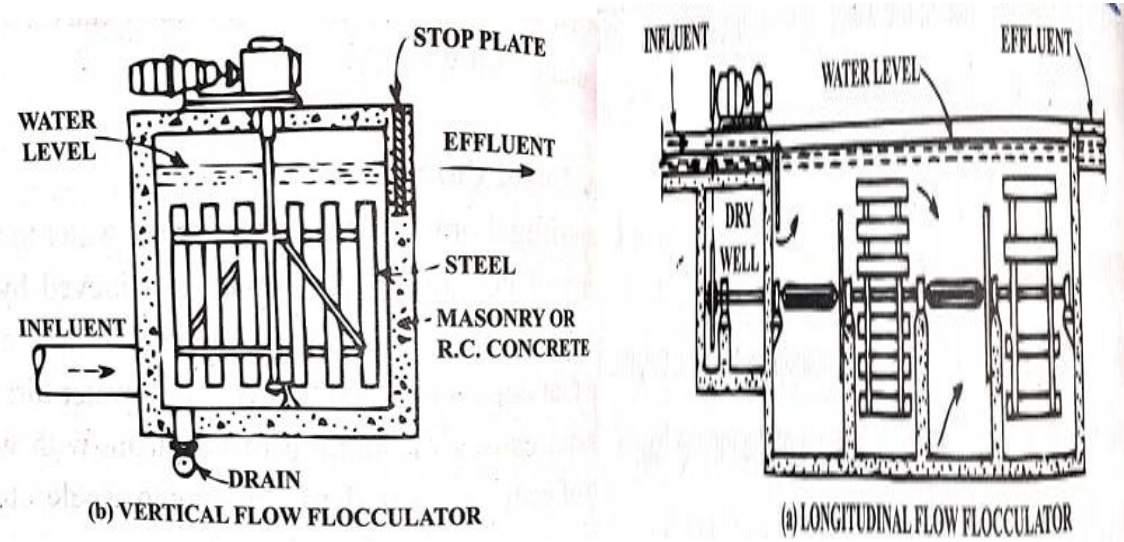


Figure 4: Flocculator (Kansakar, 2015)

6.5.5 Clarifier

- Water from flocculators is taken to clarifier after flocculation.
- The primary objective of the clarifier is to allow these suspended flocs to settle by gravity and produce clear water at the top, ready for further treatment or filtration.
- In the clarifier, water is retained long enough to allow the suspended solids to settle down to the bottom of the tank. This is achieved by maintaining a specific detention time, typically ranging from 2 to 2.5 hours, which ensures sufficient contact time for sedimentation to occur effectively.
- The performance of a clarifier is often evaluated using the surface overflow rate (SOR), which is the flow of water per unit surface area of the tank. For effective clarification, the surface overflow rate is usually maintained between 30 to 40 cubic meters per day per square meter ($\text{m}^3/\text{day}/\text{m}^2$).

- The settled sludge at the bottom of the tank is periodically removed, and the clarified water from the top is collected through weirs for further purification steps



Figure 5: Clarifier source: (www.monroeenvironmental.com/water-and-wastewater-treatment/circular-clarifiers-and-thickeners/, n.d.)

6.5.6 Jar test

- The jar test is a standard laboratory method used to identify the most effective treatment conditions for water or wastewater, especially for coagulation and flocculation processes.
- It involves a mechanical setup known as a **multiple stirrer**, which includes a series of rods and paddles attached to a rotating device.

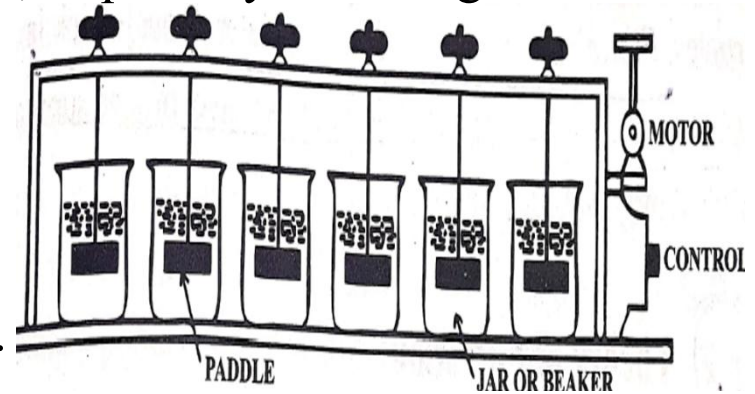


Figure 6: Jar Test Apparatus(Source: (Kansakar, 2015)

- The main objective of this test is to determine the appropriate amount of coagulant required to produce well-formed flocs that can settle efficiently.

- The **optimum coagulant dose** is the amount at which the water reaches its **lowest turbidity**, indicating the best possible clarification.
- The apparatus typically consists of **six stirring paddles**, each immersed in a **1-liter beaker**. One beaker usually serves as a control, while different dosages or treatment conditions are tested in the remaining five.
- A speed regulator or **RPM gauge** ensures that all containers are mixed at the same rate, maintaining consistent agitation throughout the test.

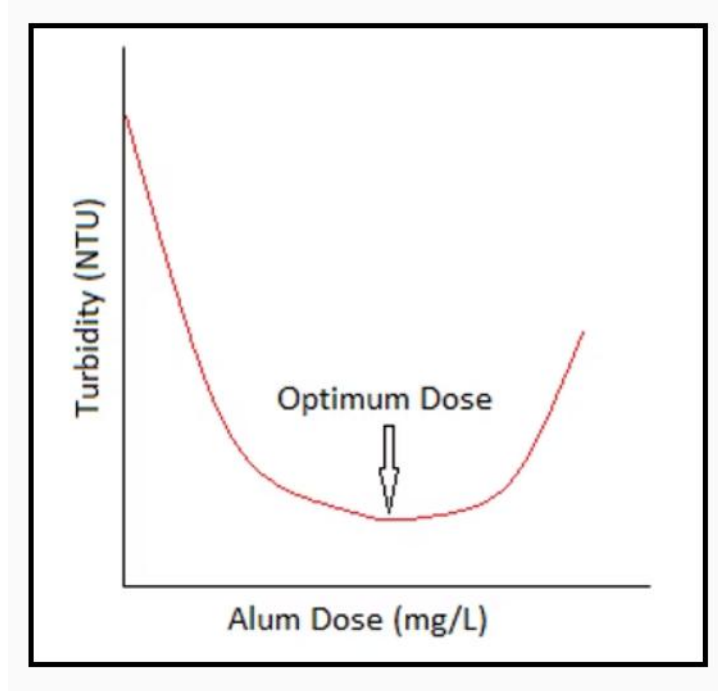


Figure 7: Residual Turbidity Vs Coagulant Dose
(www.filtsol.com/jar-test, 2020)

6.6 Filtration

Filtration is a key step in water treatment where water is made to pass through layers of porous materials—usually a **bed of sand** placed over a **layer of gravel**. This helps in removing impurities that couldn't be fully eliminated during sedimentation or coagulation, such as **fine suspended particles** and **flocs**.

6.6.1 Purpose

To remove remaining suspended impurities, flocs, and microorganisms from water after sedimentation, ensuring clearer and safer water for consumption.

In essence: It provides final polishing and disinfection support in the water treatment process.

6.6.2 Theory of filtration

Filtration works through several mechanisms. The major ones include:

- a. **Mechanical Straining:** This is a physical process where **particles larger than the spaces (pores)** in the filter medium get trapped and held back. It effectively removes larger suspended solids but is **not effective for very fine particles**, such as **colloids or bacteria**, which are much smaller than the pore size.
- b. **Sedimentation and Adsorption:**
 - o Some particles settle within the filter medium due to gravity.
 - o More importantly, adsorption plays a major role: tiny suspended and colloidal particles stick to the surface of sand grains due to intermolecular forces. A thin film of water around each grain helps attract and hold these impurities, including dissolved inorganic substances.

c. **Biological Action** – The adsorbed bacteria utilize organic impurities such as algae, plankton etc. present in water and convert them into harmless compounds by the complex biochemical reactions.

d. **Electrolytic action**

When particles of suspended and dissolved matter having electricity of opposite polarity come in contact with sand grains, they neutralize each other and it results in changing the chemical characteristics of water.

Together, these processes enhance the clarity and quality of water by capturing the impurities that earlier processes may have missed.

6.6.3 Types of filters

On the basis of the filtration rate and the driving force to overcome the frictional resistance encountered by the water flowing through filter, the filters are classified as

- Slow sand filters (gravity type)
- Rapid sand filters (gravity type)
- Pressure filters

6.6.3.1 Slow sand filter

Components of Slow Sand Filter

SSF consists of following:

Enclosure tank

- Rectangle tank of stone, brick and concrete.

1. Slow sand filter (SSF)

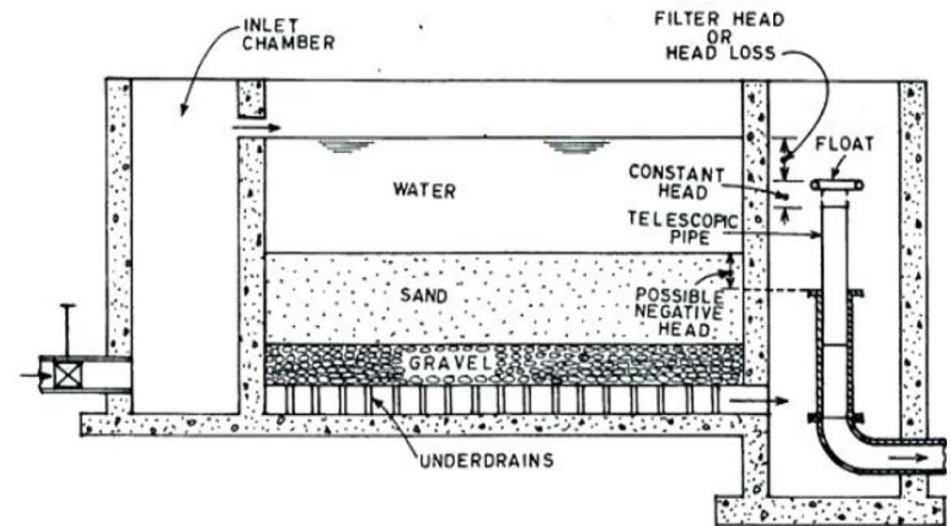


Figure 8: Slow sand filter (Kansakar, 2015)

- Depth: 2.5-4m Area: 50-1000sq.m

Filtration rate: 100-200lit/hour/sq.m

Filter media

- Sand layer: 90-100cm thick with 0.25-0.35mm sand size.
- Cu: 3-5 (d60/d10) (Cu smaller=uniform gradation)
- Finer the sand more the efficiency of filtration.
- Sand shouldn't contain more than 2% of Ca and Mg as carbonate.

Base media

- Gravel bed
- of 30-75 cm thick to support filter media.
- This bed is laid in layers 15 cm thickness.

Under drainage system

- It collects the filtered water and delivers it to the clean water reservoir.
- It consists of central drain and lateral drains.
- Lateral drains are placed at a distance of 2 to 3m
- Lateral drains may consist of earthenware pipe or perforated pipes of 7.5 to 10 cm diameter laid with open joints or patented drain devices.
- depth for Underdrain = 0.2m

Appurtenance

For effective working vertical air pipes, depth controlling

Devices, head loss measuring device, flow regulator, etc. are installed.

Working of a Slow Sand Filter

A slow sand filter removes impurities from water through a combination of sedimentation, straining, adsorption, and biological and chemical actions.

In the initial few days of operation, the purification of water is primarily achieved through mechanical and physico-chemical processes. As the filter matures, biological activity becomes the dominant mechanism for purification.

Operational Process

1. Inlet of Water

Water coming from sedimentation tanks is allowed to enter the slow sand filter. It is distributed evenly over the sand bed to prevent any disturbance to the filter media.

2. Filtration Rate

The water passes through the sand bed at a slow and consistent rate of 100 to 200 liters per square meter per hour (lit/m²/hr).

3. Filter Head Development

Initially, the water experiences a small resistance with a filter head of only 10 to 15 cm.

As filtration continues, impurities clog the pores in the sand, increasing resistance to flow and thus the loss of head.

Filtration continues until the head loss reaches a maximum of 75 cm or until 60 to 85% of the sand bed thickness is involved in filtration.

4. Clogging and Termination

- With time, the filter media gets clogged due to the accumulation of impurities. As a result, the loss of head increases.

- When the loss of head reaches its permissible limit, the filter is taken out of service for cleaning or maintenance

Cleaning of slow sand filter

- ❖ First drain the tank and Scrap the top layer (15-30mm)
- ❖ Wash scraped sand and store for future use
- ❖ Fill filter with water from below to avoid to prevent air entrap
- ❖ Keep stand for 12 hrs. and run with $\frac{1}{5}$ normal for 12 hours to help formation of biological layer.
- ❖ During this period the filtered water is diverted to the wash water drain and it is not taken into use.
- ❖ Thereafter the filtered water is diverted to the clear water storage tanks, but the rate of filtration is kept $\frac{1}{3}$ of the normal rate for another 3 to 4 days.

- ❖ The slow sand filter requires cleaning after one to three months depending upon the impurities present in the raw water

6.6.3.2 Rapid sand filter

- The rapid sand filter or rapid gravity filter is a type of filter used in water purification and is commonly used in municipal drinking water facilities as part of a multiple-stage treatment system.
- Raw water is fed to filters only after it has been treated through sedimentation with coagulation.
- It uses relatively coarse sand and other granular media to remove particles and impurities.
- The parts of rapid sand filter are:
 - ❖ Enclosure tank

- ❖ Filter media
- ❖ Base material
- ❖ Under drainage system
- ❖ Appurtenances

(i) Enclosure tank

- It is an open watertight rectangular tank constructed of stone or brick masonry concrete.
- The depth of the tank is about 2.5 to 3.5 m and surface area may vary from 10 to 50 m².
- Depending on the total surface area of filter required a number of small filter units are provided in series.

- The length to width ratio of tank is normally kept 1.25 to 1.35.
- The rate of filtration varies from 3000 to 6000 liters/hr/m².

(ii) Filter media

- It consists of sand layer 60 to 75 cm thick.
- The effective size of sand varies from 0.45 to 0.70 mm.
- The uniformity coefficient C_u of sand varies from 1.3 to 1.7 common being 1.5.
- Due to higher value of effective size and lower value of uniformity coefficient the void space in the filter media is increased which results in higher rate of filtration.

(iii) Base material

- The sand layer is supported on base material which consists of 45 to 60 cm thick gravel bed.
- The gravel bed is graded and laid in layers.

(iv) Under drainage system

- In rapid sand filters the under drainage system serves two purposes:
 - a) It collects the filtered water uniformly over the area of gravel bed.
 - b) It provides uniform distribution of backwash water without disturbing or upsetting the gravel bed and filter media.
- Commonly adopted under water drainage:
 - a) Perforated pipe system
 - b) Pipe and strainer system

(v) Appurtenances

- The important appurtenances provided with rapid sand filter are as follows:
 - a) Wash Water troughs

b) Air compressor

- During back washing if compressed air is used, an air compressor should be installed.
- It should have the capacity to supply compressed air at the rate of 0.60 to 0.80 m³ per minute per m² of the filter area in 5 minutes.

c) Rate control device

d) The various accessories such as head loss indicators, meters for measuring the flow rates are also provided.

- **Back washing**

- When maximum allowable head loss of 2.5 to 3 m is reached backwashing is required.
- It is done to remove trapped materials

and restore filter sand.

- Filtered water is used
- Not exceeding 2-3% of treated water
- Should be done for 10 mins at 600 lit/min/m²
- Should be done in 1 to 3 days for 10-15 mins as rapid sand filters get clogged faster

Efficiency of Rapid sand filter

Bacterial load

- less efficient in the removal of bacterial load.
- Remove about 80 to 90% of bacterial load

Turbidity

- Can remove turbidity to the extent of 35 to 40 ppm.
- Water should be pretreated in coagulation sedimentation tank

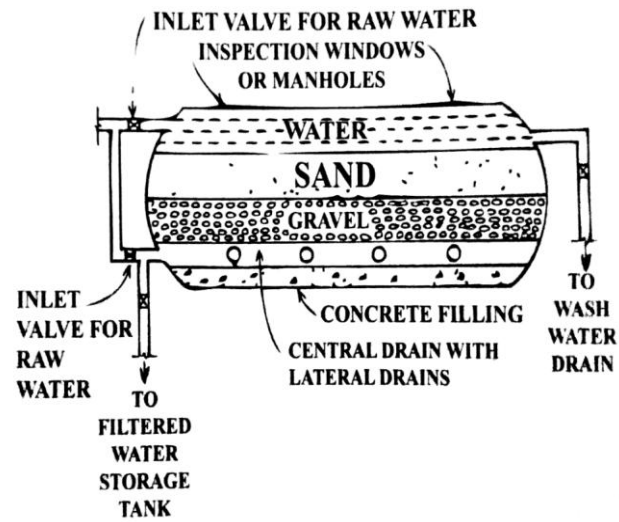
Color

- The intensity of color can be brought down below 3 on cobalt scale

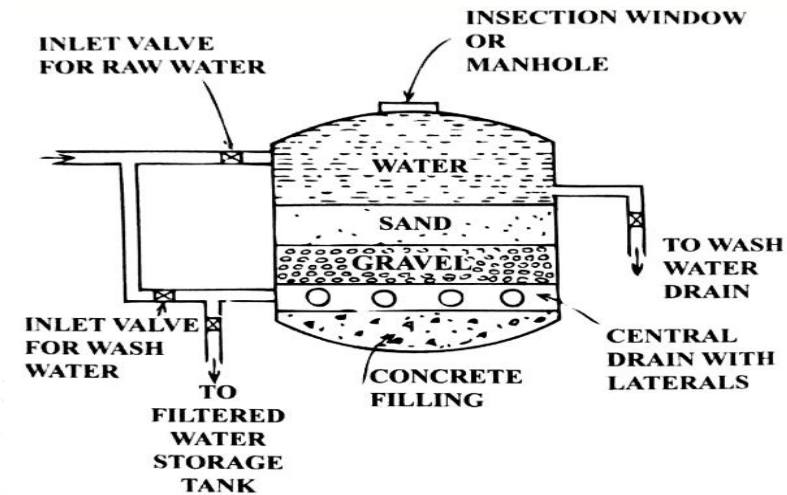
6.6.3.3 Pressure filter

- These are types of rapid sand filters in closed cylindrical tanks through which water to be treated is passes under pressure of 0.3 to 0.7 N/m²
- Diameter : 1.5 – 3m
- Length or Height: 3.5 – 8 m
- Difference in operation of rapid sand & pressure filter is: Coagulated raw material is fed directly to filters without mixing, flocculation and sedimentation in case of pressure filters
- Convenient for small schemes like swimming pool and colonies
- Not suitable for public supply scheme due to less efficiency
- Less efficient in terms of bacterial removal, color and turbidity removal

- Higher rate of filtration than rapid sand filters. 6000-15000 liters/hr/m² of filter area



(a) PRESSURE FILTER - HORIZONTAL TYPE



(b) PRESSURE FILTER - VERTICAL TYPE

(Kansakar, 2015)

6.6.4 Numerical on dimensions and units of filters

Q.1. Average water consumption rate is 150 lpcd in an urban area. Design a slow sand filter having a population of 10000 at the base year 2068.

Solution:

Base year=2068

Population at the base year , $P=10000$

Per capita demand of water=150 lpcd

Assume design period =15 years

Annual population growth rate , $r=1.5\%$

Design year=Base year + Design period = 2068 +15 =2083

Population in 2083 ,

$P_{2083} = P(1+ r/100)^{15}$

$$=10000(1+1.5/100)15=12502$$

Water demand in design year ,

$Q = \text{Population} \times \text{per capita demand}$

$$=12502 \times 150 = 1875300 \text{ liters/day} = 78137.50 \text{ liters/hr}$$

Assume filtration rate = 150 liters/hr/m² .

Filtration rate should be 100-200 liters/hr/m²

Surface area, $A_s = (Q/\text{filtration rate}) = (78137.50/150) = 520.92 \text{ m}^2$

Provide 3 units of slow sand filters including one stand by unit.

Surface area of each unit , $A_s = 520.92 / 2 = 260.46 \text{ m}^2$

Assume $L/b = 2$

$$A_s = L \times B = 2B \times B = 260.46 \text{ m}^2$$

$$B = \sqrt{(260.46/2)} = 11.41 \text{ m} , \text{ say } 11.50 \text{ m}$$

$$L = 2B = 2 \times 11.50 = 23.0 \text{ m}$$

Provide depth as follows

$$\text{Free board} = 0.5 \text{ m}$$

$$\text{Water depth} = 1.0 \text{ m (1-1.1 m)}$$

$$\text{Sand depth} = 1.0 \text{ m}$$

$$\text{Gravel depth} = 0.6 \text{ m (0.5-0.6)}$$

$$\text{Depth for under drain pipe} = 0.2 \text{ m}$$

$$\text{Total depth} = 3.3 \text{ m}$$

Provide 3 nos of slow sand filters of 23.0 m x 11.5 m x 3.3 m

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Thank You!!!