

# CHAPTER-FOUR

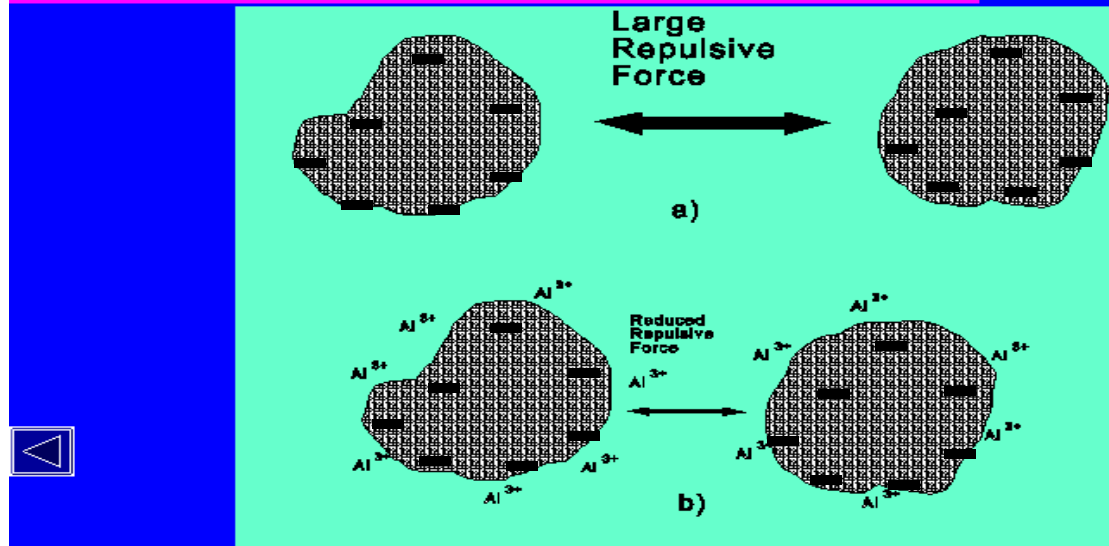
## Coagulation and Flocculation in Water Treatment



# What is Coagulation?

- ❑ Coagulation is the destabilization of colloids by addition of
  - chemicals that neutralize the negative charges
- ❑ The chemicals are known as coagulants, usually higher valence cationic salts ( $\text{Al}^{3+}$ ,  $\text{Fe}^{3+}$  etc.)
- ❑ Coagulation is essentially a chemical process

## Charge neutralization



## Purpose of process

- ✓ *process is the removal of turbidity from the water*
- ✓ *Turbidity is a cloudy appearance of water caused by small particles suspended therein.*
- ✓ *Water with little or no turbidity will be clear*



No Turbidity



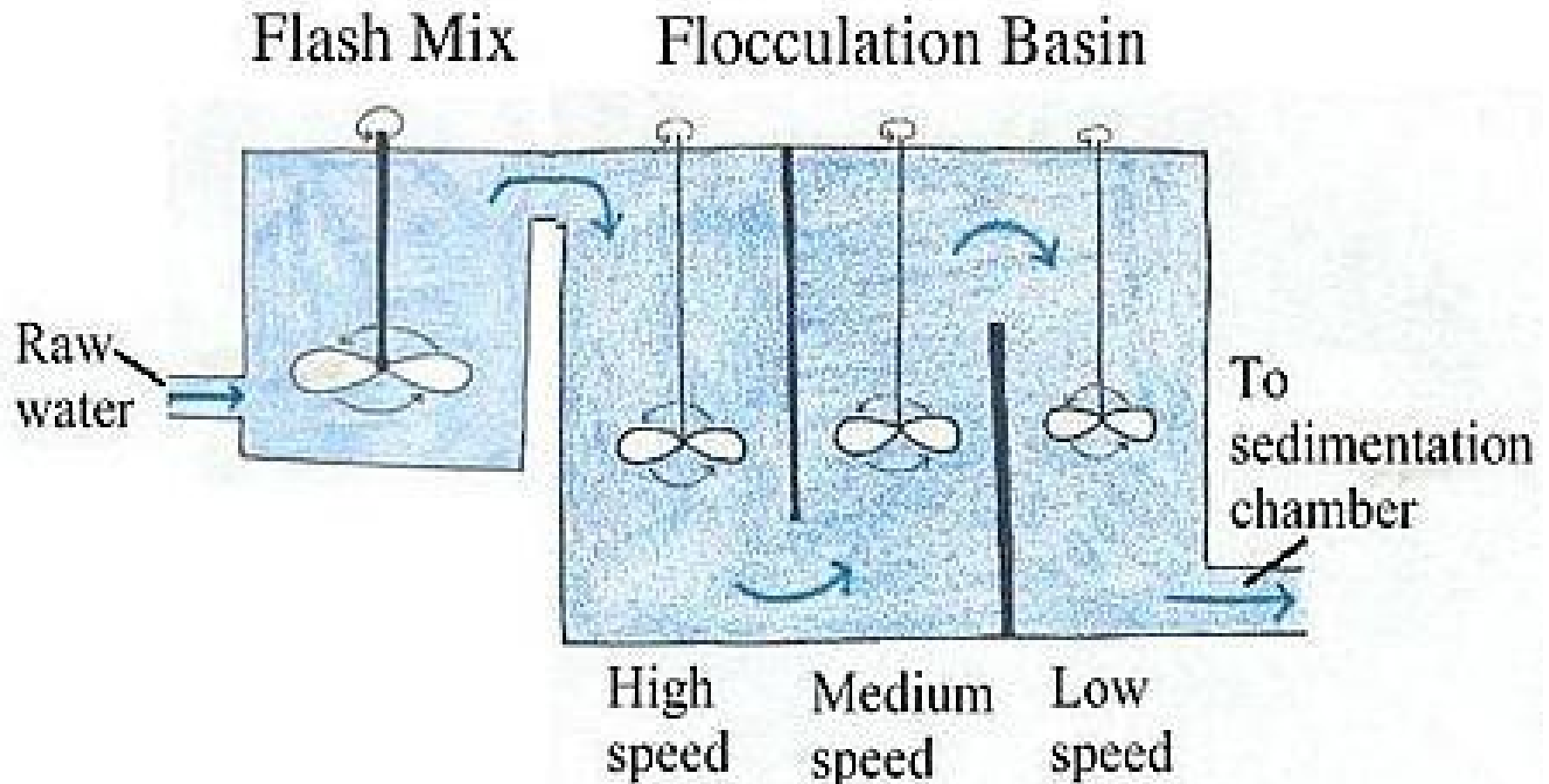
80 NTU

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# ***LOCATION IN THE TREATMENT PLANT***

- ✓ After the source water has been screened and has passed through the optional steps of pre-chlorination and aeration, it is ready for coagulation and
- ✓ ~~in practice~~ in the treatment plant, flocculation. there are only two steps in the coagulation/flocculation process - the water first flows into the flash mix chamber, and then enters the flocculation basin.



## ***Flash Mixer and Flocculation Basin***

**Aeration**

**Chemical  
mixing and  
Coagulation**

**Flocculation  
and  
Sedimentation**

**Filtration**



# ***Principle of coagulation***

- ✓ ***The principle of coagulation can be explained from the following two conditions:***

## ***I. FLOC FORMATION***

- ✓ ***When coagulants (chemicals) are dissolved in water and thoroughly mixed with it, they produce a thin gelatinous precipitate.***
- ✓ ***This precipitate is known as floc and this floc has got the property of arresting suspended impurities in water during downward travel towards the bottom of tank .***

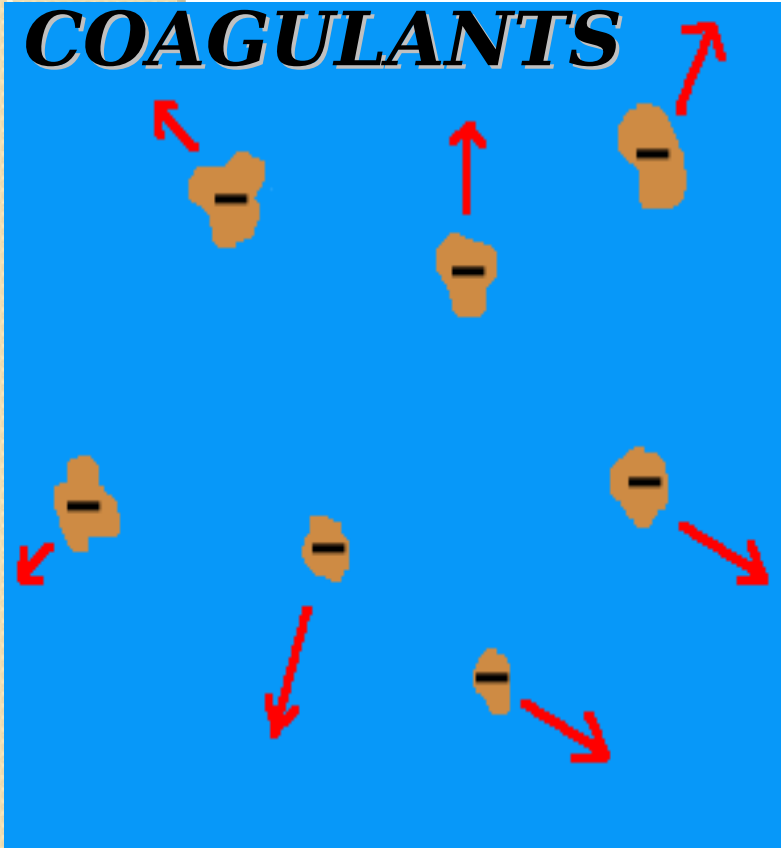
## ***II. ELECTRIC CHARGES***

- ✓ ***Most particles dissolved in water have a negative charge, so they tend to repel each other. As a result, they stay dispersed and dissolved or colloidal in the water.***
- ✓ ***Coagulants tend to be positively charged. Due to their positive charge, they are attracted to the negative particles in the water***
- ✓ ***The combination of positive and negative charge results in a neutral. As a result, the particles no longer repel each other.***

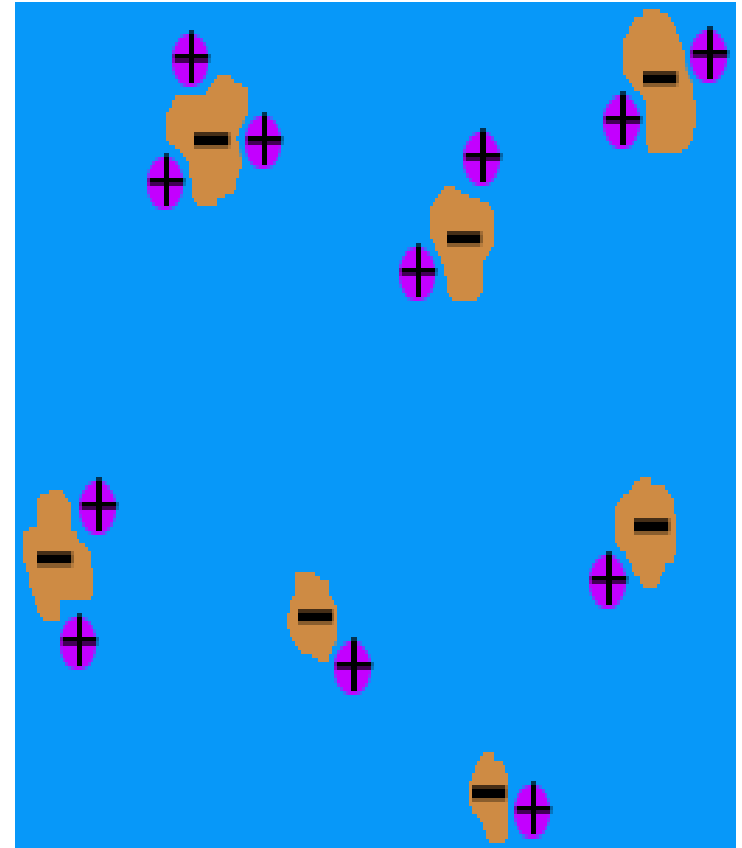
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# ***NEGATIVELY CHARGED PARTICLE AND POSITIVELY CHARGED COAGULANTS***

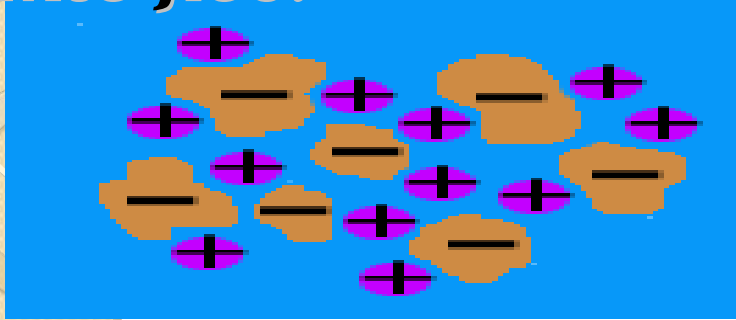


Negatively charged particles repel each other due to electricity



positively charged  
coagulants attract to  
negatively each other due to  
electricity charged particles  
due to electricity.

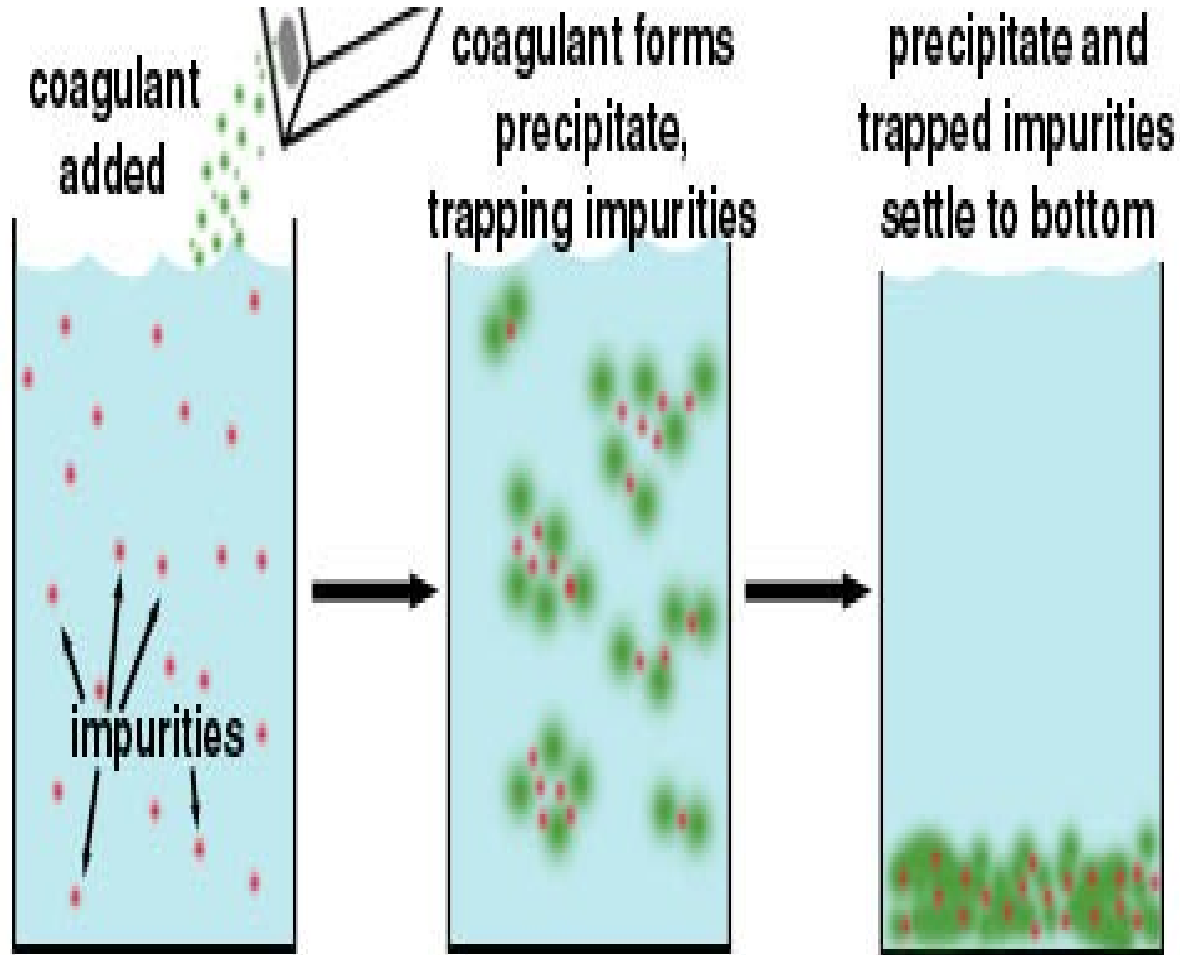
***Particles and coagulants join together into floc.***



## ***FACTORS AFFECTING COAGULATION:***

- 1. Type of coagulant***
- 2. Dose of coagulant***
- 3. Characteristic of water***
  - ***Type and quantity of suspended matter***
  - ***Temperature of water***
  - ***pH of water***
- 4. Time and method of mixing***

# Coagulation aim



# Common Coagulants

Coagulant chemicals come in two main types :-

**Primary coagulants** neutralize the electrical charges of particles in the water which causes the particles to clump together

**Coagulant aids** add density to slow-settling flocs and add toughness to the flocs so that they will not break up during the mixing and settling processes.

In water treatment plants, the following are the coagulants most commonly used:

## **I. ALUMINUM SULFATE [AL 2(SO4) 3.18H2O].**

✚It is also called Alum. It is the most widely used chemical coagulant in water purification work.

✚Alum reacts with water only in the presence of alkalinity. If natural alkalinity is not present, lime may be added to develop alkalinity.

✚It reacts with alkaline water to form aluminum hydroxide (floc), calcium sulphate and carbon dioxide.

✚Due to the formation of calcium sulphate, hardness and corrosiveness of water is slightly increased. .

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***Due to the following reason, Alum is the most widely used chemical coagulant.***

***+It is very cheap***

***+It removes taste and color in addition to turbidity***

***+It is very efficient***

***+Flocs formed are more stable and heavy***

***+It is not harmful to health***

***+It is simple in working, doesn't require skilled supervision for dosing***

**ii. Sodium aluminates ( $\text{Na}_2\text{Al}_2\text{O}_4$ )**

**iii. Chlorinated Copperas**

### **EXAMPLE Electrolytes**

Find out the quantity of alum required to treat 18million liters of water per day.

The dosage of alum is 14mg/lit. Also work out the amount of  $\text{CO}_2$  released per liter of treated water.

- **dosage** is the required concentration of the chemical within the water (mg/l).
- **chemical feed** is the amount of chemical you add to the water (mg/day)
- Coagulants may be put in raw water either in powder form or in solution form.

❑ **Dry-Feed Type**

❑ **Wet feeding type**

## **Mixing devices**

The mixing is done by mixing device

**Hydraulic jump** - flume with considerable slope is developed

**Pump method** - centrifugal pump is used to raise raw water

**Compressed air method** - compressed air is diffused from bottom of the mixing tank

**Mixing channels** - The channel in which flume has been done.

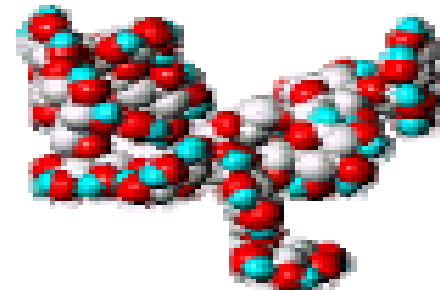
**Mixing basin with baffle wall**

**Mechanical mixing basins** - Agitate the mixture

# What is Flocculation?

**Flocculation** is the agglomeration of destabilized particles into a large size particles known as flocs which can be effectively removed by sedimentation or flotation.

- Gentle mixing or *flocculation*, then causes the destabilized (reduced charge) colloids to cluster.
- Another method of enhancing agglomeration is to add organic polymers.
- These compounds consist of a long carbon chain with active groups such as amine, nitrogen, or sulfate groups along the chain.



# Water coagulation and flocculation

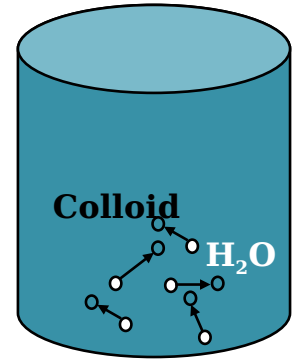
Various sizes of particles in raw water

| Particle diameter (mm) | Type           | Settling velocity |
|------------------------|----------------|-------------------|
| 10 m/s                 | Pebble         | 0.73              |
| 1 m/s                  | Course sand    | 0.23              |
| 0.1                    | Fine sand      | 0.6 m/min         |
| 0.01                   | Silt           | 8.6 m/d           |
| 0.0001 (10 micron)     | Large colloids | 0.3 m/y           |
| 0.000001 (1 nano)      | Small colloids | 3                 |

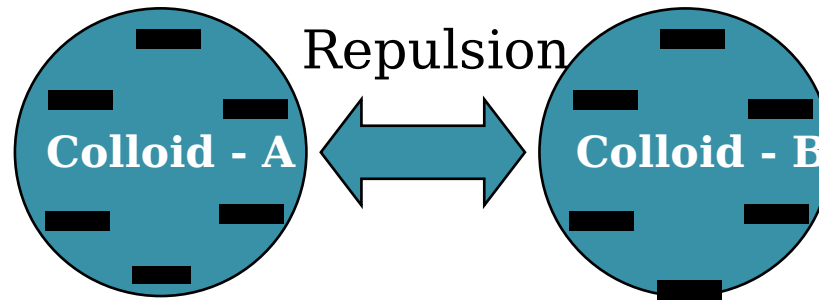
Gravity settling

Colloids - so small: gravity settling not possible

# Colloid Stability



- ✓ Colloids have a net negative surface charge
- ✓ Electrostatic force prevents them from agglomeration



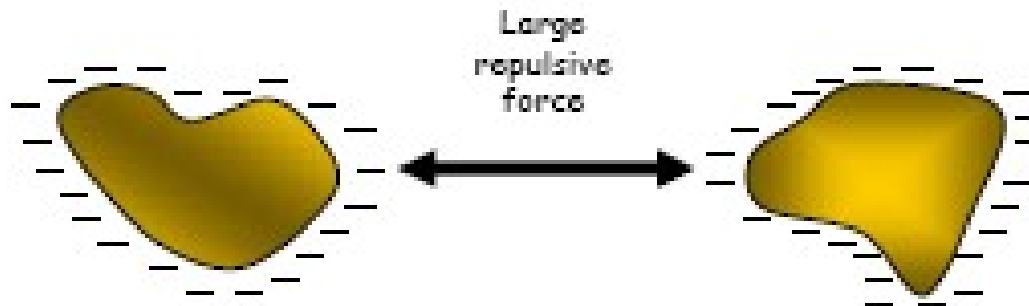
- ✓ Brownian motion keeps the colloids in suspension
  - ✓ Impossible to remove colloids by gravity settling

# Colloidal interaction

- There are two major forces acting on colloids:

## 1) electrostatic repulsion

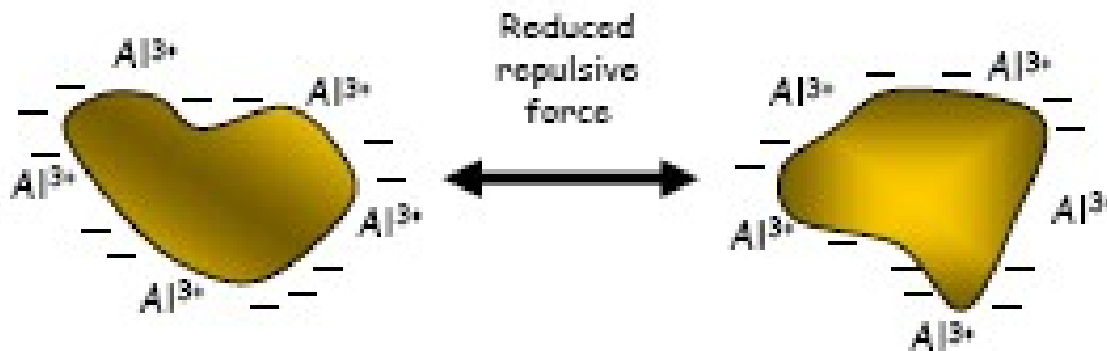
(simply, negative colloids repel other negatively charged colloids)



## 2) intermolecular, or van der Waals, attraction.

# Charge reduction

- Coagulants can be used to reduce the electrostatic repulsive forces
- The electrostatic repulsion reduced by the addition of countercharged ions [ $Al^{3+}$ ]



# Colloid Destabilization

- **Colloids can be destabilized by charge neutralization**
- **Positively charged ions ( $\text{Na}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Al}^{3+}$ ,  $\text{Fe}^{3+}$  etc.) neutralize the colloidal negative charges and thus destabilize them.**
- **With destabilization, colloids aggregate in size and start to settle**

# Jar Tests

- ❑ The jar test – a laboratory procedure to determine the optimum pH and the optimum coagulant dose

- ❑ A jar test simulates the coagulation and flocculation processes

## Determination of optimum pH

- ❑ Fill the jars with raw water sample (500 or 1000 mL) – usually 6 jars
- ❑ Adjust pH of the jars while mixing using  $\text{H}_2\text{SO}_4$  or  $\text{NaOH}$ /lime (pH: 5.0; 5.5; 6.0; 6.5; 7.0; 7.5)
- ❑ Add same dose of the selected coagulant (alum or iron) to each jar

(Coagulant dose: 5 or 10 mg/L)



**Jar Test**

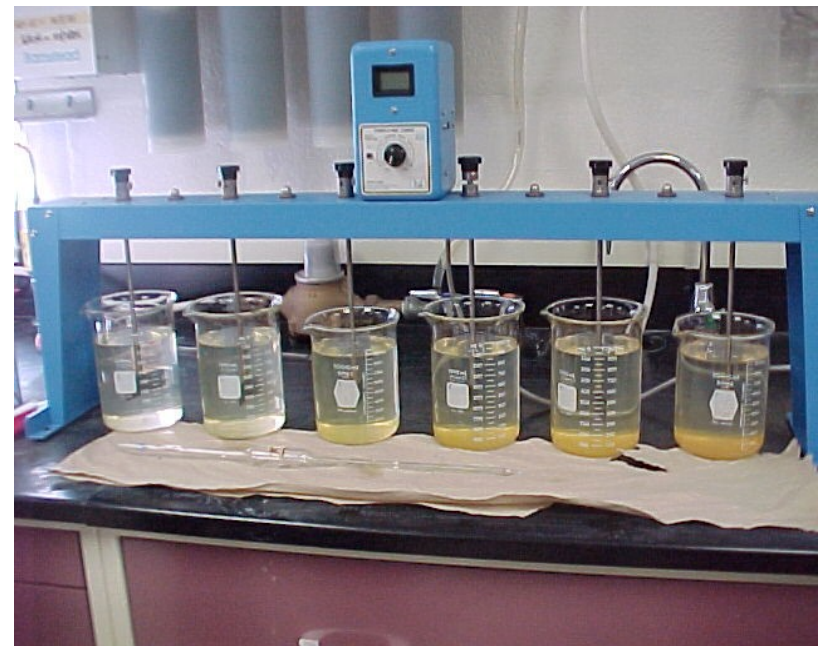
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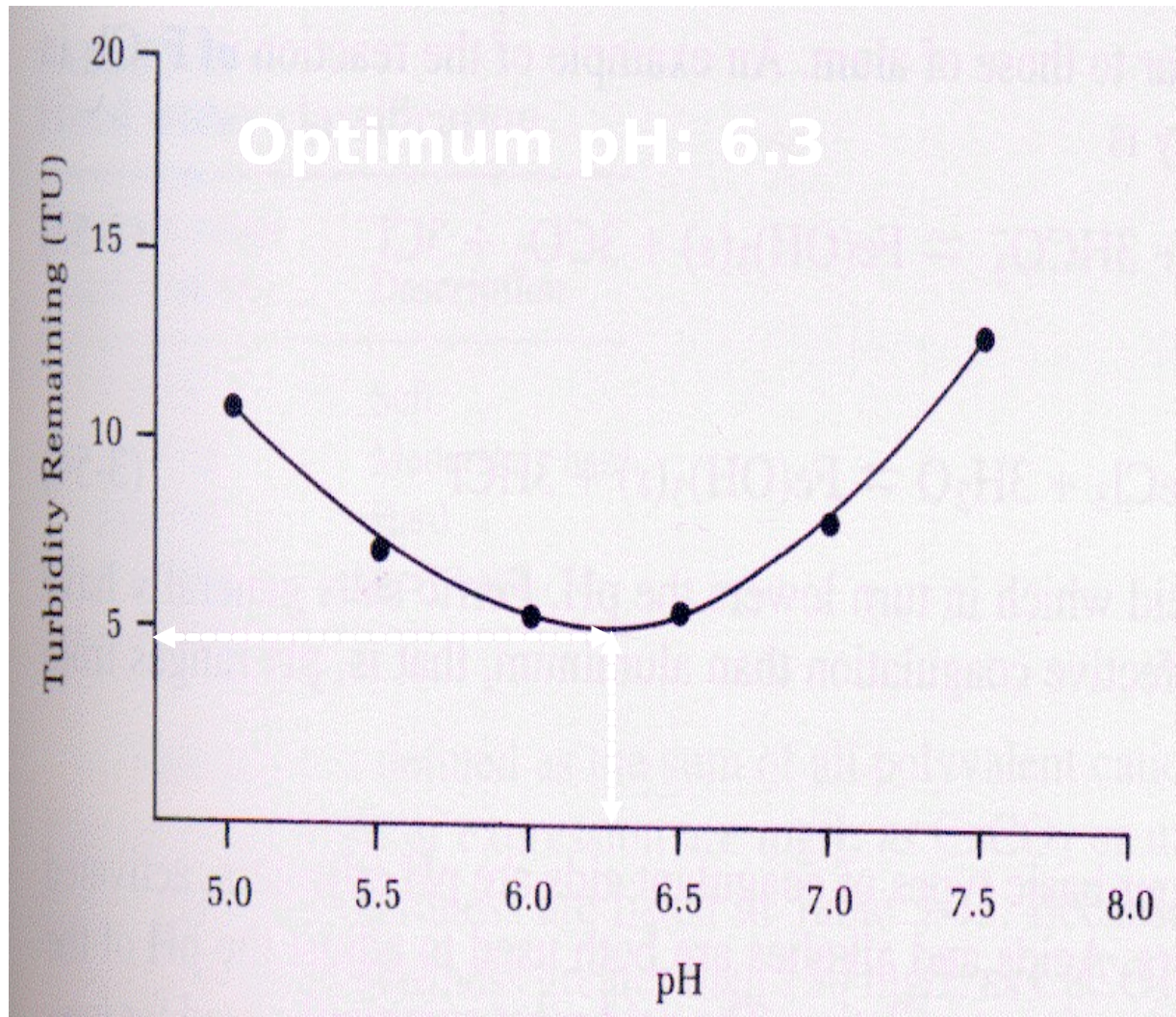
# Jar Tests - determining optimum pH

- ❑ Rapid mix each jar at 100 to 150 rpm for 1 minute. The rapid mix helps to disperse the coagulant throughout each container
- ❑ Reduce the stirring speed to 25 to 30 rpm and continue mixing for 15 to 20 mins  
This slower mixing speed helps promote floc formation by enhancing particle collisions, which lead to larger flocs
- ❑ Turn off the mixers and allow flocs to settle for 30 to 45 mins
- ❑ Measure the final residual turbidity in each jar
- ❑ Plot residual turbidity against pH

## Jar Test set-up

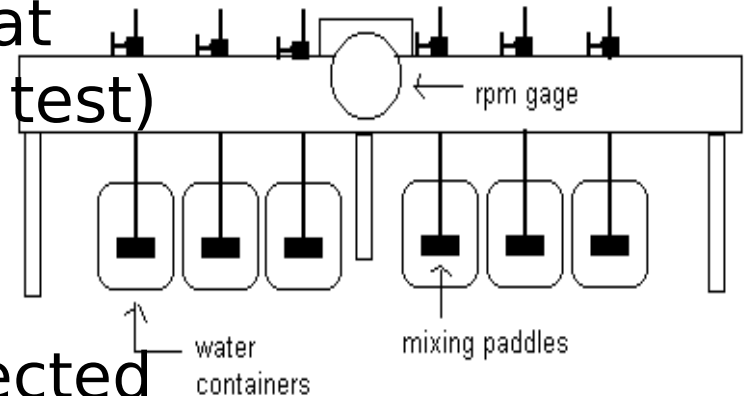


# Jar Tests - optimum pH



# Optimum coagulant dose

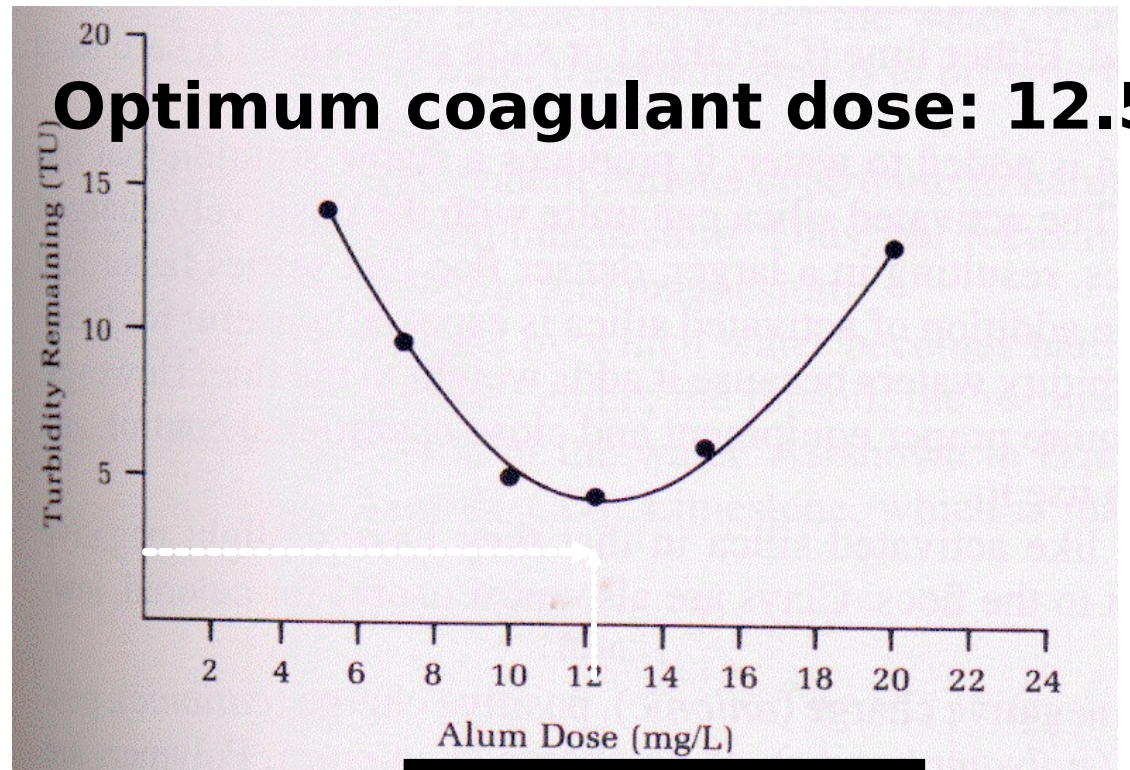
- ❑ Repeat all the previous steps
- ❑ This time adjust pH of all jars at optimum (6.3 found from first test) while mixing using  $\text{H}_2\text{SO}_4$  or NaOH/lime
- ❑ Add different doses of the selected coagulant (alum or iron) to each jar (Coagulant dose: 5; 7; 10; 12; 15; 20 mg/L)
- ❑ Rapid mix each jar at 100 to 150 rpm for 1 minute. The rapid mix helps to disperse the coagulant throughout each container
- ❑ Reduce the stirring speed to 25 to 30 rpm for 15 to 20 mins



# Optimum coagulant dose

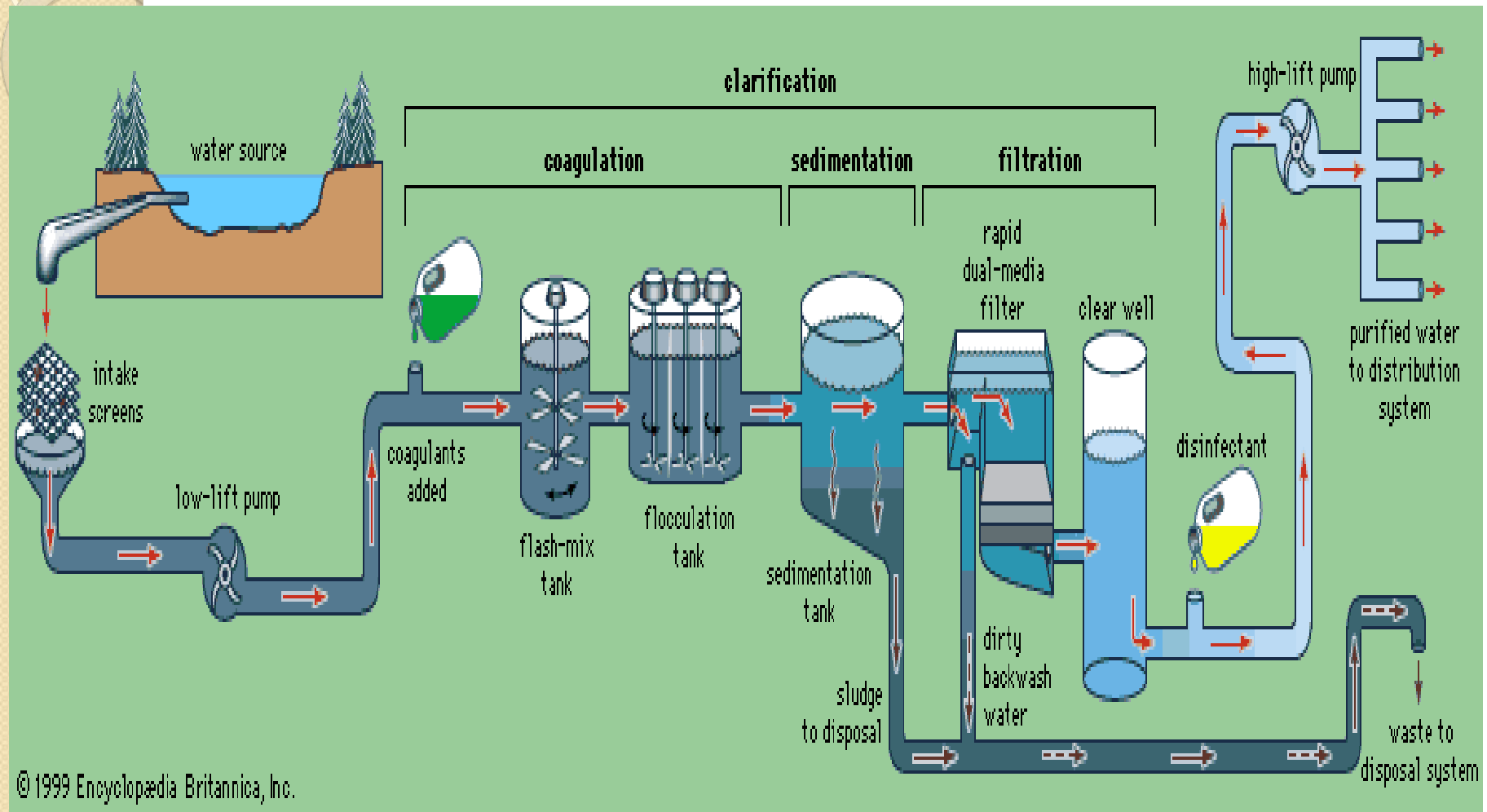
- ❑ Turn off the mixers and allow flocs to settle for 30 to 45 mins
- ❑ Then measure the final residual turbidity in each jar
- ❑ Plot residual turbidity against coagulant dose

The coagulant dose with the lowest residual turbidity will be the optimum coagulant dose



Coagulant Dose

# ical layout of a water treatment pla



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# Topics of Discussion

- ***The place of flocculation within a water treatment process***
- ***The use of coagulation and flocculation in the water industry***
- ***Softening***
- ***Separation of flocs by settling and flotation***

# Flocculation: Purpose

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- ◆ Promote agglomeration of particles into larger floc
- ◆ Units often designed on the basis of mixing intensity as described by the velocity gradient,  $G$ 
  - some mixing is needed to keep particles in contact with other particles
  - too much mixing can cause floc break-up



# Design of Flocculator (Slow & Gentle mixing)

Flocculators are designed mainly to provide enough interparticle contacts to achieve particles agglomeration so that they can be effectively removed by sedimentation or flotation

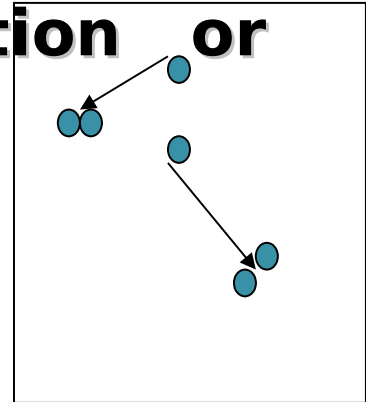
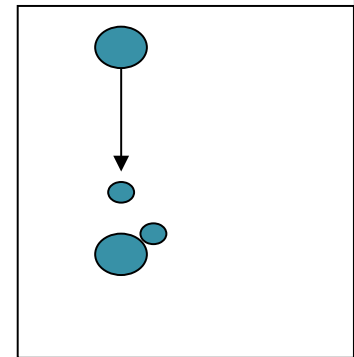
**Transport Mechanisms**  
**Brownian motion** (the random motion of particles suspended in a fluid resulting from their collision)- important for small particles ( $< 0.5\mu\text{m}$ ) ---

*Perikinetic flocculation*

**Stirring**- mechanical stirring strong enough to cause particle collisions but not so strong as to break up particles. ---

*Orthokinetic flocculation*

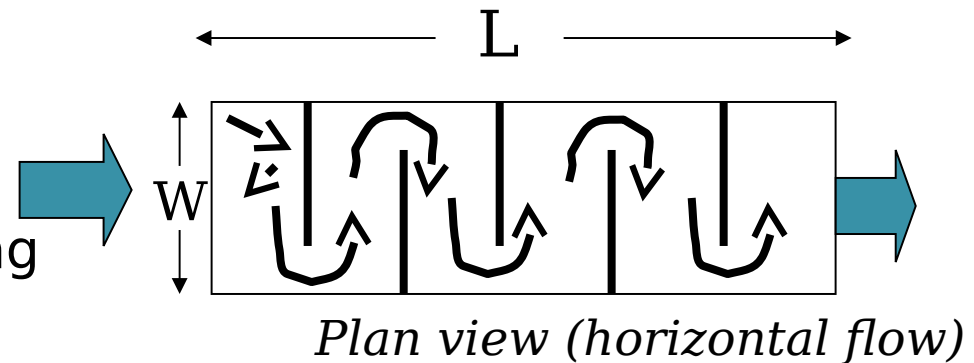
**Differential settlement** - larger, faster settlement



# Hydraulic Flocculation

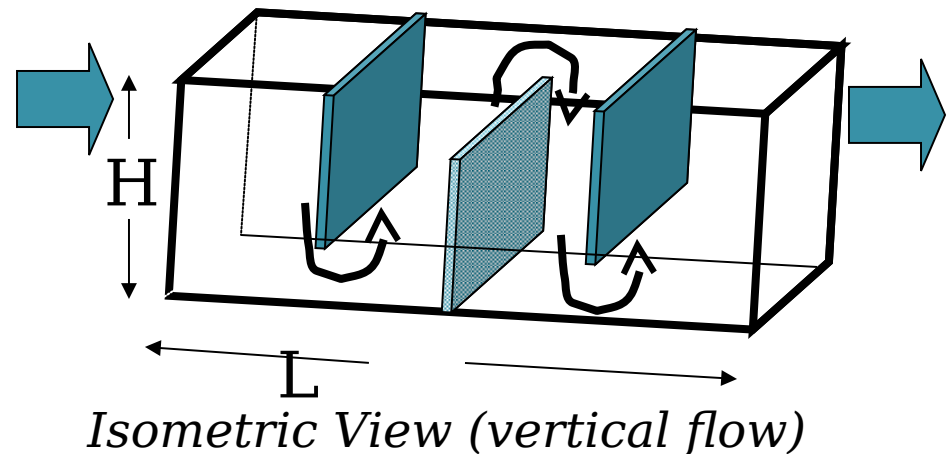
- *Horizontally baffled tank*

The water flows horizontally.  
The baffle walls help to create turbulence and thus facilitate mixing



- *Vertically baffled tank*

The water flows vertically.  
The baffle walls help to create turbulence and thus facilitate mixing



# Hydraulic Flocculation

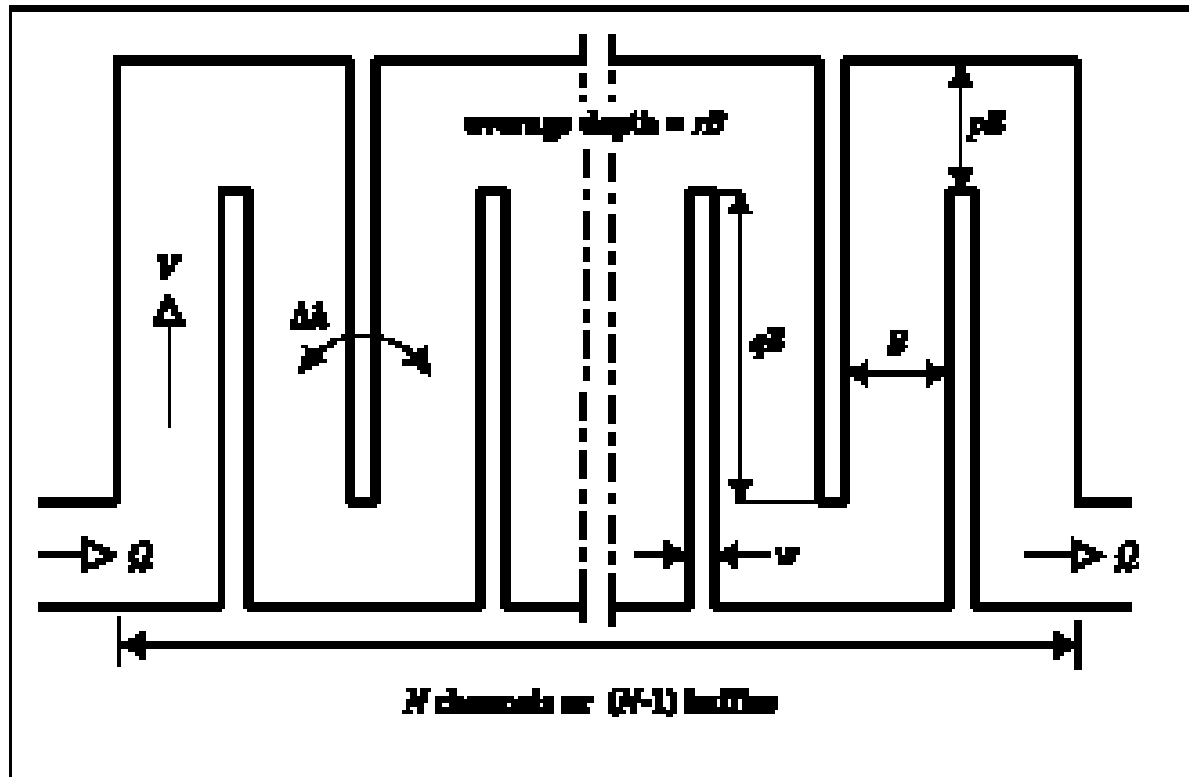
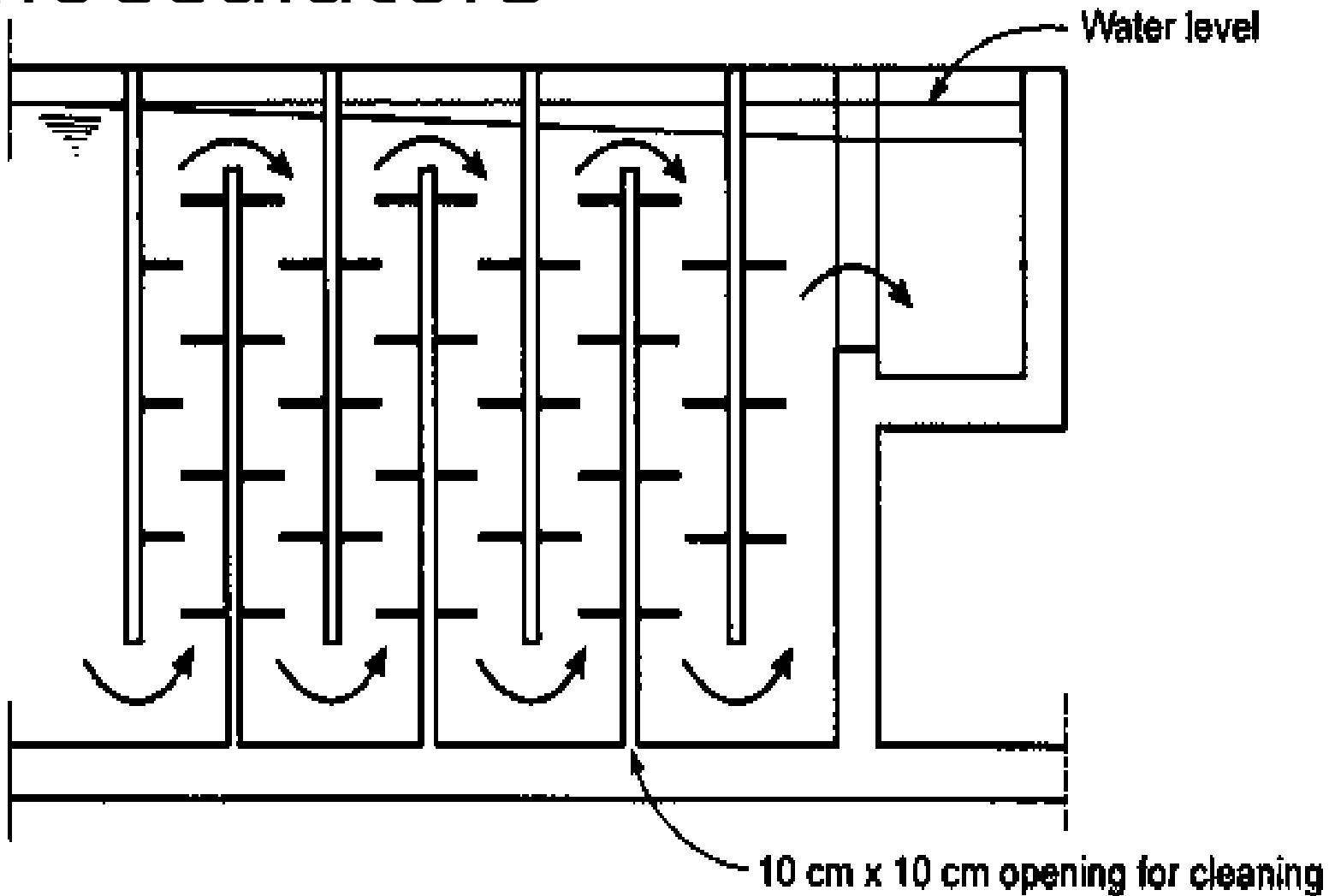


Figure 1 | Schematic layout of an around-the-end hydraulic flocculator, showing the notation used in this paper.

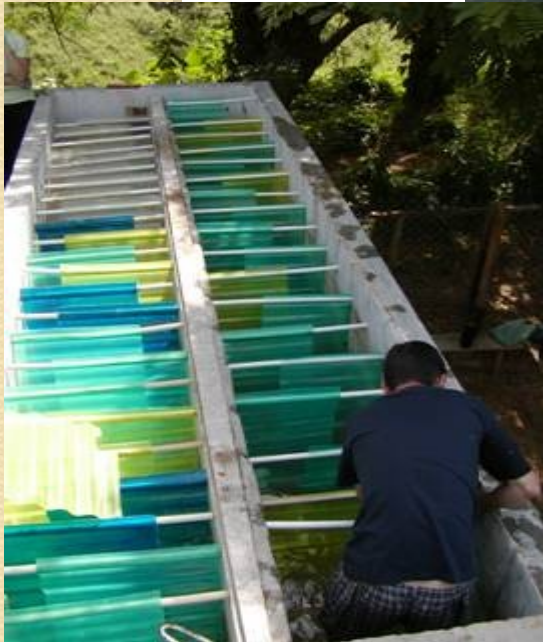
# Hydraulic flocculators



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# Hydraulic flocculators: simple technology



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# Flocculators integrated with settling



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# Mixing and Power

➤ The degree of mixing is measured by **Velocity Gradient (G)**

➤ **Higher G value, intenser mixing**  
**Velocity Gradient:** relative velocity of the two fluid particles/distance

$$G = dv/dy = 1.0/0.1 = 10 \text{ s}^{-1}$$

**In mixer design, the following equation is useful**

$G$  = velocity gradient,  $\text{s}^{-1}$ ;

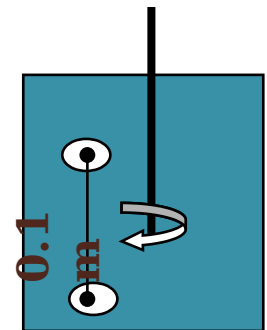
$P$  = Power input,  $\text{W}$

$V$  = Tank volume,  $\text{m}^3$ ;

$\mu$  = Dynamic viscosity,  
( $\text{Pa}\cdot\text{s}$ )

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1 m/s

➤ **G value for coagulation: 700 to 1000  $S^{-1}$ ; 3000 to 5000  $S^{-1}$  for**

**Mixing time: 30 to 60 S**  
➤ **G value for flocculation: 20 to 80  $S^{-1}$ ; in-line blender; 1-2 sec**  
**Mixing time: 20 to 60 min**

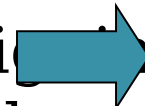
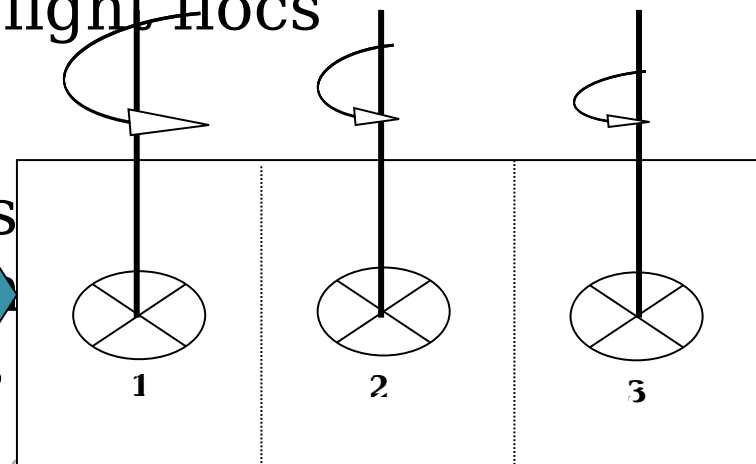
**In the flocculator design, Gt (also known Camp No.); a product of G and t is commonly used as a design parameter**

**Typical Gt for flocculation is  $2 \times 10^4 - 10^5$**

Large G and small T gives small but dense floc

Small G and large T gives big but light flocs

We need big as well as dense flocs which can be obtained by design  
floculator with different G values



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# PADDLE FLOCCULATORS

$$F = C_D A \rho v^2 / 2$$

Where  $F$  = drag force, N

$C_D$  = dimensionless drag coefficient for plates moving faces normal to direction of motion

$A$  = cross-sectional area of the paddles,  $m^2$

$v$  = relative velocity between paddles and fluid, m/s

$\rho$  = density,  $1000 \text{ kg/m}^3$

The power input can be computed as the product of drag force and velocity:

$$P = Fv = C_D A \rho v^3 / 2$$

If this is substituted in the equation for  $G$ , the mean velocity gradient  $G$  becomes

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# What you need to know

- How to determine the velocity gradient and volume, chemical and energy requirements for flocculation
- Be able to size settling tanks on the basis of particle settling rates and identify important zones in the settling tank
- Softening calculations

# Flocculation: cont.

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Power input

$$G = \left( \frac{P/V}{\mu} \right)^{0.5}$$

Tank volume

Dynamic viscosity

Extent of Mixing =  $Gt$

## EXAMPLE

Design a conventional vertical-shaft rapid mix tank unit for uniformly dispersing coagulant in 10 MLD of settled raw water as per design

parameters given below:

|                                                            |                                                               |
|------------------------------------------------------------|---------------------------------------------------------------|
| Detention time (t):                                        | 20 – 60 s                                                     |
| Ratio of tank height (H) to diameter (D):                  | (1:1 to 1:3)                                                  |
| Ratio of impeller diameter ( $D_I$ ) to tank diameter (D): | (0.2:1 to 0.4:1)                                              |
| Velocity gradient (G):                                     | $> 300s^{-1}$                                                 |
| <u>Gt</u> :                                                | 10000 – 20000                                                 |
| Tank diameter (D):                                         | $< 3$ m                                                       |
| Paddle tip speed ( $v_p$ ):                                | 1.75 – 2.0 m/s                                                |
| Velocity of paddle relative to water (v):                  | 0.75 * paddle tip speed                                       |
| Paddle area ( $A_p$ )/Tank section area ( $A_T$ ):         | 10:100 – 20:100                                               |
| Coefficient of drag on impeller blade ( $C_D$ ):           | 1.8                                                           |
| Maximum length of each impeller blade (L):                 | 0.25 * impeller diameter                                      |
| Maximum width of impeller blade (B):                       | 0.20 * impeller diameter                                      |
| Impeller height from bottom ( $H_B$ ):                     | 1.0 * impeller diameter                                       |
| Kinematic viscosity:                                       | <u><math>1.003 \times 10^{-6} \text{ m}^2/\text{s}</math></u> |
| Dynamic viscosity of water:                                | $1.002 \times 10^{-3} \text{ Ns/m}^2$                         |

# Determine

- Tank dimensions (provide a freeboard of 0.5 m),
- Impeller diameter,
- Paddle dimensions,
- Number of paddles,
- Clearance of the impeller from tank bottom,
- Paddle rotation speed and
- Power input requirement.

**Solution:**

Let the detention time (t) be 40s

Therefore, volume of tank (V)

$$V = 1000 * \frac{40}{60 * 60 * 24} = 4.63 m^3$$

Let the tank diameter (D) be 2 m

Tank cross-sectional area ( $A_{cs}$ )

$$A_{cs} = \frac{\pi D^2}{4} = \frac{\pi 2^2}{4} = 3.14 m^2$$

Tank height (H) = 1.5m, provide freeboard of 0.5m

Total height ( $H_T$ ) = 2 m

Tank height (H) to tank diameter (D) ratio

$$\frac{H}{D} = \frac{1.5}{2} = 0.75$$

(within the range of 0.33–1.0, hence ok!)

Let velocity gradient,  $G = 400 \text{ s}^{-1}$

Therefore,

Let the paddle tip speed ( $v_p$ ) be  $1.8 \text{ m/s}$  [1.75, 2.0 m/s]

Hence, velocity of paddle relative to water ( $v$ )

$$v = 0.75 * (1.8) = 1.35 \text{ m/s}$$

To calculate the paddle area the following empirical formula can be used:

$$G = \left\{ \frac{C_d A_p v^3}{2vV} \right\}^{1/2}$$

$$400 = \left\{ \frac{1.8 * A_p 1.35^3}{2 * 1.003 * 10^{-6} * 4.63} \right\}^{1/2}$$

$$A_p = 0.336 \text{ m}^2$$

$$\text{Tank sectional area} = (D) * (H) = (1.5) * (2) = 3.0 \text{m}^2$$

$$\frac{\text{Paddle area}}{\text{Tank sectional area}} = \frac{A_p}{D * H} = \frac{0.336}{3} = 0.112$$

[0.1, 0.2], hence ok!

Let the impeller diameter be 0.8 m, i.e.,

$$\frac{D_I}{D} = \frac{0.8}{2} = 0.4 \quad \text{ok!}$$

Choose length of each impeller blade (L) as 0.20m, i.e.,

$$\frac{L}{D_I} = \frac{0.2}{0.8} = 0.25 \quad \text{ok!}$$

Choose breadth of each impeller blade (B) as 0.15m, i.e.,

$$\frac{B}{D_I} = \frac{0.15}{0.8} = 0.187 \quad \text{ok!}$$

Area of each blade ( $A_b$ )

$$A_b = L * B = 0.2 * 0.15 = 0.03 \text{ m}^2$$

Therefore, number of blades ( $n_b$ ) to be provided

$$n_b = \frac{A_p}{A_b} = \frac{0.336}{0.03} = 11.20 \cong 12$$

Clearance of the paddles from the tank bottom = 0.8m

Paddle rotation speed ( $w$ , radians/s)

$$w = \frac{2 * v_p}{D_I} = \frac{2 * 1.8}{0.8} = 4.5 \text{ radians/s}$$

$$w = \frac{4.5}{2\pi} * 60 = 43 \text{ RPM}$$

Power requirement is given by:

$$G = \left[ \frac{P}{\mu V} \right]^{1/2}$$

$$P = G^2 \mu V = 400^2 * 1.002 * 10^{-3} * 4.63 = \mathbf{742 \text{ watt}}$$

$$P = \mathbf{74.2 \text{ kW/Mm}^3/\text{d}} \quad \text{within the range of } 49 - 196 \text{ kW/Mm}^3/\text{d}$$

## CHAPTER FIVE FILTRATION

In this chapter we will answer the following questions:

- How does filtration fit into the water treatment process?
- How does filtration clean water?
- What types of filters are used for water treatment?
- How are filters cleaned?
- What media are used in filters?
- What factors affect filter efficiency?



➤ **Filtration** is one of the water purification processes in which water is allowed to pass through a porous medium to remove remaining flocs or suspended solids from the previous treatment processes.

➤ In the filter, up to 99.5% of the suspended solids in the water can be removed, including minerals, floc, and microorganisms.

➤ Filtration process assist significantly by reducing the load on the disinfection process, increasing disinfection efficiency.

# Theory of Filtration

Filtration consists of passing water through a thick layer of sand.

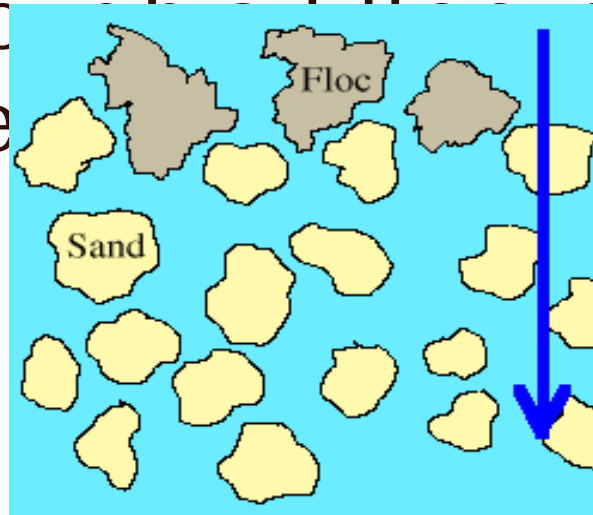
During the passage of water through sand, the following effects take place.

- Suspended matter and colloidal matter are removed
- Chemical characteristic of water get changed
- Number of bacteria considerably reduced

➤ These phenomena can be explained on the basis of the following **mechanisms of filtration**.

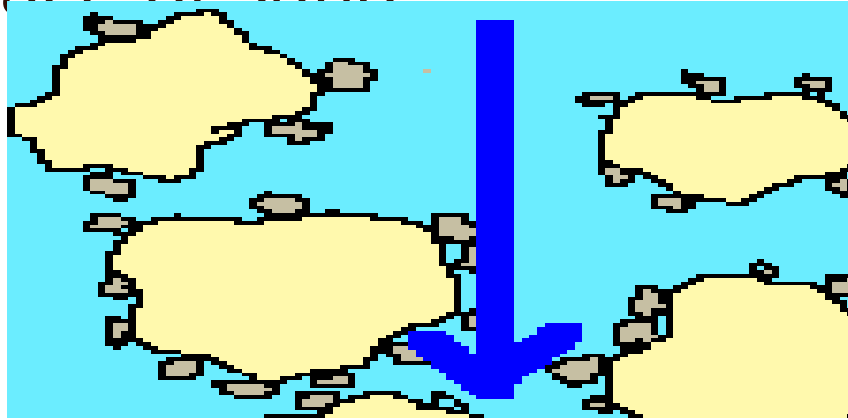
## 1. Mechanical straining

Mechanical straining of suspended particles in the sand pores. Passing the water through the filter medium in which the pores are smaller than the size of the particles to be removed.



## 2. Sedimentation and Adsorption

**Adsorption** is the gathering of dissolved solids onto the surface of sand



## 3. Electrolytic action

- Due to the friction between medium and suspended solids, certain amount of dissolved and suspended matter is ionized.
- These neutralize each other; change the chemical character of water.

## 4. Biological Action

- The growth and life process of the living cells, biological metabolism.
- The surface layer gets coated with a film in which the bacterial activities are the highest and which feed on the organic impurities.
- The bacteria convert organic impurities by a complex biochemical action into simple, harmless compounds – purification of water.

# Rate of Filtration

Rate of filtration (loading rate) is the flow rate of water applied per unit area of the filter. It is the velocity of the water approaching the face of the filter:

Where  $v_a$  = face velocity,  $m/d$  = loading rate,  $m^3/d/m^2$

$Q$  = flow rate onto filter surface,  $m^3/d$

$A_s$  = surface area of filter,  $m^2$

# Types of filters

Two types of filter:

1. Gravity filter system

- i. Slow Sand Filter (SSF)
- ii. Rapid Sand Filter (RSF)

2. Pressure filter system

## Slow Sand Filters

- The slow sand filter removes particles from the water through ***adsorption and straining***.
- A layer of dirt, debris, and microorganisms builds up on the top of the sand. This layer is known as *schmutzdecke*
- The sand used for the filtration is specified by the ***effective size*** and ***uniformity coefficient***.

- The effective size,  $D_{10}$ , which is the sieve in mm that permits 10% sand by weight to pass. The uniformity coefficient is calculated by the ratio of  $D_{60}$  and  $D_{10}$ .

## **Construction of slow sand filter**

- Top layer of **fine sand** of effective size 0.2 to 0.3mm and uniformity coefficient 2 to 3.
- The thickness of the layer may be 75 to 90 cm.
- At middle **coarse sand** of such size whose voids do not permit the fine sand to pass through it.

➤ The **gravel** is laid in layers such that the smallest sizes are at the top. The gravel layer is used to retain the coarse sand layer and is laid over the network of open jointed clay pipe or concrete pipes called ***under drainage***.

➤ Water collected by the under drainage is passed

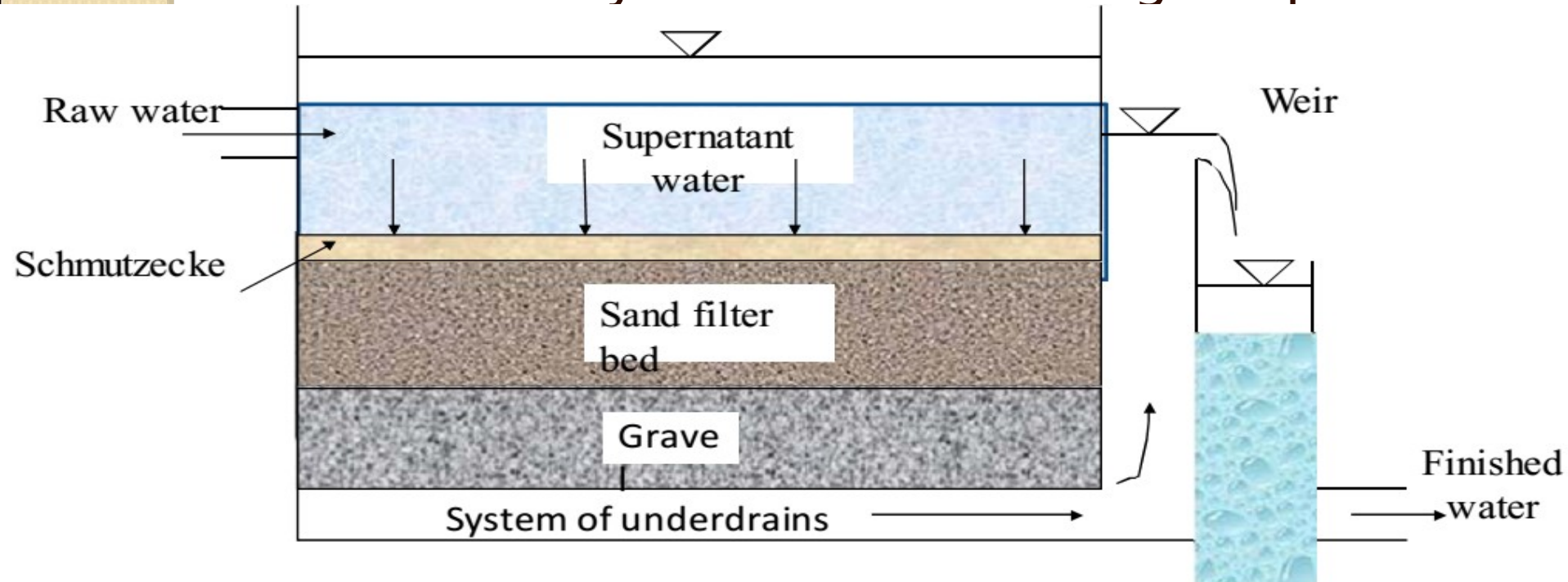


Figure 2:Section of slow sand filter

# Uses of SSF

- The slow sand filters are effective in removal of 98 to 99% of bacteria of raw water and completely all suspended impurities and turbidity is reduced to 1 NTU.
- Slow sand filters also removes odours, tastes and colours from the water but not pathogenic bacteria which requires disinfection to safeguard against water-borne diseases.
- The slow sand filter requires large area for their construction and high initial cost for establishment. The rate of

## Rapid Sand Filter(RSF)

- The rapid sand filter differs from the slow sand filter in a variety of ways, the most important of which are the much greater filtration rate ranging from 100 to 150m<sup>3</sup>/m<sup>2</sup>/day, the ability to clean automatically using backwashing and require small filter area.
- The mechanism of particle removal also differs in the two types of filters - rapid sand filters do not use biological filtration and depend primarily on ***adsorption*** and some straining.

# **The main features of rapid sand filter are as follows**

- Effective size of sand - 0.45 to 0.70mm
- Uniformity coefficient of sand - 1.2 to 1.7
- Depth of sand - 60 to 75cm
- Filter gravel - 2 to 50mm size (Increase size towards bottom)
- Depth of gravel - 45cm
- Depth of water over sand during filtration - 1 to 2m
- Overall depth of filter including 0.5m free board - 2.5m
- Area of single filter unit - 100m<sup>2</sup> in two parts of each 50m<sup>2</sup>
- Loss of head - max 1.8 to

## Comparison of slow sand filter and rapid sand filter

Table 4.1 Comparison of slow sand filter and rapid sand filter

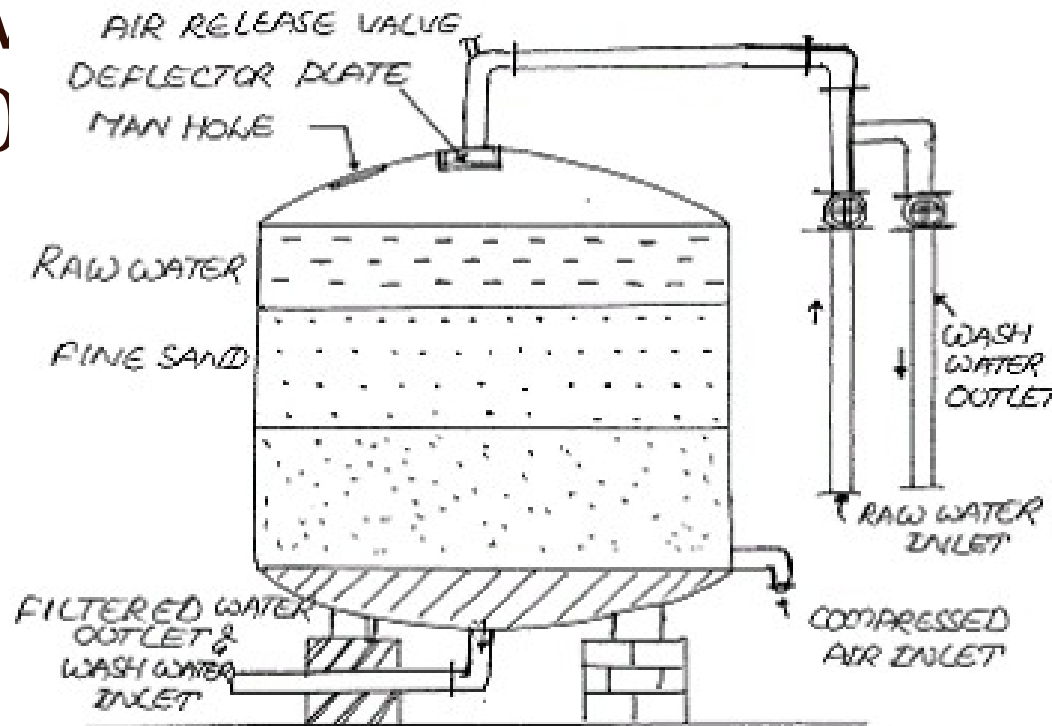
| No | Parameter                 | SSF                                                                                                                     | RSF                                                                                                                 |
|----|---------------------------|-------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
| 1  | Raw water turbidity       | Not more than 30 NTU                                                                                                    | Not more than 10 NTU hence coagulation is required                                                                  |
| 2  | Rate of filtration        | 2.4 – 3.6 m <sup>3</sup> /m <sup>2</sup> /d                                                                             | 100 – 150 m <sup>3</sup> /m <sup>2</sup> /d                                                                         |
| 3  | Loss of head              | 0.6 – 0.7m                                                                                                              | 1.8 – 3.0m                                                                                                          |
| 4  | Filter material           | d <sub>10</sub> = 0.15-0.35mm<br>U <sub>c</sub> ≤ 2-3<br>Only relatively fine media used, usually sand                  | d <sub>10</sub> = 0.45–0.7mm<br>U <sub>c</sub> ≤ 1.2 – 1.7<br>Sand, anthracite, coal, magnetite, plastics,          |
| 5  | Filter depth              | 0.6-1.5m                                                                                                                | 0.5-2.0m                                                                                                            |
| 6  | Construction cost         | High                                                                                                                    | Low                                                                                                                 |
| 7  | Land requirement          | Large                                                                                                                   | Small (20% of SSF)                                                                                                  |
| 8  | Operational cost          | Very low                                                                                                                | high                                                                                                                |
| 9  | Equipment and accessories | Few, simple                                                                                                             | Many and sophisticated                                                                                              |
| 10 | Level of sophistication   | Low                                                                                                                     | Very high                                                                                                           |
| 11 | Filtration Mechanism      | Biological action, straining, and adsorption.                                                                           | Primarily adsorption. Also some straining.                                                                          |
| 12 | Cleaning of filter        | Scraping of 2.5 cm thick layer washing and replacing.<br>Cleaning interval that is replacement of sand at 1 to 2 months | Backwash with clean water under pressure to detach the dirt on the sand.<br>Backwashing daily or on alternate days. |
| 13 | Efficiency                | Bacterial removal<br>Taste, odour, colour and turbidity removal                                                         | There is no removal of bacteria. Removal of colour, taste, odour and turbidity is good                              |
| 14 | Common Applications       | Small groundwater systems.                                                                                              | Most commonly used type of filter for surface water treatment.                                                      |

## 2. Pressure Filter

- Pressure filter is type of rapid sand filter in a closed water tight cylinder through which the water passes through the sand bed under pressure.
- All the operation of the filter is similar to rapid gravity filter; expect that the coagulated water is directly applied to the filter without mixing and flocculation.
- These filters are used for industrial plants but these are not economical on large scale.

➤ Pressure filters may be vertical pressure filter and horizontal pressure filter.

➤ Backwash is carried by reversing the flow with a flow rate of 120 to 300



## **Example 1:**

11.75 MLD of water after secondary sedimentation (Turbidity:  $< 10$  NTU) is to be filtered through a battery of rapid sand filters to reduce water turbidity to  $< 1.0$  NTU. Based on pilot plant studies, it was determined that 60 cm deep filter beds of sand (0.5 mm average sand diameter) were suitable for this purpose. It was further determined that such beds could be safely operated up to 7.5 hours at a filtration rate of  $10 \text{ m}^3/\text{m}^2/\text{hr}$  without the terminal head-



A filter unit will be off-line for 30 minutes during each backwash operation. Based on this information, determine the numbers of filter units to be provided and dimensions of each unit. The maximum surface area per filter is limited to  $50\text{m}^2$ . Determine how much filtered water is required for backwashing each day. Also determine the schedule of operation of the filters in a typical day.

## **Solution:**

Note that the total water to be filtered is more than 11.75 MLD, since filter backwash (say,  $B \text{ m}^3/\text{d}$ ) is cycled back to the head for the flocculation tank and filtered again.

So, total water to be filtered

$$= (11750 + B) \text{ m}^3/\text{d}$$

Considering a filter is off-line 1.5 hours/day for backwashing

$(11750 + B) \text{ m}^3$  of water must be filtered in 22.5 hours at a filtration rate of  $10 \text{ m}^3/\text{m}^2/\text{hr}$ .

Therefore,

$$(11750 + B) = (22.5) * (10) * A$$

*= backwashing rate*

*\* backwash time*

*\* number of backwash per day*

*\* filter area*

$$B = 1 * 5 * 3 * A = 15A$$

$$11750 + 15.A = 22.5 * 10 * A$$

$$A = 55.95 \text{ m}^2$$

$$B = 15 * A = 15 * 55.95$$

$$= 840 \frac{\text{m}^3}{\text{d}}$$

Hence total water produced = 12590  $\text{m}^3$  in 22.5hrs using 55.95 $\text{m}^2$  filter area

Provide 2 filters (in parallel), each with cross-sectional area of  $55.95/2 = 27.98\text{m}^2$

Take  $L/B = 1.4$

[1.3:1 – 1.5:1]

$L = 6.25\text{m}$ ;  $B = 4.47\text{m}$

12590  $\text{m}^3$  filtered in 22.5 hours

840  $\text{m}^3$  filtered in 1.5 hours = 90 minutes

Water (for consumption)

actually produced by a filter for  
 $22.5 - 1.5 = 21$  hours

In 21 hours of useful operation  
per day, the filter produced  
 $11750 \text{ m}^3$  of water

The filter produces further  $840$   
 $\text{m}^3$  of water in 1.5 hours of  
operation to be used for  
backwashing

The filter is off-line (producing no water) for 1.5 hours a day for backwashing

# CHAPTER SIX- DISINFECTION

- The process of killing harmful bacteria from water and making it safe to the consumers is said to be ***disinfection***.
- The materials which are used for disinfection of water are called the ***disinfectants***.

# REQUIREMENT OF DISINFECTANT

- Destroy bacteria/pathogens
- Effective at variable compositions, concentration and conditions of water treated.
- Don't change water properties
- Have residual in a sufficient concentration to provide protection against recontamination
- Dispensable at reasonable cost
- Safe and easy to store, transport, handle and supply
- Don't form toxic by-products due to their reactions with any naturally occurring materials in water.

# METHODS OF DISINFECTION

The disinfection of water can be done by one of the following methods:

- Boiling of water
- Ultra-Violet rays and bromine
- Ozone  $O_3$
- Excess lime
- Potassium permanganate [ $KMnO_4$ ]
- **Chlorine**

## CON`T

➤ The most common method of disinfection is the use of chlorine i.e. ***chlorination***.

➤ The various chlorine compounds which are available in the market and used as disinfectants are:

❑ Calcium hypochlorite  $[\text{Ca}(\text{OCl})_2]$

– **powder form**

❑ Sodium hypochlorite  $[\text{NaOCl}]$  –

**liquid form**

❑ Free chlorine  $\text{Cl}_2$  – **Gaseous form**

# CHLORINATION CHEMISTRY

- When chlorine is added to water, a variety of chemical processes take place.
- chlorine reacts with compounds in the water and with the water itself.
- Some of the results of these reactions (known as the **chlorine residual**) are able to kill microorganisms in the water.

# CHLORINE DEMAND

- The total amount of chlorine which is used up in reactions with compounds in the water is known as the **chlorine demand**.
- When chlorine enters water, it immediately begins to react with compounds found in the water.
- It will also react with reducing agents such as hydrogen sulfide, ferrous ions, manganous ions, and nitrite ions.

# Dosage of Chlorine

The chlorine dose required depends on two considerations: the chlorine demand and the desired chlorine residual

$$Dose (mg/l) = Demand (mg/l) + Residual (mg/l)$$

$$Dose (mg/l) = \frac{Feed\ rate\ (mg/day)}{Flow\ (l/day)}$$

## Example 1:

A water treatment plant has used 150.6 kg of chlorine during the past 24 hours. The flow for the same period was 19.95 MLD. What is the dose of chlorine applied to the water in mg/l?

Solution:

$$\begin{aligned} Dose (mg/l) &= \frac{Feed\ rate\ (mg/day)}{Flow\ (l/day)} \\ &= \frac{150.6 * 10^6\ mg/day}{19.95 * 10^6\ l/day} = 7.55\ mg/l \end{aligned}$$

# Con` t

## (A) PLAIN CHLORINATION

- Plain chlorination is the process of addition of chlorine only when the surface water with no other treatment is required.
- The water of lakes and springs is pure and can be used after plain chlorination.
- A rate of 0.8mg/lit/hour at 15N/cm<sup>2</sup> pressure is the normal dosage so as to maintain in residual chlorine of

## **(B) SUPER CHLORINATION**

- Super chlorination is defined as administration of a dose considerably in excess of that necessary for the adequate bacterial purification of water.
- About 10 to 15 mg/lit is applied with a contact time of 10 to 30 minutes under the circumstances such as during epidemic breakout water is to be dechlorinated before supply to the distribution system.

## (c) BRAKE POINT CHLORINATION

The graph below shows what happens when chlorine (either chlorine gas or a hypochlorite) is added to water. Next, between points A and B, the chlorine reacts with organics and ammonia which is naturally found in the water. Some combined chlorine residual is formed - *chloramines*. Note that if chloramines were to be used as the

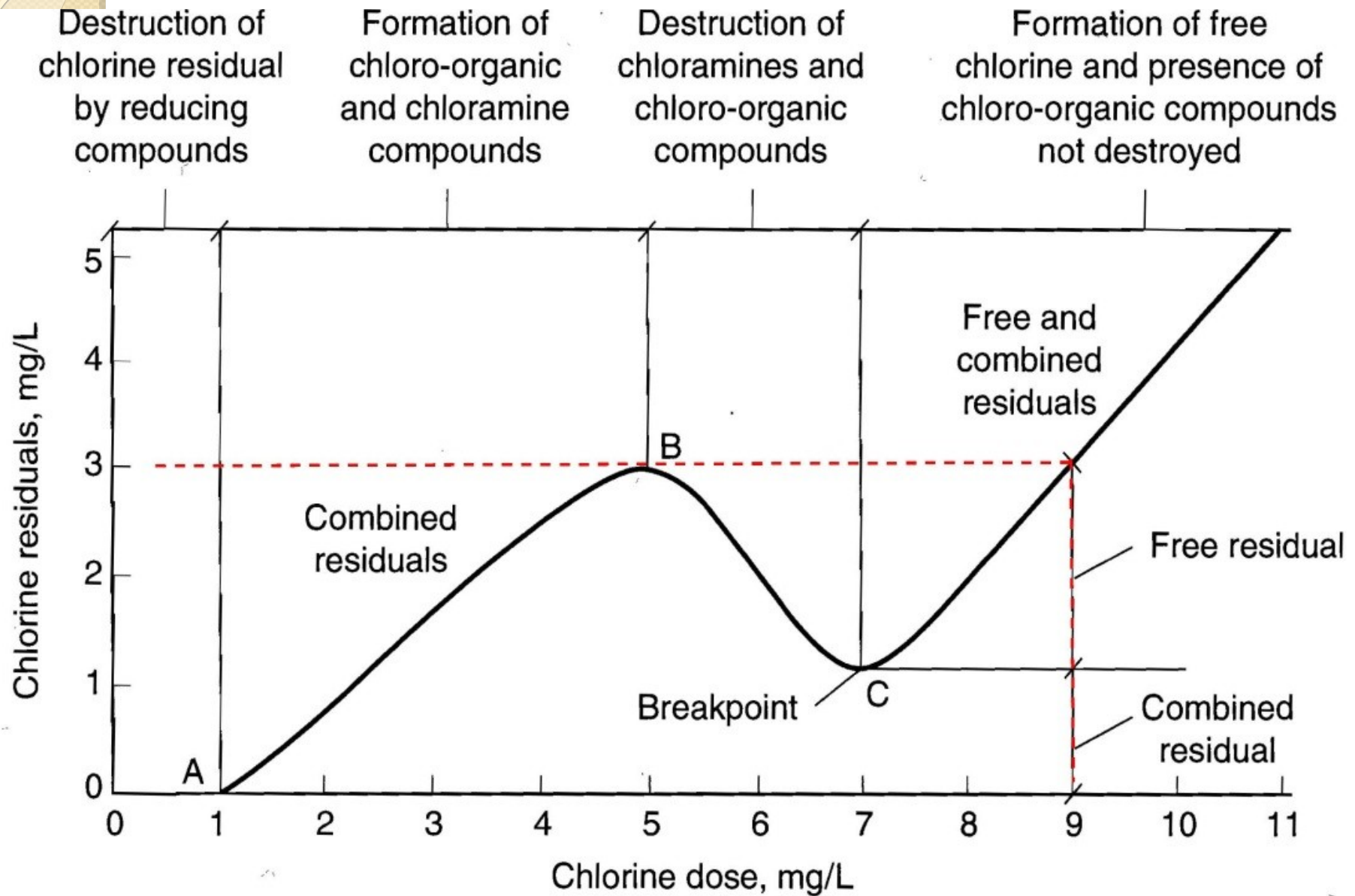


Figure: Break point chlorination

➤ The **breakpoint** is the point at which the chlorine demand has been totally satisfied - the chlorine has reacted with all reducing agents, organics, and ammonia in the water.

➤ ***breakpoint chlorination***, is the most common form of chlorination, in which enough chlorine is added to the water to bring it past the breakpoint and to create some ***free chlorine residual***.

## **(D) DE-CHLORINATION**

➤ Removal of excess chlorine resulting from super chlorination in part or completely is called 'De-chlorination'.

➤ Excess chlorine in water gives pungent smell and corrodes the pipe lines.

➤ Hence excess chlorine is to be removed before supply.

# POINTS OF CHLORINATION

Chlorine applied at various stages of treatment and distribution accordingly they are known as pre, post and re-chlorination.

## □ Pre-Chlorination

Chlorine applied prior to the sedimentation and filtration process is known as *pre-chlorination*. This is practiced when the water is heavily polluted and to remove taste, odour, colour and growth of algae on

Pre-chlorination improves coagulation and post chlorination dosage may be reduced.

## ❑ **POST CHLORINATION**

When the chlorine is added in the water after all the treatment is known as post-chlorination. After chlorination water is sent for distribution to the consumers.

## ❑ **RE-CHLORINATION**

In long distribution systems, chlorine residual may fall tendering