

# Module – 1

## Water Technology

Module:1	Water Technology	5 hours	SLO: 1,14
Characteristics of hard water - hardness, DO, TDS in water and their determination – numerical problems in hardness determination by EDTA; Modern techniques of water analysis for industrial use - Disadvantages of hard water in industries.			

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# Module – 1 : Water Technology



## Characteristics of water

- Hardness, DO, TDS and their determination
- Numerical problems in hardness determination by EDTA;
- Modern techniques of water analysis for industrial use
- Disadvantages of hard water in industries.



# Sources of Water

Naturally available water can be classified as:

**a) Surface water :**

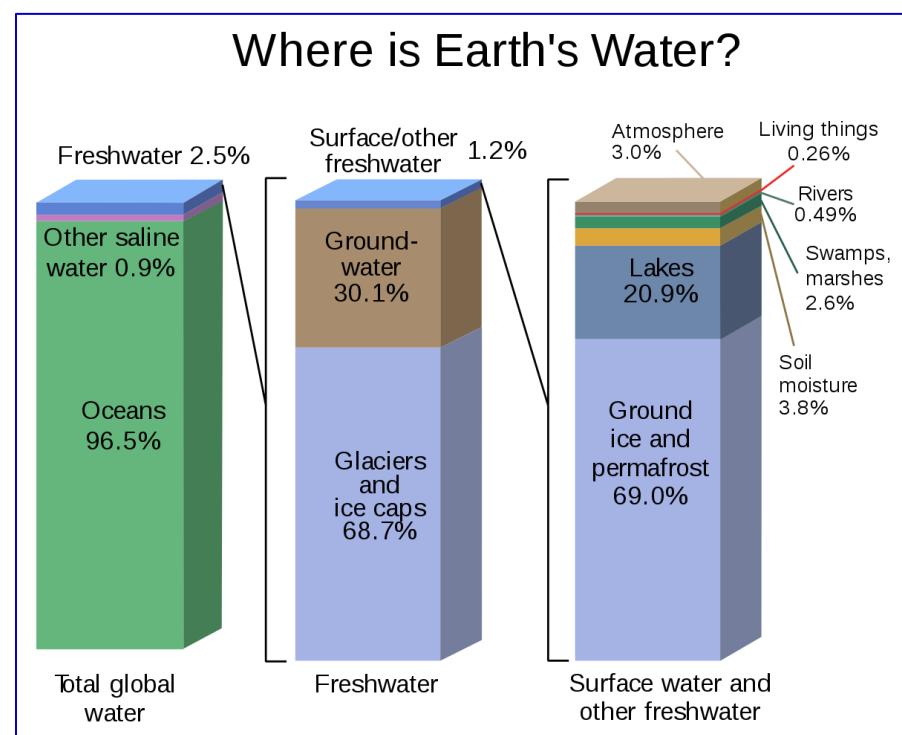
- Flowing water - streams, rivers
- Still water - ponds, lakes and reservoirs

**b) Underground water**

- springs and wells

**b) Sea water and**

**c) Rain water**





# Sources of Water

**Rainwater :** It is the purest form of natural water but contains dissolved toxic gases like  $\text{CO}_2$ ,  $\text{SO}_2$ ,  $\text{NO}_2$  etc. and other solids. Also its supply is unpredictable.

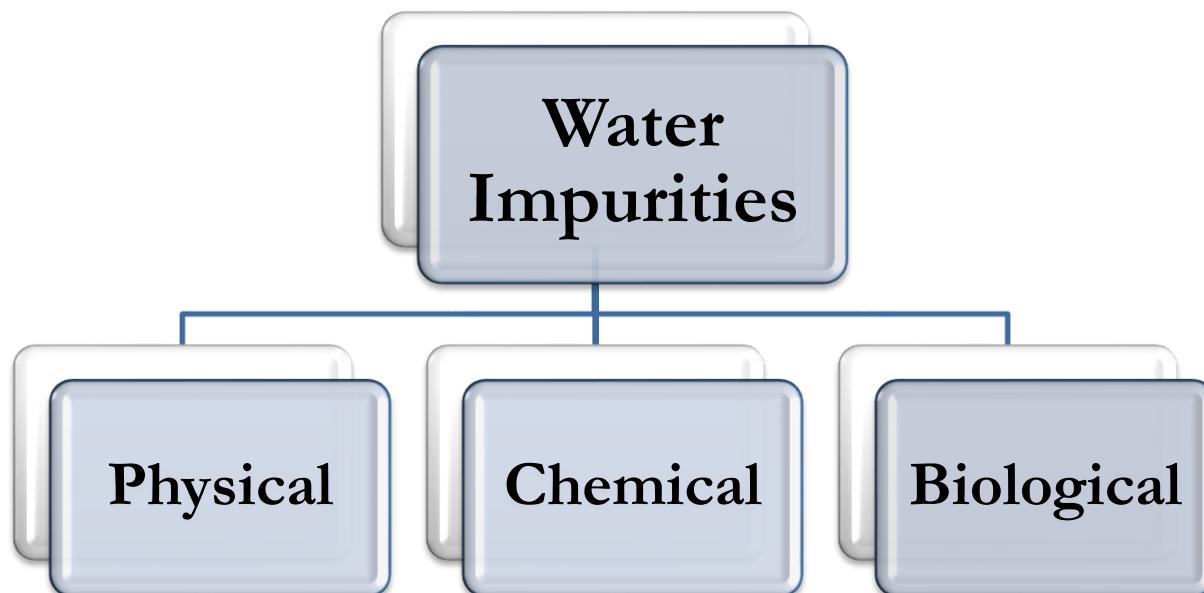
**Sea water :** It is the most impure form of water containing about 3.5% dissolved salts of which about 2.6% is  $\text{NaCl}$ . Other salts present include sulphates, bicarbonates, bromides of sodium, potassium, magnesium etc.

It is therefore, necessary to depend on ground and surface water after removing different impurities that are present in them, as required.



# Water Impurities

- ❖ The substances that pollute water are called “**Water Impurities**”
- ❖ Water is being polluted by throwing wastes into rivers, oil leakage by water transport, etc.





# Impurities in water

Water has different physical, chemical and biological Impurities which can cause problems in both domestic and industrial applications.

## o Physical

- Inorganic such as clay, sand
- Organic such as oil globules, vegetable/animal matter
- Colloidal such as  $\text{Fe(OH)}_3$ , Complex proteins, amines

## o Chemical

- Anions such as  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{NO}_3^-$  of Ca & Mg
- Cations such as  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Fe}^{3+}$ ,  $\text{Al}^{3+}$
- Dissolved gases such as  $\text{O}_2$ ,  $\text{N}_2$ ,  $\text{CO}_2$ ,  $\text{H}_2\text{S}$ ,  $\text{NH}_3$

## o Biological

- Microorganisms such as algae, fungi, bacteria  
(Pathogenic causing Malaria, diarrhea, typhoid etc.)

# Water Quality Indicators - *Physical*



- **Colour** – Inorganic salts
- **Odour** – Organic & Inorganic compounds
- **Transparency** – Suspended solids
- **Taste** – Bitter – Fe, Mn, Al sulphates, **Soapy** –  $\text{NaHCO}_3$



# Water Quality Indicators - *Chemical*

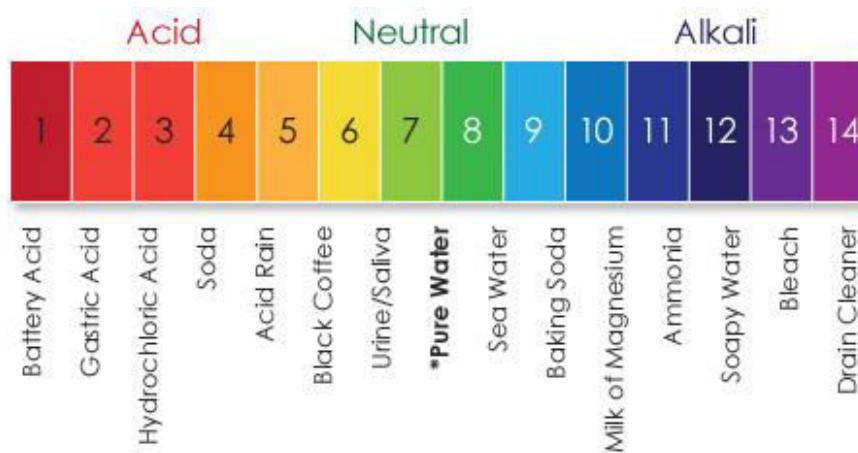


- pH
- Dissolved Oxygen (DO)
- Biological Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Total Dissolved Solids (TDS)
- Hardness



# pH of water

- Concentration of H<sup>+</sup> ions



## Domestic

Drinking water 6.5 – 8.5

pH < 7 acidic → Dissolved CO<sub>2</sub> (acidity)

pH > 7 Basic → Dissolved hydroxides and carbonate salts (alkalinity)

## Industrial Applications

pH ~ 8.5

acidic → Corrosive

Basic → Prone to scale formation

# Dissolved Oxygen



Dissolved oxygen (DO) is the amount of oxygen dissolved in a given quantity of water at a particular temperature and atmospheric pressure.

## ○ DO depends on

- Aeration
- Photosynthetic activity of the water
- Respiration of animals and plants
- Speed of water flow
- Roughness of surface over which water flows
- Temperature of the water body



# Dissolved Oxygen

## ○ Oxygen Demanding Wastes

### - Chemical Oxygen Demand (COD)

Chemicals/Organic wastes present in water consume the DO

### - Biological Oxygen Demand (BOD)

Organic wastes reaching water consume oxygen from water bodies for their decomposition by bacteria through biochemical oxidation

## ○ These are useful measures to check water quality



# Dissolved Oxygen (DO)

Oxygen that is freely available in the form of  $O_2$  in water

## Source

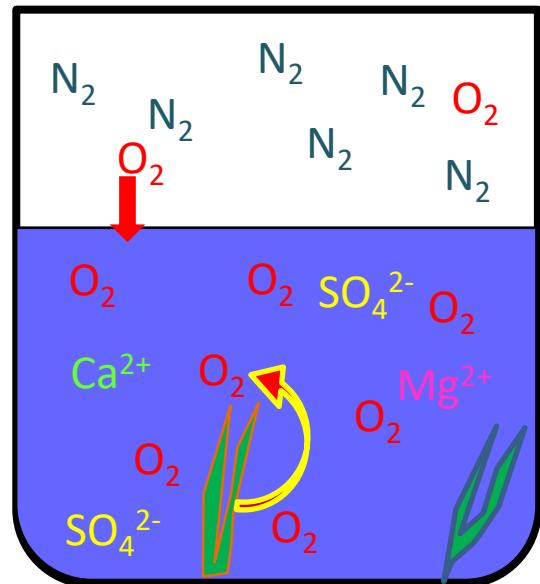
- Atmosphere
- Emitted from photosynthesis process of algae & aquatic plants

DO in water  $\propto$  Pressure (henry's law)

$\propto 1/\text{Temperature}$  (molecular vibrations)

Cold and Fresh water

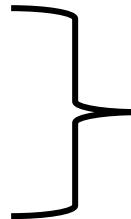
Warm and Salty water





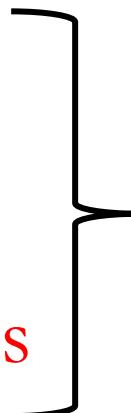
# Parameters affect DO

- Pressure
- Aquatic plants



**Positive effect**

- Temperature
- Salinity
- Dead plants
- Chemically oxidizable Impurities



**Negative effect**

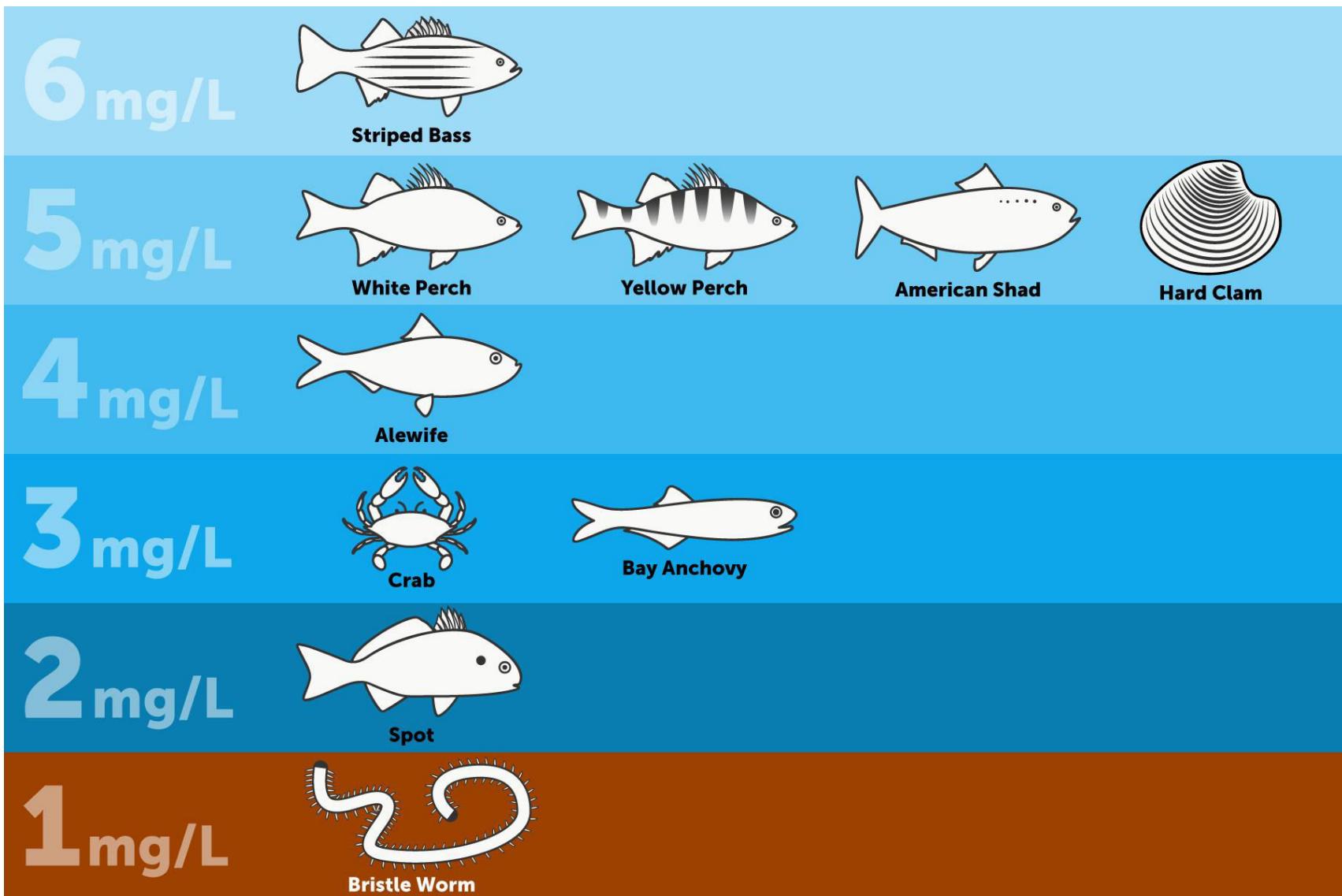
# Importance of DO in water



- It is necessary for healthy aquatic life
- Concentration of DO determines the type of fish and aquatic life in the region
- Higher DO → Healthy aquatic life
- Lower DO → Presence of larva and worms
- Industry → higher DO leads to the corrosion of boilers



# Importance of DO in water





# Dissolved Oxygen Determination

- Sample water with DO + Chemical Compound which takes oxygen from water and oxidizes

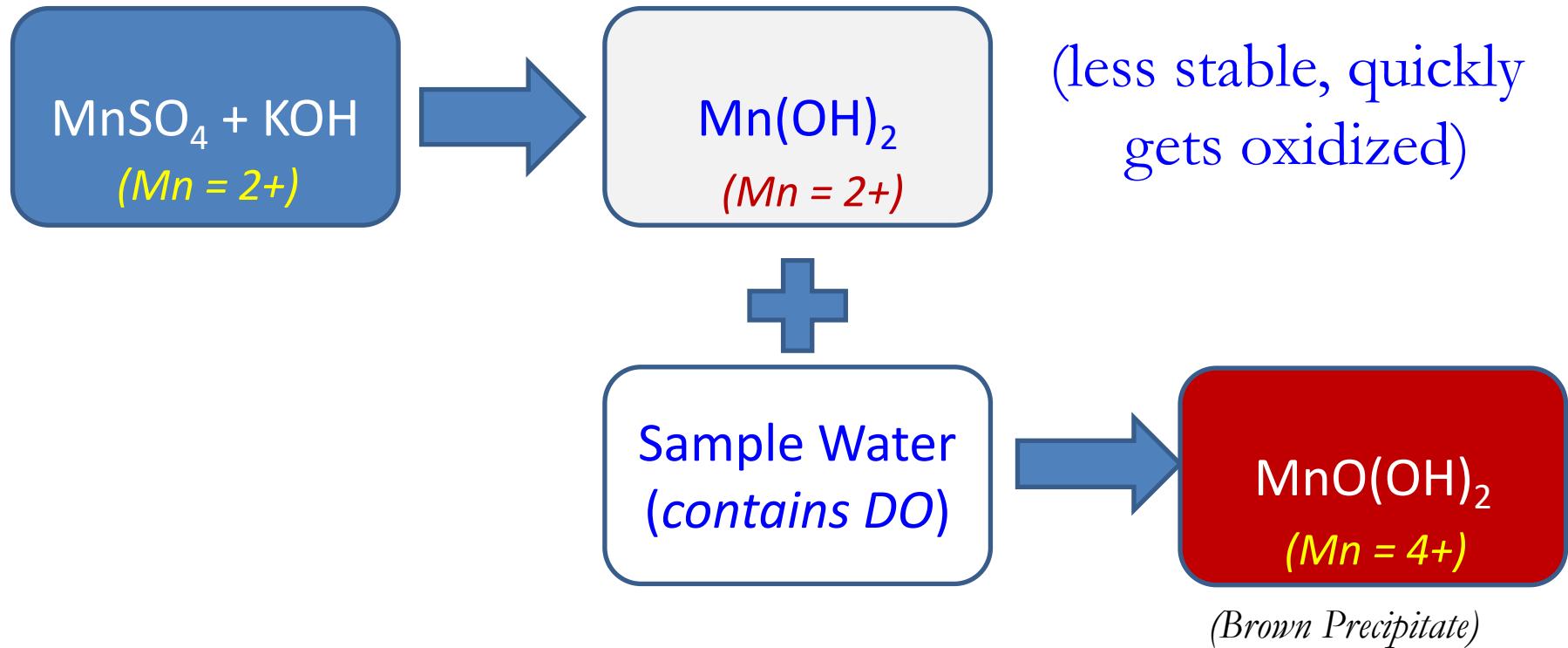
Concentration of oxidized  
chemical compound

$\alpha$  DO

# DO Determination - Winkler's method



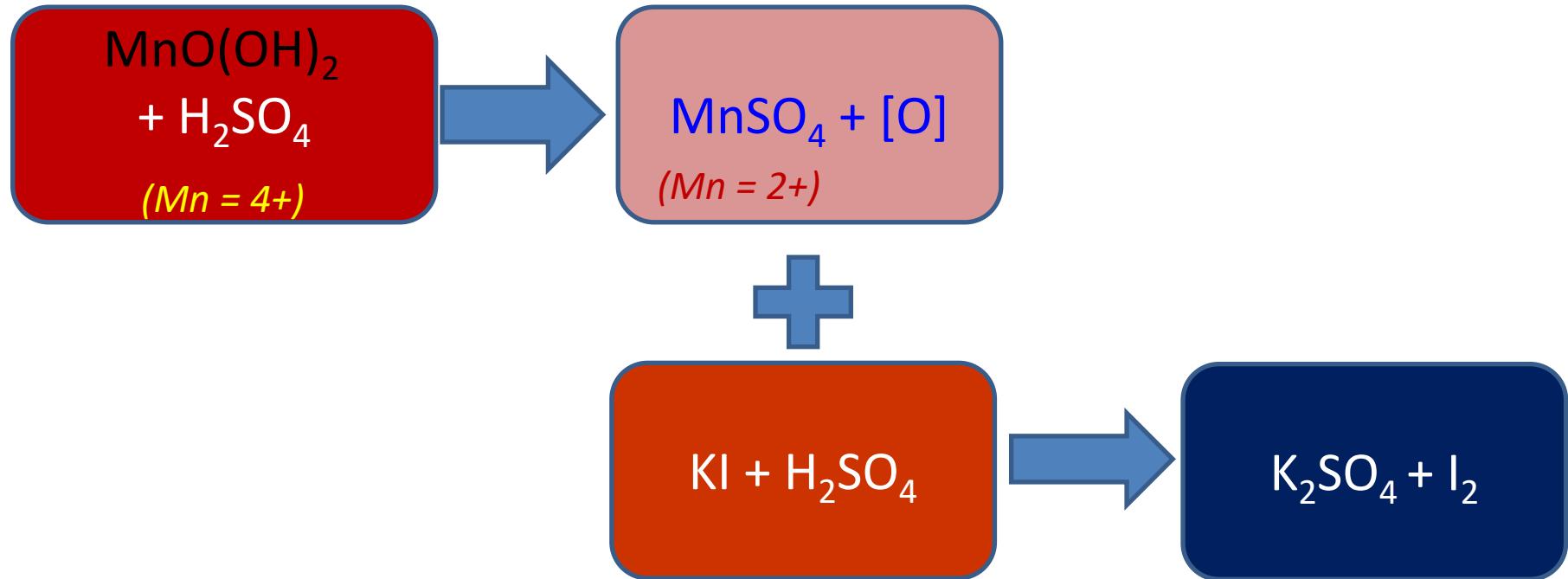
22 Dissolved Oxygen Estimation



- Oxygen present in sample water oxidizes  $\text{Mn}^{2+}$  to  $\text{Mn}^{4+}$



# DO Determination - Winkler's method



- i)  $\text{Mn}^{4+}$  in sulphate form reacts with KI and liberates  $\text{I}_2$   
(Iodometric titration)
- ii)  $[\text{DO}] \propto [\text{Mn}^{4+}] \propto [\text{I}_2]$

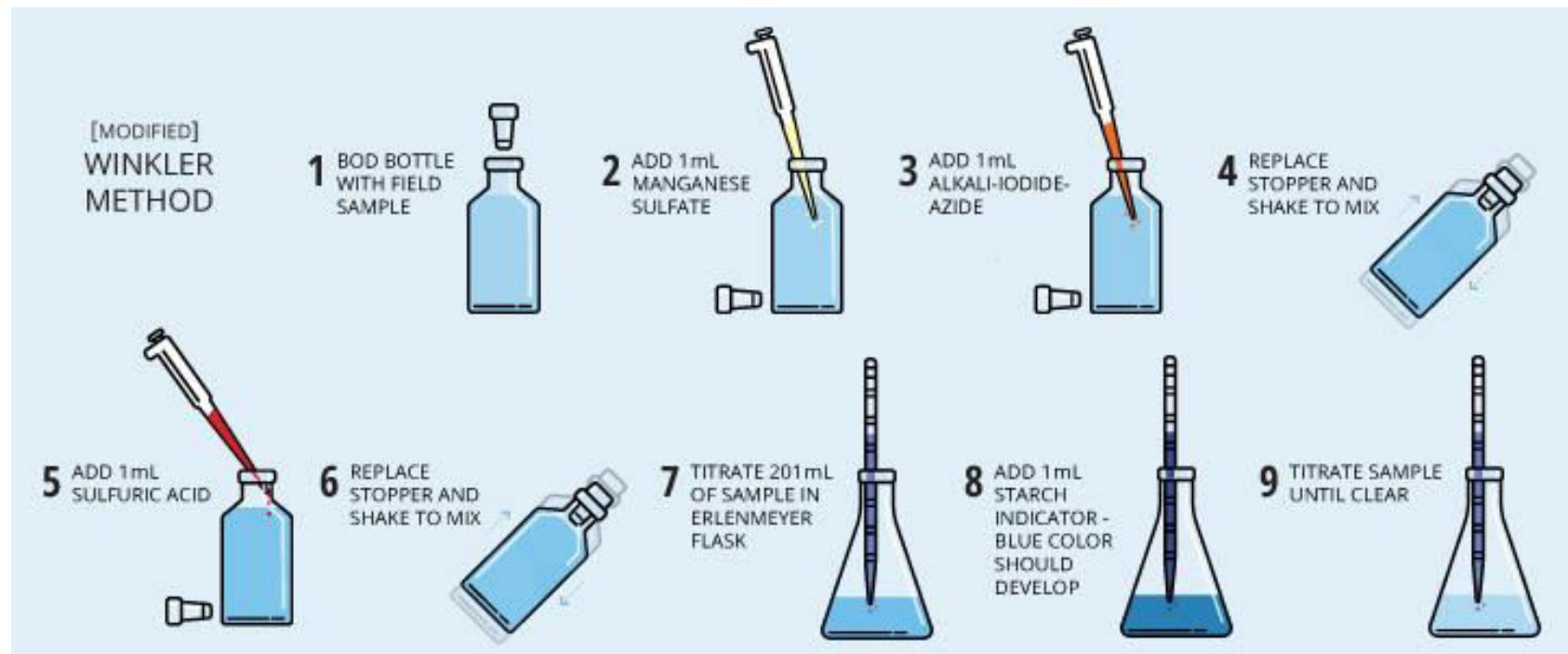
*(Sodium thiosulphate can be used to estimate the concentration of  $\text{I}_2$  with Starch Indicator)*



# Estimation of DO by Winkler's method

## Theory of Winkler's Method:

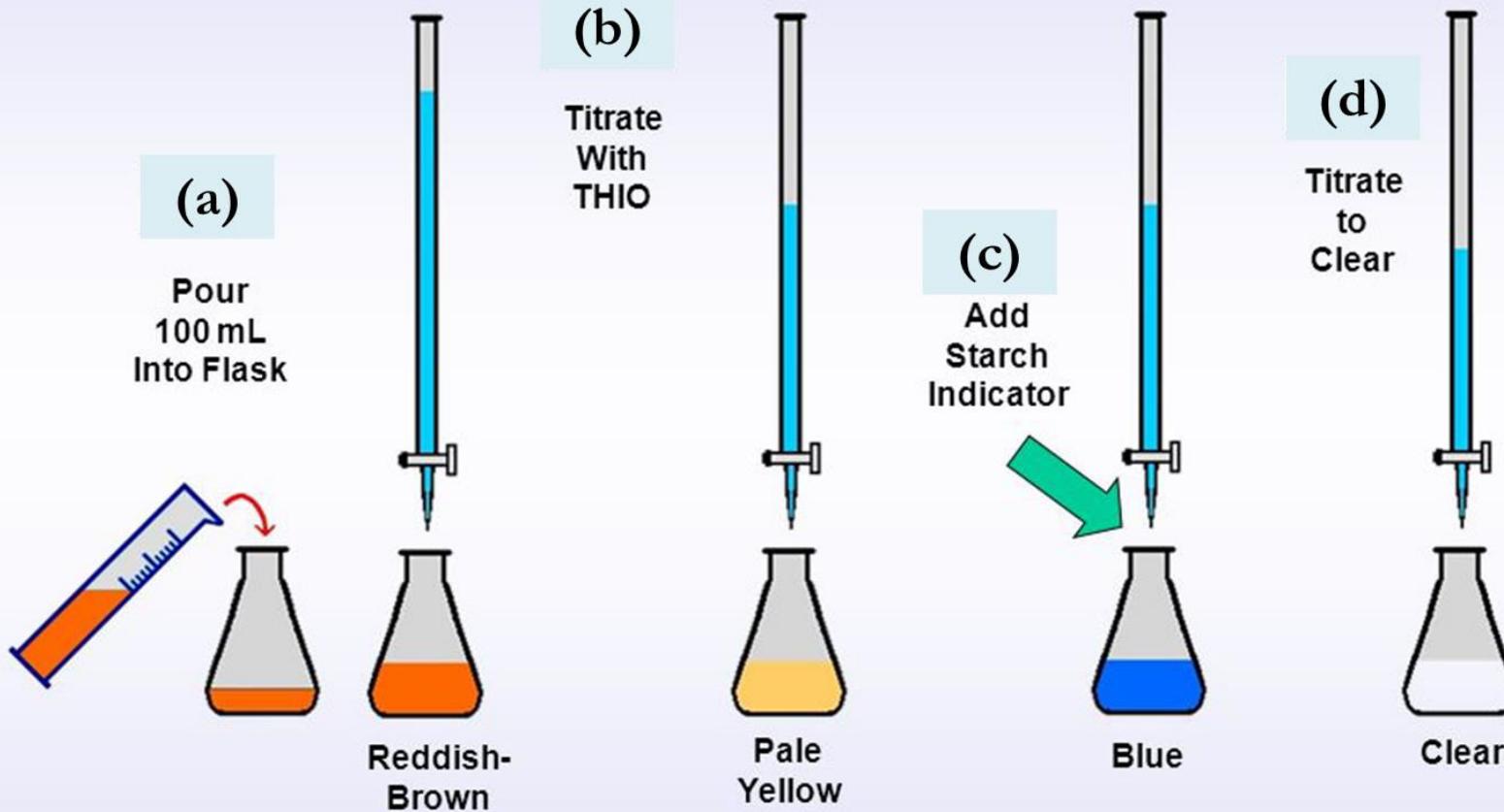
- Oxygen in the water sample oxidizes iodide ion ( $I^-$ ) to iodine ( $I_2$ ) quantitatively.
- The amount of iodine generated is then determined by titration with a standard thiosulfate ( $S_2O_3^{2-}$ ) solution.
- The endpoint is determined by using starch as a visual indicator.





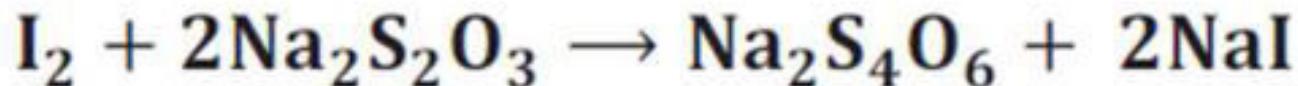
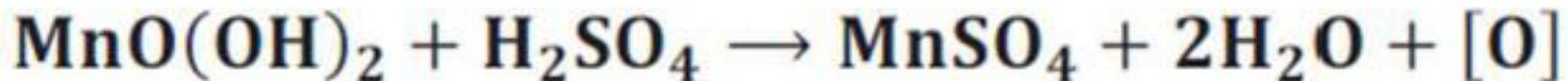
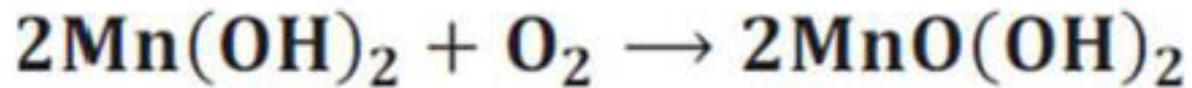
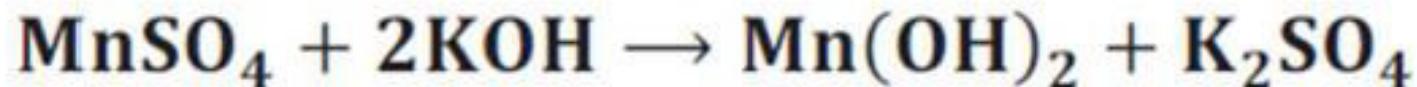
# Estimation of DO by Winkler's method

## Titration of Iodine Solution





# Estimation of DO by Winkler's method

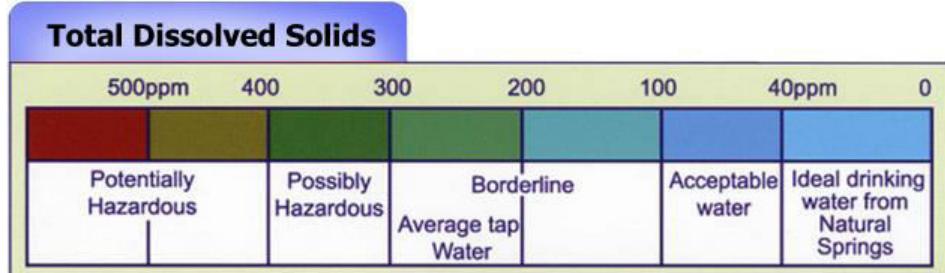


- The amount of oxygen can then be computed from the titre values

# Total Dissolved Solids (TDS)



- Amount of dissolved Ions and molecules remains in water after passing through the filter with the pores  $\sim 2 \mu\text{m}$
- Inorganic salts and some organic compounds
- Normal drinking water  $\sim 25\text{-}250 \text{ mg/L}$ , permissible limit  $< 500 \text{ mg/L}$ , rain water  $\sim 10 \text{ mg/L}$



Changes in TDS → affects the flow of water in and out of the cell

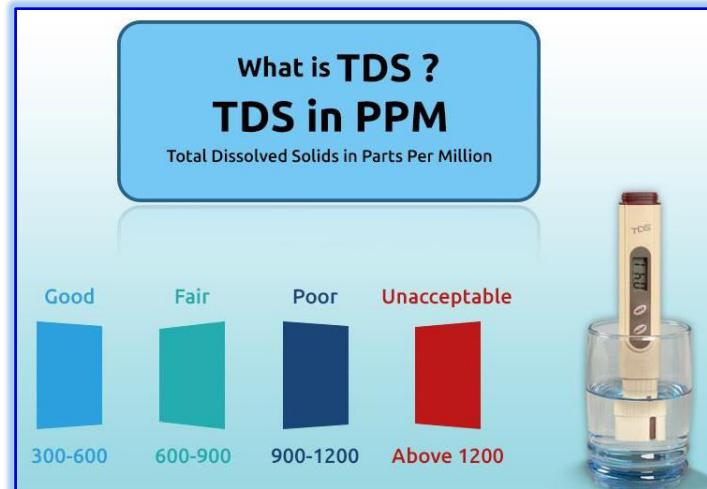
High TDS →  
Hinders the photosynthesis

# Total Dissolved Solids (TDS)



**Total dissolved solids (TDS) is the amount of particles dissolved in water**

- They come from
  - a) Organic sources (leaves)
  - b) Silt (fine sand, clay, or other material carried by running water and deposited as a sediment)
  - c) Industrial wastage and sewage as well as runoff from urban sources, fertilizers and pesticides
  - d) Inorganic materials such as rocks and air that may contain calcium bicarbonate, nitrogen, iron, sulphur and other minerals

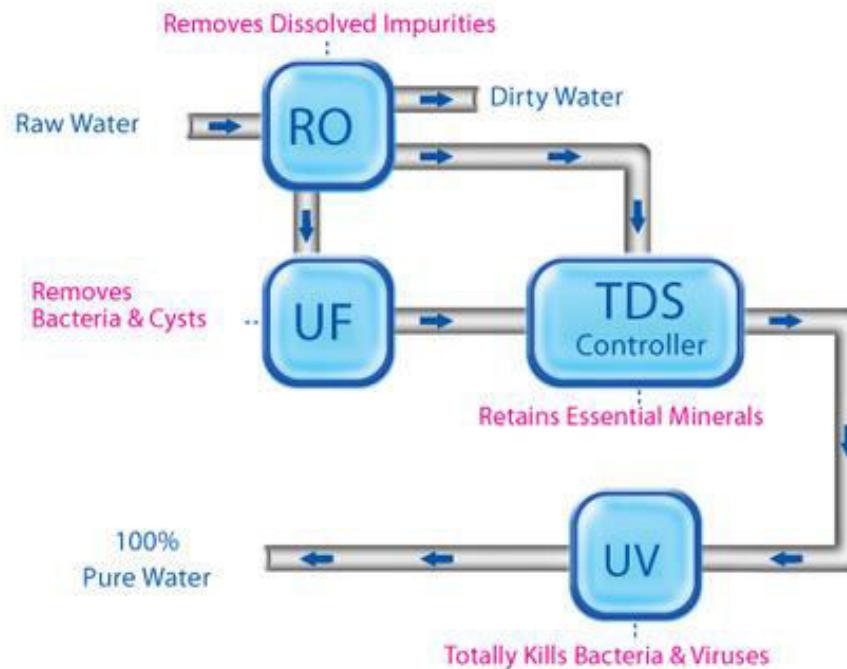


Levels of TDS (milligrams per litre)	Rating
Less than 300	Excellent
300 - 600	Good
600 - 900	Fair
900 - 1,200	Poor
Above 1,200	Unacceptable

# Total Dissolved Solids (TDS)



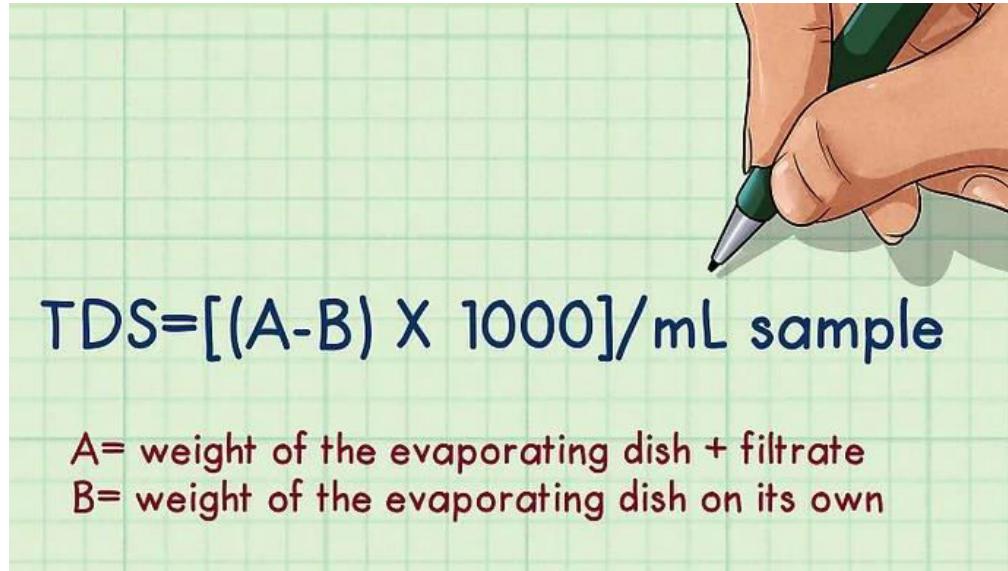
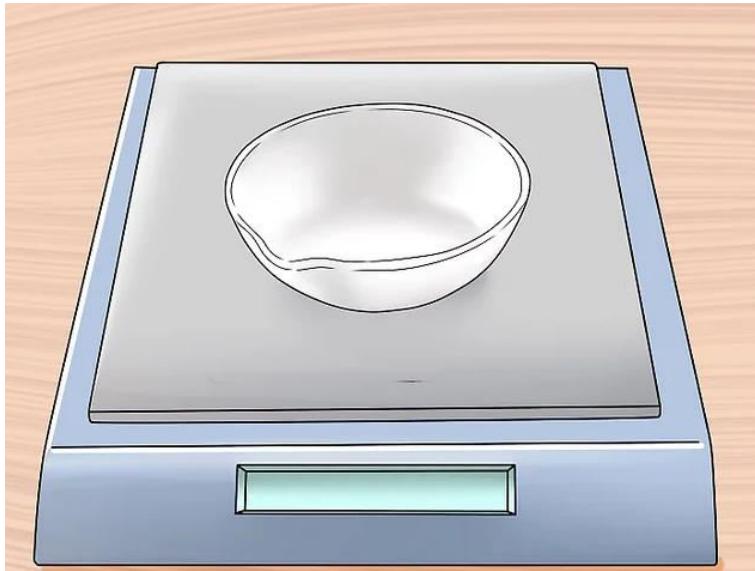
- A constant level of minerals, e.g. Phosphorous, nitrogen and sulphur, is necessary for aquatic life.
- Concentration of dissolved solids should not be too high or too low which can affect the growth and leads to death of many aquatic organisms.
- High concentration of dissolved solids reduces the clarity of water and can decrease the photosynthesis and raises the water temperature.



# Total Dissolved Solids (TDS) - Measurement



- It can be determined taking a known amount (say 100 mL) of water and by evaporating the contents carefully to dryness.
- The residue (W/g) left after evaporation of the filtered sample shows the total dissolved solids present in that particular water sample.





$$\text{TDS} = (W/100) \times 10^6 \text{ mg/L or ppm}$$

## Measurement Methods

- Conductivity
- Gravimetric
- TDS for distilled water will be 0.5-1.5 mg/L
- TDS ranges from 100-20,000 mg/L in river water and will be generally higher in ground water
- Sea water have ~3500 mg/L of TDS
- Lakes and streams will have a TDS of 20-250 mg/L



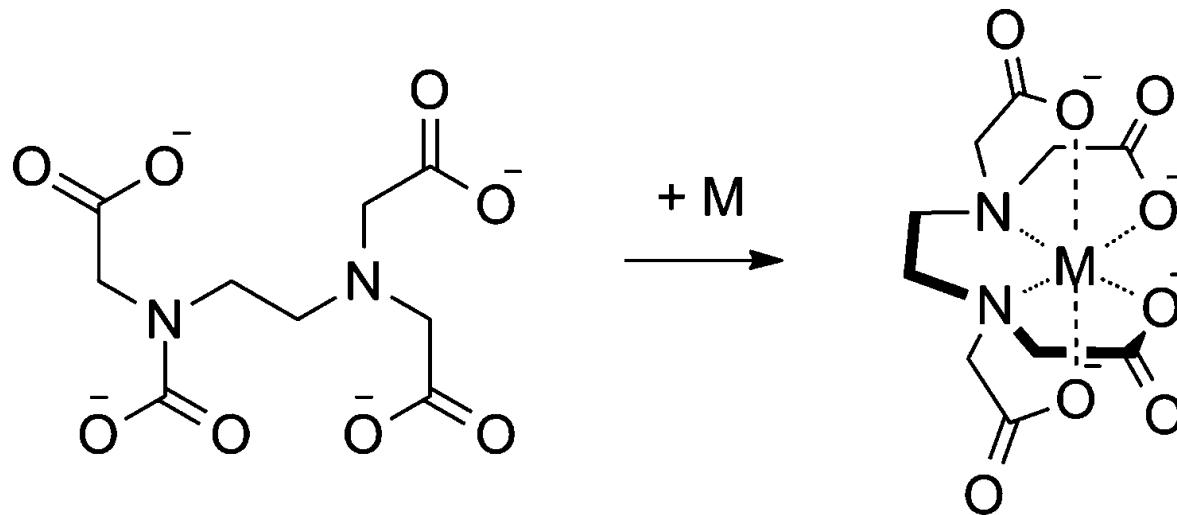
# Estimation of Hardness of Water



## Advantages of EDTA method

This method is preferable because of

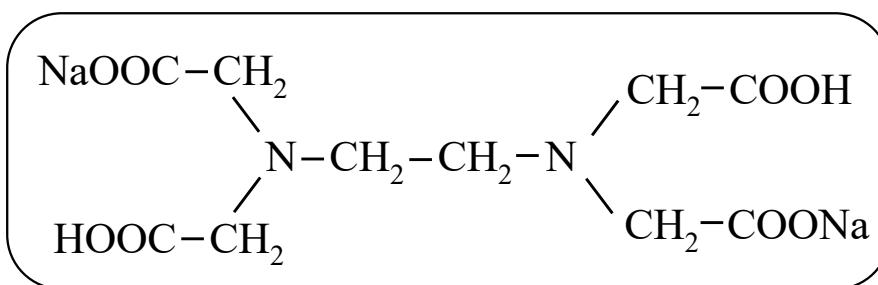
- 1) Greater accuracy
- 2) Convenience
- 3) More rapid procedure



# EDTA method



- Ethylene diamine tetra acetic acid disodium salt (EDTA disodium salt) is used as a strong complexing agent with  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in hard water.
- The structure of EDTA disodium salt is:



- Initially,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  are treated with Eriochrome black T (EBT) indicator using ammonia buffer (to maintain pH between 9-10) to get an unstable complex of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  formed with EBT.



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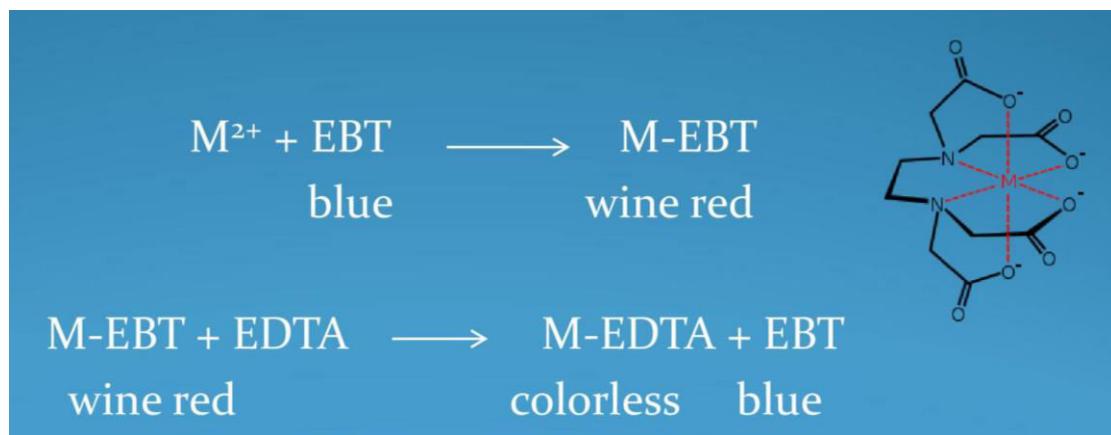
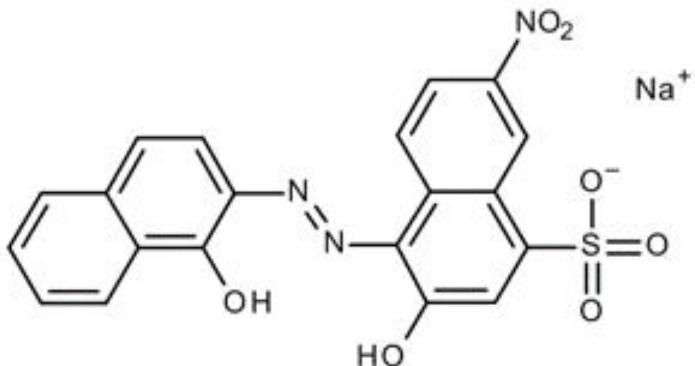
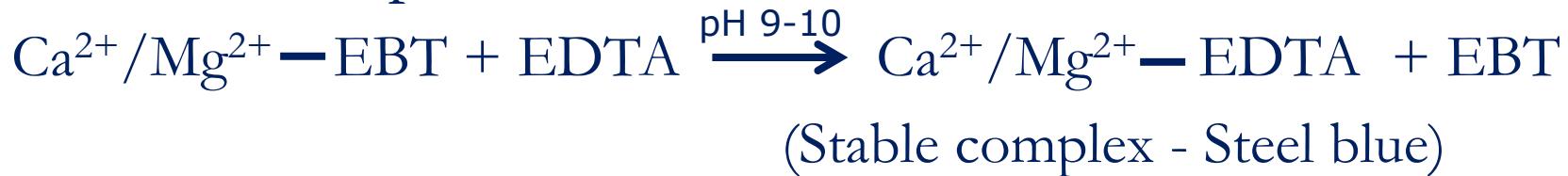
(unstable complex – wine red)



# Estimation Water Hardness

On addition of EDTA, EBT gets replaced by EDTA since EDTA forms a stronger complex with the metal ions.

This is indicated by the formation of a *steel blue* coloured complex.





# Experimental Procedure

## 1) Standardization of EDTA

- o First EDTA Solution is standardized using standard hard water (1 mg/mL of  $\text{CaCO}_3$  equivalents is prepared as standard hard water).
- o For this, first known aliquot of Standard hard water is taken and 10-15 mL of ammonia buffer is added to bring the pH between 9-10.
- o Then a few drops of EBT solution is added to form the unstable complex giving **wine red** colour.
- o This solution is titrated with the EDTA solution till the solution turns to **steel blue** indicating the formation of stable EDTA-Metal ion complex.
- o This volume of EDTA is noted as  $V_1$ .



# Experimental Procedure

## 2) Estimation of Total Hardness

- o The above procedure is repeated with sample hard water of unknown hardness.
- o Volume of EDTA is noted as  $V_2$ .

## 3) Estimation of Permanent Hardness

- o Then sample hard water of 250 mL is taken and evaporated to a volume of 50mL when the temporary hard salts settle down.
- o The solution is filtered and washed thoroughly and made up again to 250mL.
- o From this solution, 50 mL is pipetted out and titrated in similar manner as done with standard hard water.
- o Volume of EDTA is noted as  $V_3$ .

# Experiment

## 1. Preparation of EDTA solution (0.01 M)

i.e. dissolve 3.72 g of sodium salt of EDTA crystals in 1 litre of distilled water

## 2. Preparation of standard Hard Water

- a. dissolve 1.0 g of pure, dry  $\text{CaCO}_3$  in small quantity of conc. HCl and evaporate the solution to dryness
- b. Dissolve the residue in distilled water (1 litre)

*1ml of this solution contains 1 mg of  $\text{CaCO}_3$  equ. hardness*

## 3. Preparation of buffer solution

Add 67.5 g of  $\text{NH}_4\text{Cl}$  to 570 ml of conc. Ammonia soln. and dilute with distilled water to 1 litre

## 4. Preparation of indicator

Dissolve 0.5 g of EB-T in <sup>32</sup>100 ml alcohol



## 5. Standardization of EDTA solution

Burette - EDTA solution (0.01 M)



Conical Flask - 50 ml of std. hard water + ammonia buffer + few drops of EB-T indicator

*Volume of EDTA consumed =  $V_1$ , ml*

### a) Standardization of EDTA:

$V_1$  mL of EDTA is consumed by 50 mL of std. hard water

$V_1$  mL of EDTA = 50 mg of  $\text{CaCO}_3$

$$1 \text{ mL of EDTA} = \left( \frac{50}{V_1} \right) \text{ mg of } \text{CaCO}_3$$



## 6.Estimination of total Hardness

**Conical Flask -** 50 ml of sample + hard water      10-15 ml of ammonia buffer      few drops of EB-T indicator

b) Total hardness:

$$\text{Volume of EDTA consumed} = V_2 \text{ ml}$$

$$1 \text{ mL of EDTA} = \left( \frac{50}{V_1} \right) \text{ mg of CaCO}_3$$

$$\text{So, } V_2 \text{ mL of EDTA} = \left( \frac{50}{V_1} \right) \times V_2 \text{ mg of CaCO}_3$$

$$\text{Therefore, } 1000 \text{ mL of sample hard water} = \left( \frac{50}{V_1} \right) \times \left( \frac{V_2}{50} \right) \times 1000 \text{ mg/L}$$

$$\text{i.e. Total hardness of sample hard water} = \left( \frac{V_2}{V_1} \right) \times 1000 \text{ mg of CaCO}_3 (\text{ppm.})$$



## 7. Estimation of permanent hardness

Sample water is boiled and filtered

**Conical Flask –** **50 mL of boiled & filtered sample hard water** + **10-15 mL of ammonia buffer** + **Few drops of EB-T Indicator**

c) Permanent hardness:

*Volume of EDTA consumed =  $V_3$  mL*

$$1 \text{ mL of EDTA} = \left( \frac{50}{V_1} \right) \text{ mg of CaCO}_3$$

$$\text{So, } V_3 \text{ mL of EDTA} = \left( \frac{50}{V_1} \right) \times V_3 \text{ mg of CaCO}_3$$

$$\text{Therefore, } 1000 \text{ mL of sample hard water} = \left( \frac{50}{V_1} \right) \times \left( \frac{V_3}{50} \right) \times 1000 \text{ mg/L}$$

$$\text{i.e. Permanent hardness of sample hard water} = \left( \frac{V_3}{V_1} \right) \times 1000 \text{ mg of CaCO}_3 (\text{ppm.})$$



# Temporary hardness calculation

Temporary hardness:

**Temporary hardness = Total hardness – permanent hardness**

$$= \left( \frac{V_2}{V_1} \times 1000 \right) - \left( \frac{V_3}{V_1} \times 1000 \right)$$

$$= \left( \frac{V_2 - V_3}{V_1} \times 1000 \right)$$



# Formula

- Hardness per mL of EDTA =  $(50/V_1)$
- Total hardness of sample hard water =  $\left(\frac{V_2}{V_1}\right) \times 1000$  mg/L
- Permanent hardness =  $\left(\frac{V_3}{V_1}\right) \times 1000$  mg/L
- Temporary Hardness = Total Hardness – Permanent hardness

Provided the **volume** of standard hard water, sample hard water and boiled & filtered sample hard water **are same**

# Numerical problems in hardness determination by EDTA



- (1) The standard hard water is prepared by dissolving 1 g of  $\text{CaCO}_3$  in HCl and the solution is made up to 1000 mL with deionized water. 50 mL of the prepared solution requires 20 mL of EDTA solution for titration. 50 mL of sample water requires 15 mL of EDTA solution and after boiling and filtering 50 mL of the solution requires 10 mL of EDTA. Calculate the total, carbonate and non-carbonate hardness of the water sample.

# Numerical problems in hardness determination by EDTA



## Solution

$V_1 = 20 \text{ mL}$  (volume of standard hard water = **50 mL**)

$V_2 = 15 \text{ mL}$  (volume of sample hard water = **50 mL**)

$V_3 = 10 \text{ mL}$  (volume of boiled sample hard water = **50 mL**)

$$\begin{aligned} \text{Total hardness of sample hard water} &= \left( \frac{V_2}{V_1} \right) \times 1000 \text{ mg/L} \\ &= (15/20) \times 1000 = 750 \text{ ppm} \end{aligned}$$

$$\begin{aligned} \text{Permanent hardness} &= \left( \frac{V_3}{V_1} \right) \times 1000 \text{ mg/L} \\ &= (10/20) \times 1000 = 500 \text{ ppm} \end{aligned}$$

$$\begin{aligned} \text{Temporary Hardness} &= \text{Total Hardness} - \text{Permanent hardness} \\ &= 750 - 500 = 250 \text{ ppm} \end{aligned}$$



# Formula

- Total hardness of sample hard water =  $\left(\frac{x}{V_1}\right) \times \left(\frac{V_2}{y}\right) \times 1000$  mg/L
- Permanent hardness =  $\left(\frac{x}{V_1}\right) \times \left(\frac{V_3}{z}\right) \times 1000$  mg/L
- Temporary Hardness = Total Hardness – Permanent hardness

- x = Volume of standard hard water used for EDTA standardisation
- y = Volume of sample hard water used
- z = Volume of boiled & filtered sample hard water used

If the **volume of standard hard water, sample hard water and boiled & filtered sample hard water are different**



(2) 20 ml of std water containing 1 g/L of pure  $\text{CaCO}_3$  per liter consumed 25 ml of EDTA. 100 ml of water sample consumed 18 ml of EDTA using EBT as indicator. While same water sample after boiling requires 12 ml of EDTA for 100 mL boiled water. Calculate carbonate and non-carbonate hardness of water.

# Numerical problems in hardness determination by EDTA



## Solution

$V_1 = 25 \text{ mL}$  (volume of standard hard water = **20 mL**)

$V_2 = 18 \text{ mL}$  (volume of sample hard water = **100 mL**)

$V_3 = 12 \text{ mL}$  (volume of boiled sample hard water = **100 mL**)

$$\begin{aligned}\text{Total hardness of sample hard water} &= \left(\frac{20}{V_1}\right) \times \left(\frac{V_2}{100}\right) \times 1000 \text{ mg/L} \\ &= \left(\frac{20}{25}\right) \times \left(\frac{18}{100}\right) \times 1000 = 144 \text{ ppm}\end{aligned}$$

$$\begin{aligned}\text{Permanent hardness} &= \left(\frac{20}{V_1}\right) \times \left(\frac{V_3}{100}\right) \times 1000 \text{ mg/L} \\ &= \left(\frac{20}{25}\right) \times \left(\frac{12}{100}\right) \times 1000 = 96 \text{ ppm}\end{aligned}$$

$$\begin{aligned}\text{Temporary Hardness} &= \text{Total Hardness} - \text{Permanent hardness} \\ &= 144 - 96 = 48 \text{ ppm}\end{aligned}$$



# Numerical problems in hardness determination by EDTA

(3) 50 ml of std water containing 1 g/L of pure  $\text{CaCO}_3$  per liter consumed 20 ml of EDTA. 20 ml of water sample consumed 18 ml of EDTA. While same water sample after boiling requires 12 ml of EDTA for 40 mL boiled water. Calculate carbonate and non-carbonate hardness of water

# Numerical problems in hardness determination by EDTA



## Solution

$V_1 = 20 \text{ mL}$  (volume of standard hard water = **50 mL**)

$V_2 = 18 \text{ mL}$  (volume of sample hard water = **20 mL**)

$V_3 = 12 \text{ mL}$  (volume of boiled hard water = **40 mL**)

$$\begin{aligned}\text{Total hardness of sample hard water} &= \left(\frac{50}{V_1}\right) \times \left(\frac{V_2}{20}\right) \times 1000 \text{ mg/L} \\ &= \left(\frac{50}{20}\right) \times \left(\frac{18}{20}\right) \times 1000 = 2250 \text{ ppm}\end{aligned}$$

$$\begin{aligned}\text{Permanent hardness} &= \left(\frac{50}{V_1}\right) \times \left(\frac{V_3}{40}\right) \times 1000 \text{ mg/L} \\ &= \left(\frac{50}{20}\right) \times \left(\frac{12}{40}\right) \times 1000 = 750 \text{ ppm}\end{aligned}$$

$$\begin{aligned}\text{Temporary Hardness} &= \text{Total Hardness} - \text{Permanent hardness} \\ &= 2250 - 750 = 1500 \text{ ppm}\end{aligned}$$

# Numerical problems in hardness determination by EDTA



(4) 0.5 g of  $\text{CaCO}_3$  was dissolved in HCl and the solution made up to 1000 mL with distilled water. 50 mL of the solution required 50 mL of EDTA solution for titration. 50 mL of hard water sample required 18 mL of EDTA and after boiling and filtering required 10 mL of EDTA solution. Calculate each type of hardness of water.

0.5 g of  $\text{CaCO}_3$  was dissolved in HCl and the solution made up to 1 L with distilled water.  
06.Numericals-EDTA Experiment

1 L of standard hard water contains 0.5 g of  $\text{CaCO}_3$

1000 mL of standard hard water contains 500 mg of  $\text{CaCO}_3$

1 mL of standard hard water contains 0.5 mg of  $\text{CaCO}_3$

### Titration - I

50 mL of the solution required 50 mL of EDTA solution for titration. ( $V_1 = 50 \text{ mL}$ )

$$50 \text{ mL of EDTA} = 50 \text{ mL of standard hard water}$$

$$= 50 \times 0.5 \text{ mg of } \text{CaCO}_3$$

$$= 25 \text{ mg of } \text{CaCO}_3$$

$$1 \text{ mL of EDTA} = 25/50 = \mathbf{0.5 \text{ mg of } \text{CaCO}_3}$$

### Titration - II

50 mL of hard water sample required 18 mL of EDTA ( $V_2 = 18 \text{ mL}$ )

$$1000 \text{ mL of sample hard water} = 0.5 \times \left(\frac{V_2}{50}\right) \times 1000 \text{ mg/L}$$

$$= 0.5 \times \left(\frac{18}{50}\right) \times 1000 \text{ mg/L}$$

$$\text{Total hardness} = \mathbf{180 \text{ ppm } \text{CaCO}_3 \text{ eq.}}$$

### Titration - III

50 mL of hard water sample after boiling and filtering required 10 mL of EDTA solution ( $V_3 = 10 \text{ mL}$ )

$$1000 \text{ mL of sample hard water} = 0.5 \times \left(\frac{V_3}{50}\right) \times 1000 \text{ mg/L}$$

$$= 0.5 \times \left(\frac{10}{50}\right) \times 1000 \text{ mg/L}$$

$$\text{Permanent hardness} = \mathbf{100 \text{ ppm } \text{CaCO}_3 \text{ eq.}}$$

$$\begin{aligned} \text{Temporary hardness} &= \text{Total hardness} - \text{Permanent hardness} \\ &= 180 - 100 = \mathbf{80 \text{ ppm } \text{CaCO}_3 \text{ eq.}} \end{aligned}$$



(5) A std hard water contains 15 g of  $\text{CaCO}_3$  /1 L. 20 mL of this required 25 mL of EDTA. 100 mL of Sample water required 18 mL of EDTA solution the same sample after boiling required 12 mL of EDTA solution calculate the temporary hardness of the given sample of water in terms of ppm.

06.Numericals-EDTA Experiment  
15 g of  $\text{CaCO}_3$  was dissolved in HCl and the solution made up to 1 L with distilled water.

1 L of standard hard water contains 15 g of  $\text{CaCO}_3$

1000 mL of standard hard water contains 15000 mg of  $\text{CaCO}_3$

1 mL of standard hard water contains 15 mg of  $\text{CaCO}_3$

### Titration - I

20 mL of the solution required 25 mL of EDTA solution for titration. ( $V_1 = 25 \text{ mL}$ )

$$25 \text{ mL of EDTA} = 20 \text{ mL of standard hard water}$$

$$= 20 \times 15 \text{ mg of } \text{CaCO}_3$$

$$= 300 \text{ mg of } \text{CaCO}_3$$

$$1 \text{ mL of EDTA} = 300/25 = \mathbf{12 \text{ mg of } \text{CaCO}_3}$$

### Titration - II

100 mL of hard water sample required 18 mL of EDTA ( $V_2 = 18 \text{ mL}$ )

$$1000 \text{ mL of sample hard water} = 12 \times \left( \frac{V_2}{100} \right) \times 1000 \text{ mg/L}$$

$$= 12 \times \left( \frac{18}{100} \right) \times 1000 \text{ mg/L}$$

$$\text{Total hardness} = \mathbf{2160 \text{ ppm } \text{CaCO}_3 \text{ eq.}}$$

### Titration - III

100 mL of hard water sample after boiling and filtering required 12 mL of EDTA solution ( $V_3 = 12 \text{ mL}$ )

$$1000 \text{ mL of sample hard water} = 12 \times \left( \frac{V_3}{100} \right) \times 1000 \text{ mg/L}$$

$$= 12 \times \left( \frac{12}{100} \right) \times 1000 \text{ mg/L}$$

$$\text{Permanent hardness} = \mathbf{1440 \text{ ppm } \text{CaCO}_3 \text{ eq.}}$$

$$\text{Temporary hardness} = \text{Total hardness} - \text{Permanent hardness}$$

$$= 2160 - 1440 = \mathbf{720 \text{ ppm } \text{CaCO}_3 \text{ eq.}}$$



- (6) 0.25 gm of  $\text{CaCO}_3$  was dissolved in HCl and the solution made up to 250 mL with distilled water. 50 mL of the solution required 20 mL of EDTA solution for titration. 50 mL of hard water sample required 18 mL of EDTA and after boiling and filtering required 10 mL of EDTA solution.
- Calculate temporary hardness of water



(7) 0.45 gm of  $\text{CaCO}_3$  was dissolved in HCl and the solution made up to 500 mL with distilled water. 50 mL of the solution required 50 mL of EDTA solution for titration. 50 mL of hard water sample required 20 mL of EDTA and after boiling and filtering required 8 mL of EDTA solution. Calculate each type of hardness of water.



# Pros and Cons of EDTA Titration

## Advantages

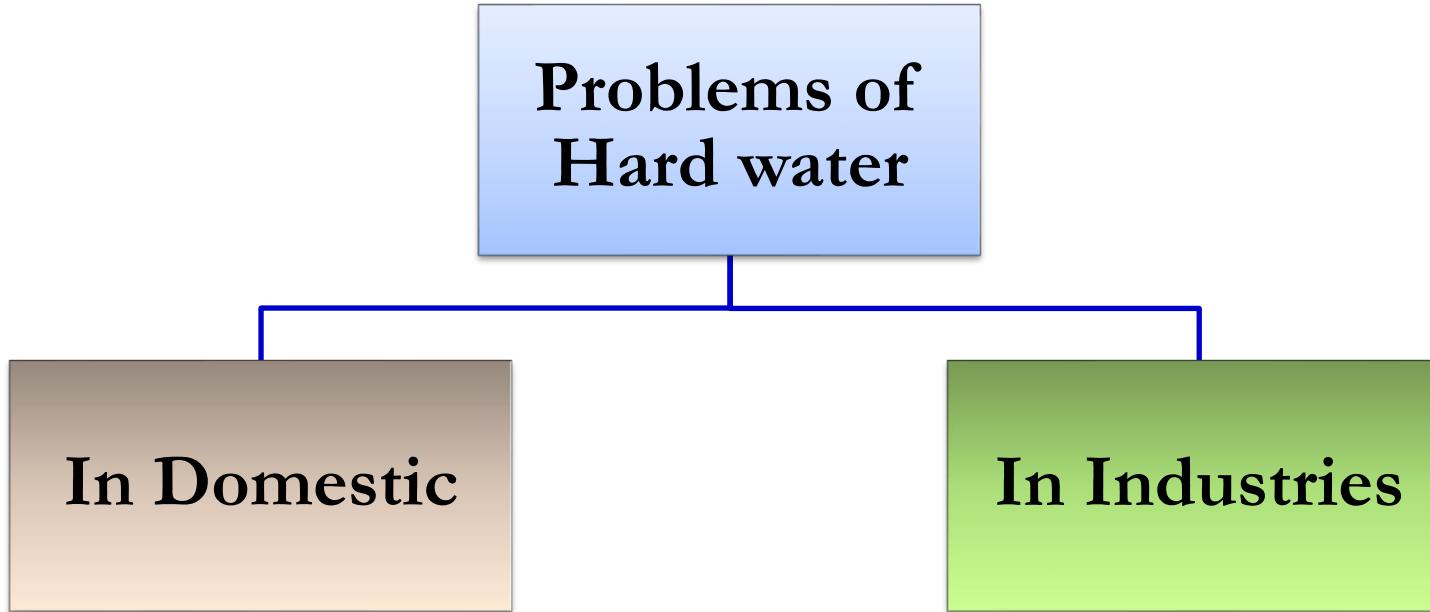
- ✓ It is very simple and fairly accurate method
- ✓ It is also very cost efficient
- ✓ It is also very quick and time efficient process when compared to gravimetric analysis

## Disadvantages

- Possible human error during the preparation of solution and the titration.
- EDTA grabs all the metal ions in the water, not just the  $\text{Ca}^{2+}$  ions. This gives us a value that is not truly the concentration of  $\text{Ca}^{2+}$  ions. This causes an experimental error of about 1%, but that is acceptable.



# Disadvantages of hard water



## In Domestic

- Washing & bathing
- Cooking
- Drinking

## In Industries

- Paper industry
- Textile industry
- Sugar industry
- In concrete making
- In steam generation boiler

# Problems of hard water - Domestic use



## a) Washing:

- Hard water, when used for washing purposes, does not lather freely with soap.
- It produces sticky precipitates of calcium and magnesium soaps.
- Similar problem exists in bathing.



## HARD WATER PROBLEMS



Tiles



TAPS

Hair  
ProblemRough  
Skin



## b) Cooking:

- Due to the presence of dissolved hardness producing salts the boiling point of water is elevated.
- Consequently more fuel and time are required for cooking.

### Colligative Property – Boiling point elevation

$$\Delta T_b = T_b - T_b^* = \left( \frac{RT_b^*}{\Delta H_{vap}} \right) \chi_{\text{Solute}}$$

$\Delta T_b$	= Boiling point elevation
$T_b$	= Boiling point of solution
$T_b^*$	= Boiling point of pure solvent
$\Delta H_{vap}$	= Enthalpy of vapourisation
$\chi_{\text{Solute}}$	= molarity of solute

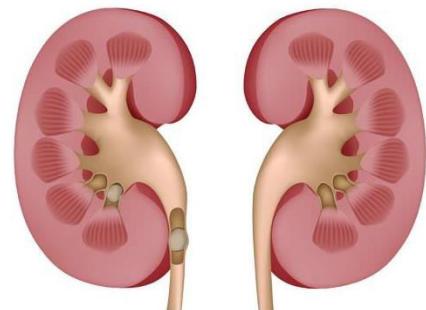
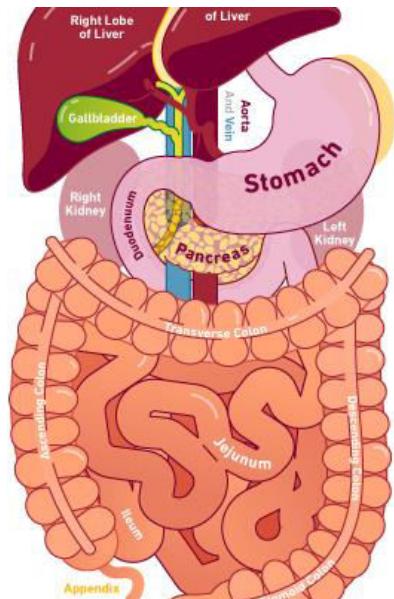
- Boiling point elevation is directly proportional to the molarity of the solute
- Each mole of solute particles raises the boiling point of 1 kg of water by 0.51 °C

# Problems of hard water - Domestic use



## c) Drinking:

- Hard water causes bad effect on our digestive system.
- The possibility of forming calcium oxalate crystals in urinary tracks is increased (Kidney stones).



**KIDNEY  
STONES AND  
HARD WATER**

# Disadvantages of hard water in industries



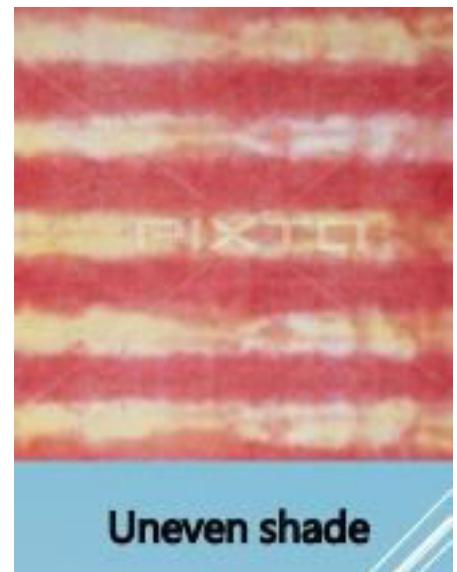
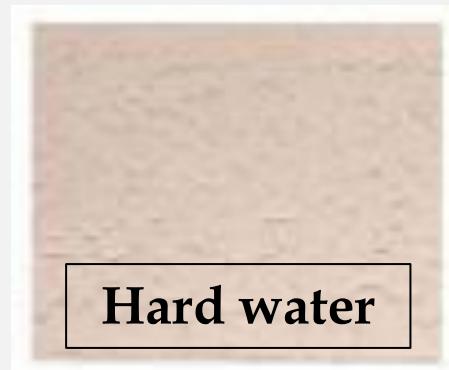
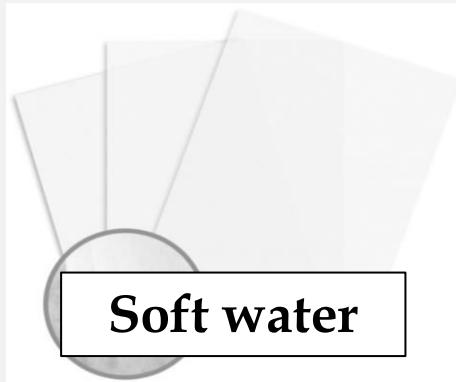
## Paper Industry:

- The presence of calcium and magnesium has impact on the properties and quality of paper and their products

## Textile industry:

- $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions of hard water react with dye molecules and precipitate the dye.
- During dyeing process, calcium and magnesium salts present in water make the quality of the shades very poor.

**Quality of paper based on the water used for the process**





# Disadvantages of hard water in industries

## Sugar industry:

- If nitrates, sulphates of calcium and magnesium are present, they cause hindrance to crystallization of sugar

## Concrete making:

- Water containing chlorides and sulphates, if used for concrete making, affects the hydration of the cement and the final strength of the hardened concrete.

## In steam generation boilers:

- If the hard water is fed directly to the boilers, which led to the many problems such as “Formation of scales which corrodes the boiler, wastage of fuel, etc.”



Sugar crystals

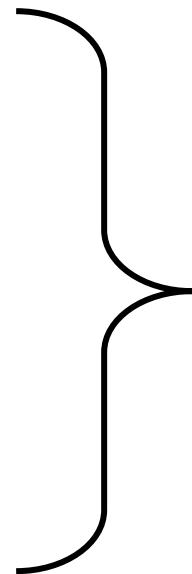


Concrete wall



# Effect of Hard water on steam boilers

1. Sludge and Scale formation
2. Priming & Foaming
3. Caustic embrittlement
4. Boiler corrosion



- How it forms
- Disadvantages
- Prevention

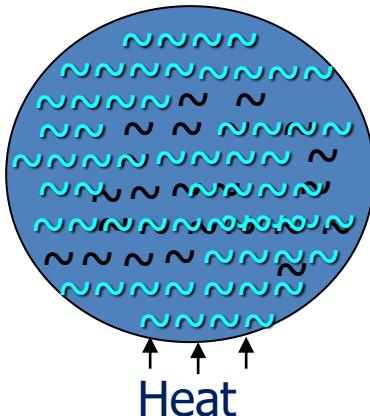


# Effect of Hard water on steam boilers

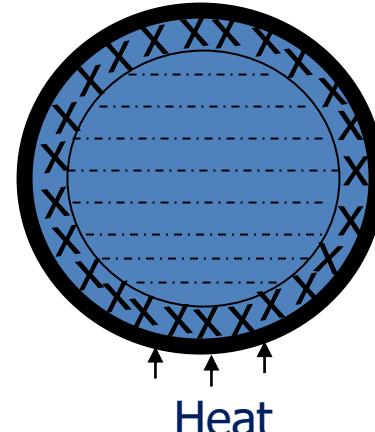
## 1. Sludge and Scale formation:

- Continuous evaporation of water takes places and concentration of dissolved salts (present in hard water) gets increased.
- At saturation point, it forms precipitates on the inner walls of the boiler
- **Sludges** : If loose & slimy precipitate formed
- **Scale** : If sticky, hard & adherent coat formed

**a) Sludges**



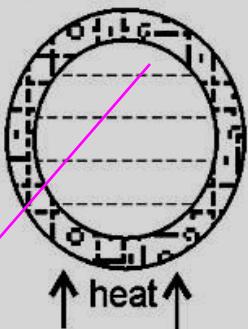
**b) Scales**





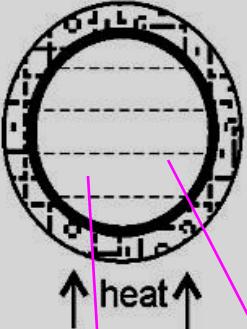
# Examples of Sludge and Scale

Loose Precipitate  
Suspended in water  
(sludge)



↑ heat ↑

Adherent  
coating inside  
the boiler  
(scale)



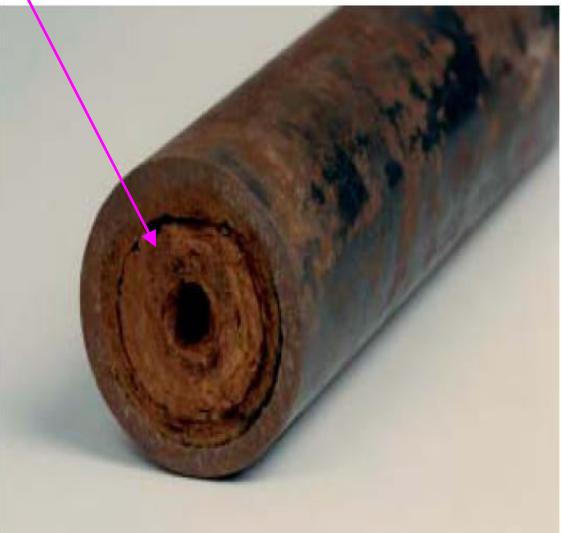
↑ heat ↑



Could this sludge be inside  
your central heating system?



Boiler scale on water side





# Difference between Sludge & Scale

<b>Sludge</b>	<b>Scale</b>
Soft, loose & slimy precipitates	Hard deposits
Non-adherent deposits & can be easily scrapped off with a wire brush	Sick very firmly to the inner surface of boiler and are very difficult to remove
Formed by substances like $\text{CaCl}_2$ , $\text{MgCl}_2$ , $\text{MgSO}_4$ & $\text{MgCO}_3$	Formed by substances like $\text{CaSO}_4$ , $\text{Mg(OH)}_2$ , $\text{CaCO}_3$ & $\text{CaSiO}_3$
Formed generally at colder portions	Formed generally at heated portions of the boiler
Decrease the efficiency of boiler but are less dangerous	Decrease the efficiency of boiler and possesses the chances of explosions



### (i) Sludge formation in boilers

- Sludge is a soft, loose and slimy precipitate formed within the boiler.
- Sludge can be easily scrapped off with the wire brush.
- It is formed comparatively colder portions of the boiler and collects in the bends where the flow rate is slow
- Sludges are formed by substances which have greater solubilities in hot water than in cold water, e.g.,  $MgCO_3$ ,  $CaCl_2$ , etc.



### (i). Sludge formation in boilers

#### Disadvantage of sludge formation

- ❖ Sludges are poor conductor of heat, so they tend to waste a portion of heat.
- ❖ Excessive sludge formation disturbs the working of the boiler.  
It settle at the bends thereby causing blocking

#### Prevention of sludge formation

By using well softened water and by frequently blow down operation



## (ii). Scales formation in boilers

### Decomposition of calcium bicarbonate

- Scales are the main source of boiler troubles. Scale composed chiefly of calcium carbonate and is the main cause of scale formation in low-pressure boilers.



Scale

- But in high-pressure boilers,  $\text{CaCO}_3$  is soluble.





### (ii). Scales formation in boilers

#### Decomposition of calcium sulphate

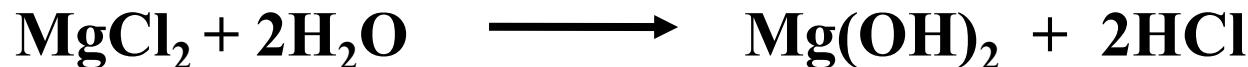
- The solubility of calcium sulphate in water decreases with increase of temperature (because dissolution of  $\text{CaSO}_4$  is an exothermic process).
- The solubility of  $\text{CaSO}_4$  is 3,200 ppm at  $15^\circ\text{C}$  and it reduces to 55 ppm at  $230^\circ\text{C}$  and 27 ppm at  $320^\circ\text{C}$
- $\text{CaSO}_4$  gets precipitated as hard scale on the heated portion of the boiler. This is the main cause of scales in high-pressure boilers.



### (ii). Scales formation in boilers

#### Hydrolysis of magnesium salts

Dissolved magnesium salts undergo hydrolysis forming magnesium hydroxide precipitate which forms a soft type of scale



#### Presence of Silica

presence of silica in small quantities deposits as calcium silicate ( $\text{CaSiO}_3$ ) or magnesium silicate ( $\text{MgSiO}_3$ ). These deposits stick very firmly on the inner side of the boiler surface and are very difficult to remove



# Disadvantage of scale formation

- Low thermal conductivity

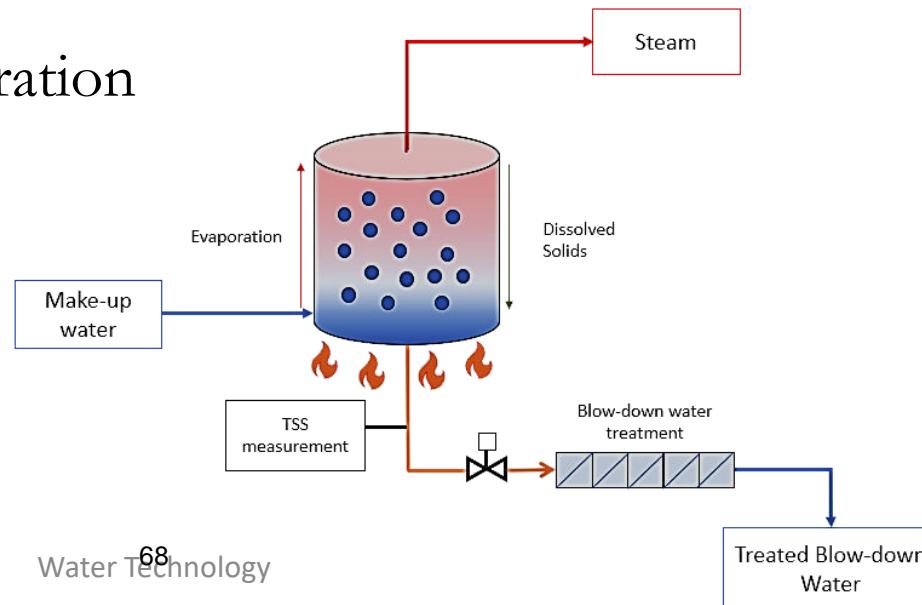
<b>Thickness of scale (mm)</b>	0.325	0.625	1.25	2.5	12
<b>Wastage of fuel</b>	10%	15%	50%	80%	150%

- Lowering boiler safety
- Decrease in efficiency
- Danger of explosion



# Removal of Scales

- By giving thermal Shock if they are brittle (heating the boiler and then suddenly cooling with cold water)
- If they are adherent and hard – dissolving them with help of chemicals.
  - Calcium carbonate scales can dissolved by using 5-10% HCl.
  - Calcium Sulphate scales can be dissolved by adding EDTA (ethylene diamine tetra acetic acid) with which they form soluble complex.
- Frequent blow down operation





# Prevention of scale formation

(will be discussed in the next module)

- External Treatment
  - Removing hardness-producing constituents of water
- Internal Treatment
  - Colloidal Conditioning
  - Phosphate conditioning
  - Carbonate conditioning
  - Calgon conditioning
  - Treatment with sodium aluminate ( $\text{NaAlO}_2$ )

# **Effect of Hard water on steam boilers**



**1. Sludge and Scale formation**

**2. Priming & Foaming**

**3. Caustic embrittlement**

**4. Boiler corrosion**



### **2. Priming and Foaming:**

#### **a) Foaming:**

- o Foaming is the production of persistent foam or bubbles in boilers which do not break easily.
- o This is because of presence of oils which reduce the surface tension of water.
- o Can be avoided by removing oil from the boiler feed water by adding anti-foaming agents like sodium aluminate ( $\text{NaAlO}_2$ ).



## Effect of Hard water on steam boilers: Priming and Foaming

### b) Priming:

- o Along with steam, some particles of water are carried (**wet steam**) which is called priming.
- o This is because of large amounts of dissolved salts, high steam velocities, sudden boiling, improper boiler design, sudden increase in steam production rate.
- o **Priming can be avoided by**
  - **Efficient softening**
  - **Maintaining low water level in boilers**
  - **Avoiding rapid steam generation**
  - **Installing mechanical steam purifiers**



### 3. Caustic embrittlement:

- Caused by using highly alkaline water in boiler
- When water is softened by lime-soda process, free  $\text{Na}_2\text{CO}_3$  is present in softened water.
- In high pressure boilers, this  $\text{Na}_2\text{CO}_3$  decomposes to  $\text{NaOH}$  and  $\text{CO}_2$

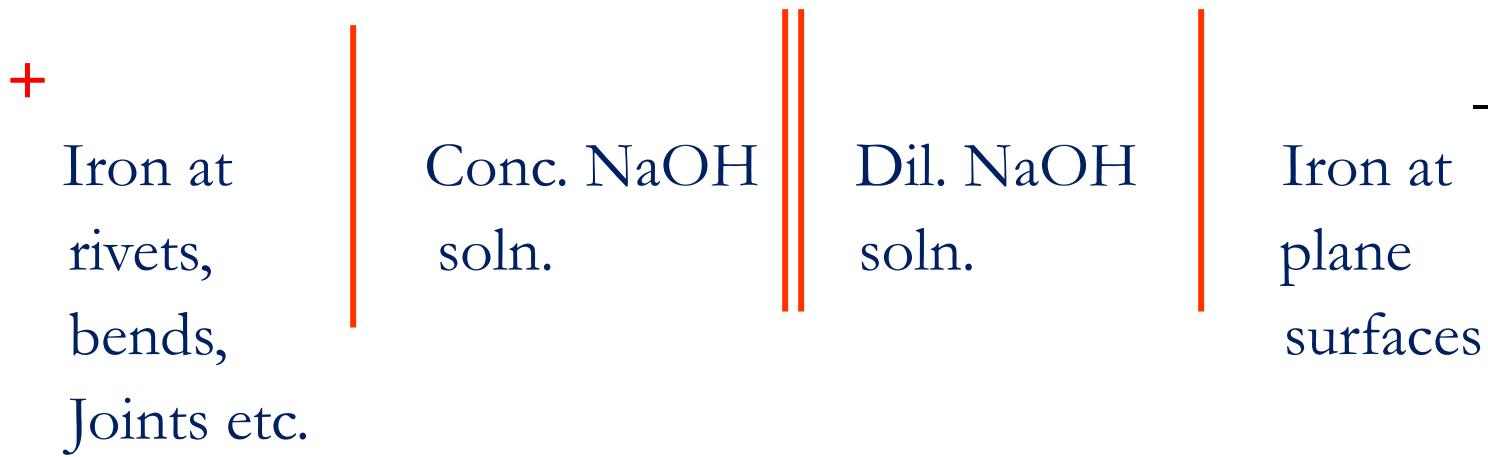


- This  $\text{NaOH}$  makes the water caustic.
- This  $\text{NaOH}$  flows through minute cracks present in the boiler by capillary action.
- As water is boiling it evaporates and the conc. of  $\text{NaOH}$  increases.
- This caustic soda attacks the boiler and forms sodium ferroate ( $\text{Na}_2\text{FeO}_2$ ).
- This makes the boiler parts brittle (embrittlement).

# Concentration cell representation of caustic embrittlement



Caustic attack on boiler parts can be represented as:



- The iron in contact with dil. NaOH becomes cathode and the iron in contact with conc. NaOH becomes anode.
  
- The anodic part slowly dissolves and corrodes.



## ○ Caustic embrittlement can be avoided:

- By using **sodium phosphate** as softening reagent instead of **sodium carbonate**
- By adding **tannin or lignin** to boilers water, since it blocks the hair-cracks, thereby preventing infiltration of caustic soda
- By adding **sodium sulphate** to boiler water – It also blocks the hairline-cracks and preventing infiltration of caustic soda.



## 4. Boiler corrosion:

- Decay of boiler material by chemical or electrochemical attack by surrounding environment.
- Reasons for boiler corrosion are:
  - a) Dissolved oxygen
  - b) Dissolved carbon dioxide
  - c) Acids from dissolved salts

### a) Dissolved oxygen (DO):



- DO can be removed by adding calculated qty. of sodium sulphite or hydrazine or sodium sulphide:



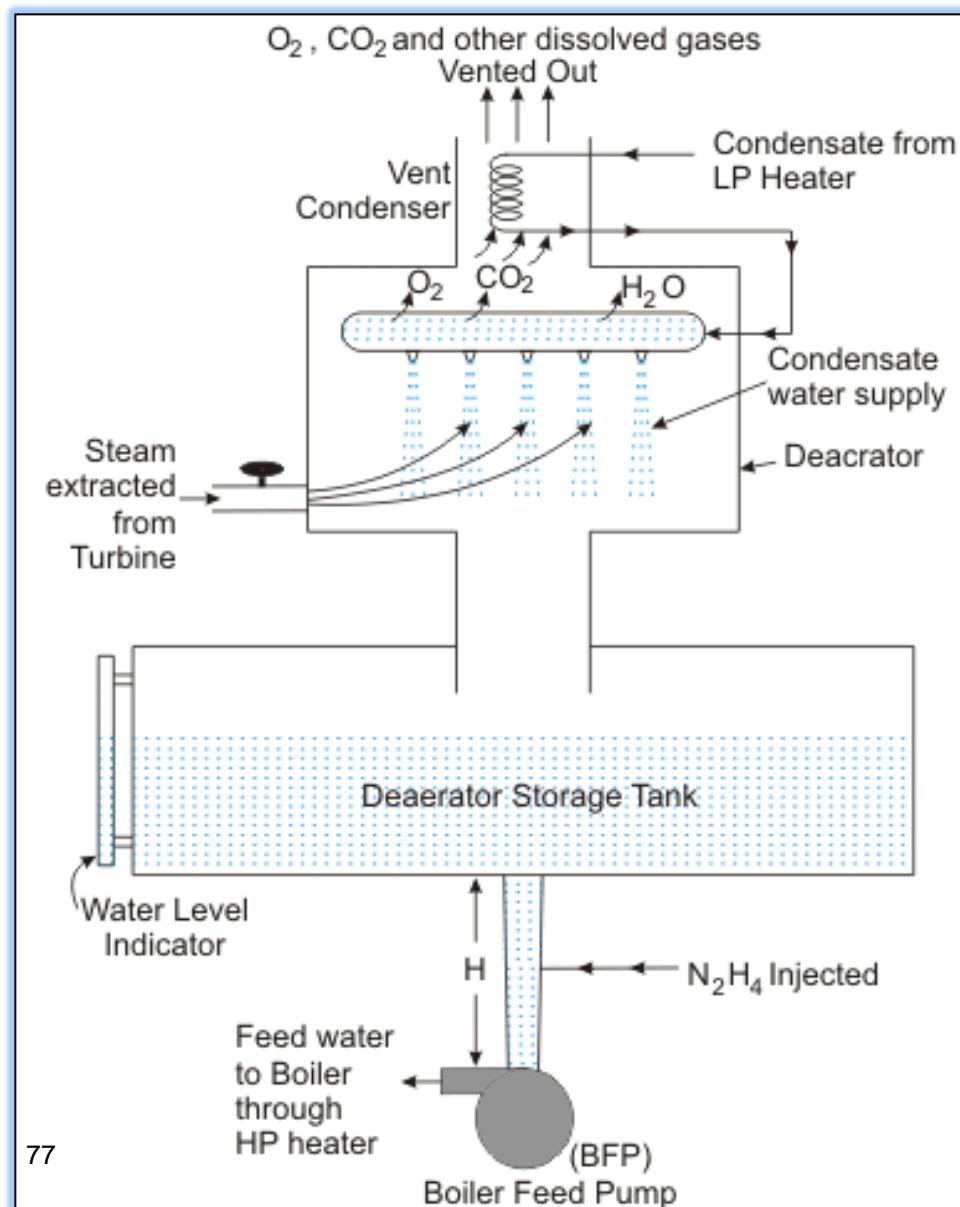
- DO can be removed by mechanical aeration also



## Removal of dissolved oxygen by de-aeration

Water spraying in a perforated plate-fitted tower, heated from sides and connected to Vacuum pump. High temperature, low pressure and large exposed surface reduces dissolved oxygen in water

Most **Deaerators** are designed in such a way that dissolved oxygen content in Deaerator outlet must be within 5-10 ppb by wt%.





## 4. Boiler corrosion:

### b) Dissolved CO<sub>2</sub>:

- Dissolved CO<sub>2</sub> forms carbonic acid which corrodes the boiler slowly.



- CO<sub>2</sub> is removed by adding calculated quantity of ammonia:



- It is also removed along with oxygen by mechanical aeration.

### c) Acids from dissolved salts:

- Dissolved magnesium salts hydrolyze to form acids:



- This acid reacts with boiler and corrodes:



- The liberated acid reacts with iron of the boiler in chain-like reactions producing HCl again and again. As a result presence of even a small amount of MgCl<sub>2</sub> will cause corrosion of iron to a large extent.

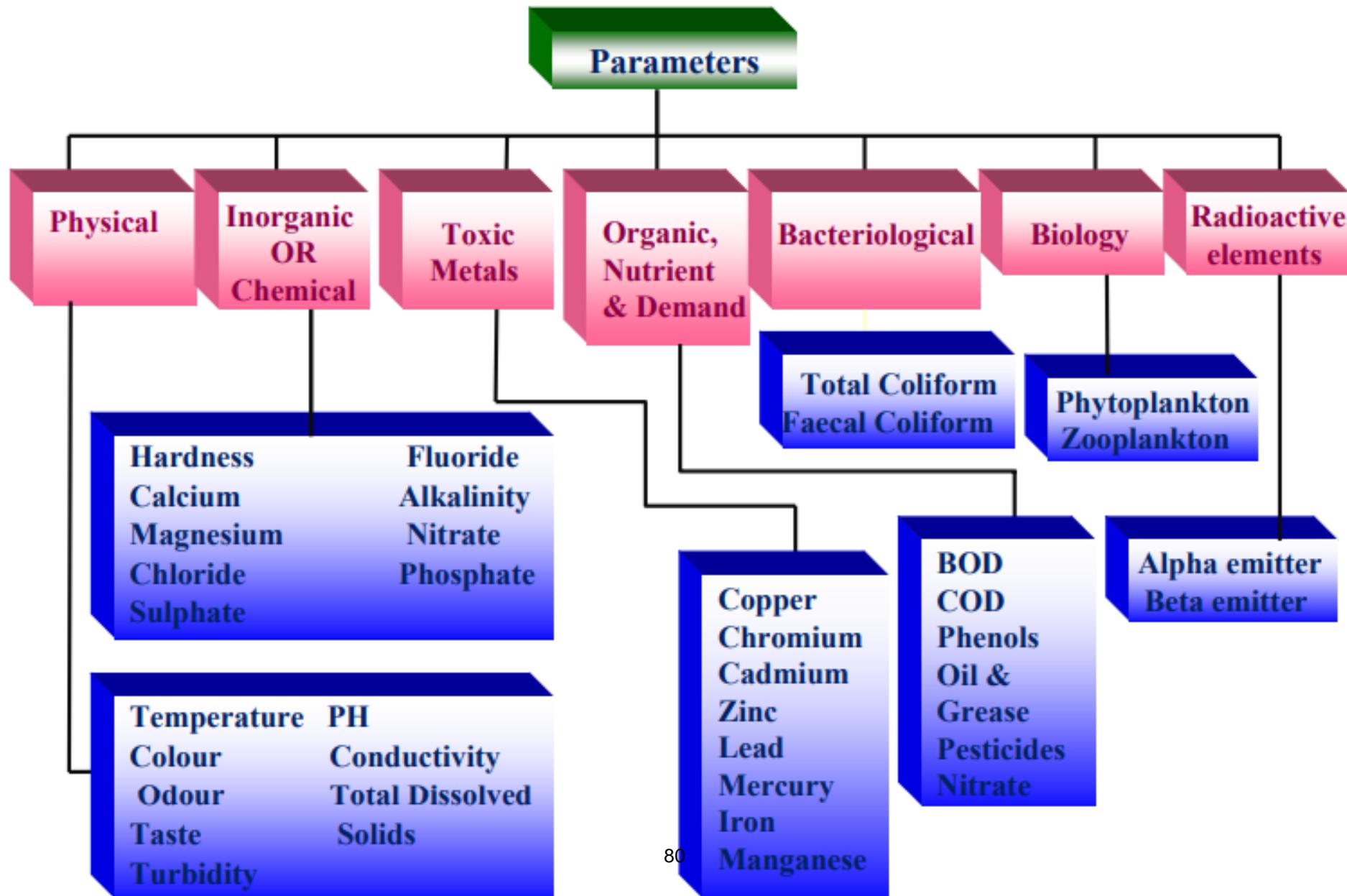


# Modern methods of water analysis

## ○ Importance of Water Analysis

- Water analysis is essential to ensure its quality or to detect pollutants that should be removed by water treatment.
- However, water quality does not mean making the water suitable for human consumption; it depends on its end use.
- For example, completely different quality standards are applied in case of industrial water compared to those applied to drink water, i.e., drinking water must be fit for human consumption, while industrial water should be free from any contaminants that may corrode or damage equipment.

# Water Quality Assessment : Potable & Industrial Uses





# Modern methods of water analysis

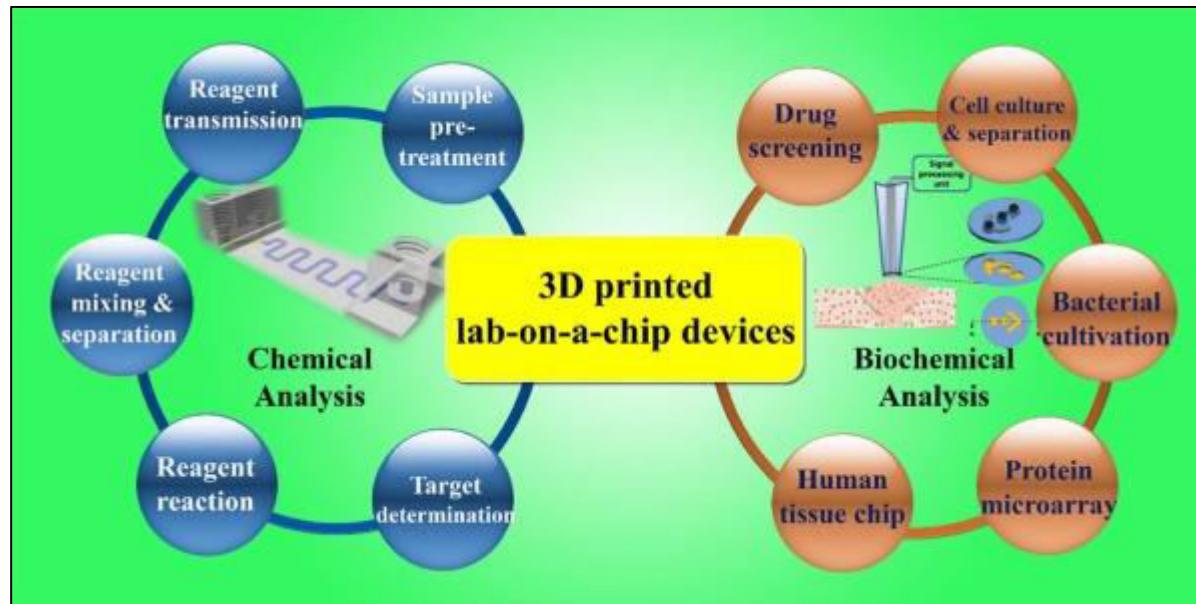
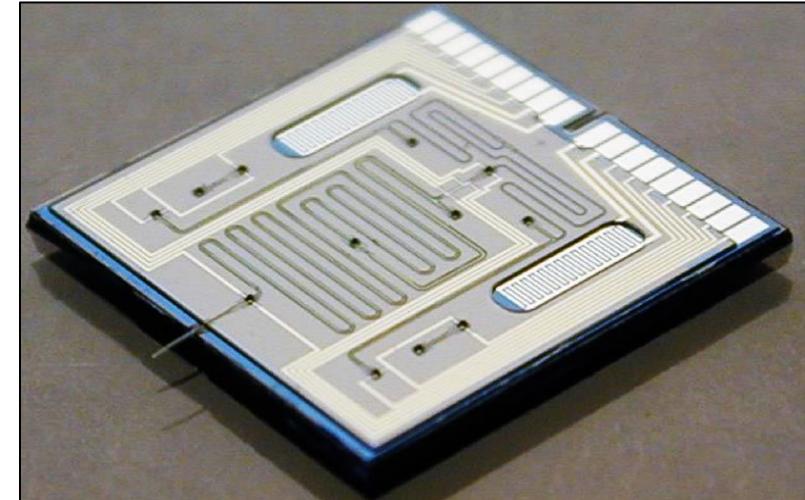
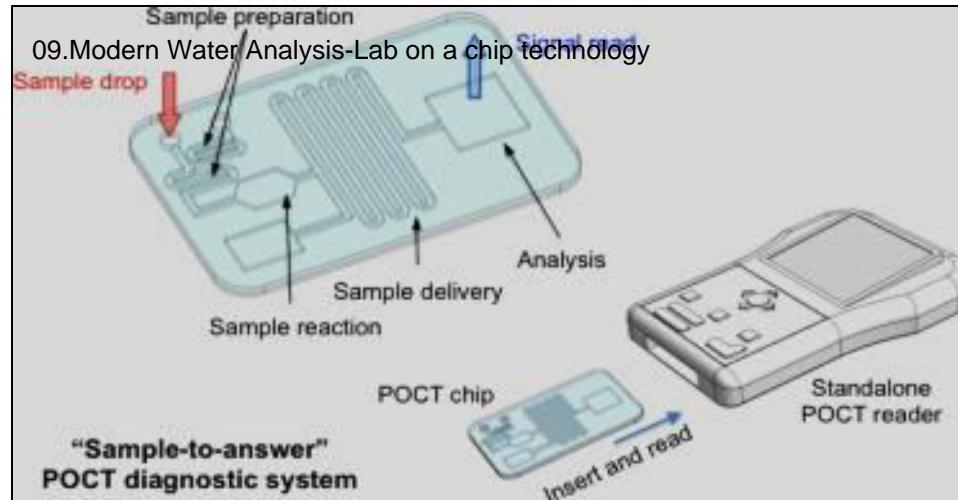
## ○ Limitations of Traditional Methods of Water Analysis

- The traditional analysis includes chemical analysis, colorimetry, spectrometry, chromatography, and atomic absorption.
- Although these techniques differ in sensitivity and accuracy, most of them are highly accurate.
- Nevertheless, they require sampling, expensive devices, and manpower; besides, they are time-consuming and difficult to conduct onsite.

# Current Applications in Water Analysis



- Lab-on-a-chip technology is rapidly developing and being used in different industrial and research fields.
- Most biological lab-on-a-chip devices are commercialized, while those for water analysis are still developing.
- However, some lab-on-a-chip applications in water analysis are already established, such as pH testing and detection of various chemicals (e.g., nitrates and nitrites, manganese, phosphates, and silicates).
- For example, the microfluidic pH analysis uses sulfonephthalein as the main indicator.
- It includes the absorption cell, a static mixer, as well as a syringe pump and four valves attached to the chip to regulate the flow.



## References:

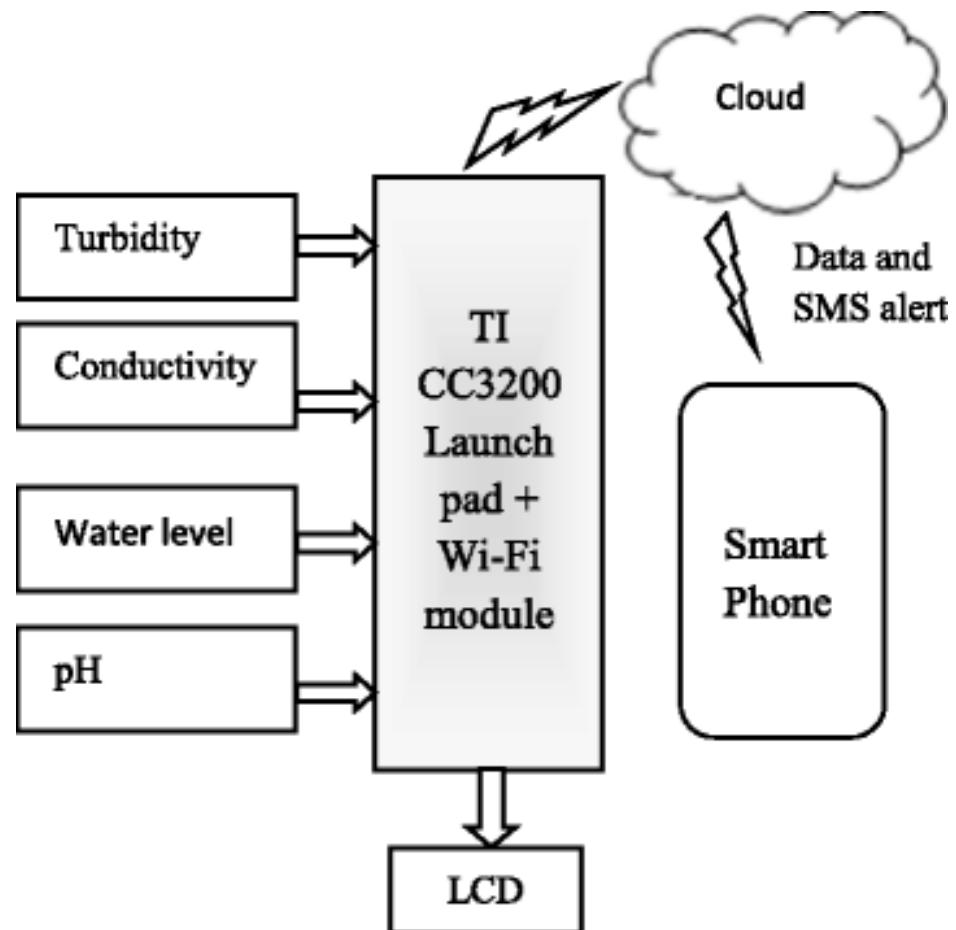
1. J. Cleary, C. Slater, D. Diamond, Analysis of phosphate in wastewater using an autonomous microfluidics-based analyser, *World Acad. Sci. Eng. Technol.* 52 (2009) 196–199.
2. R. Paul Payel, “Lab on a Chip” Systems for Environmental Analysis, University of Stavanger, 2014.<sup>83</sup>



# Modern methods of water analysis

## Sensors

- pH
- Conductivity
- DO
- Temperature
- Transparency

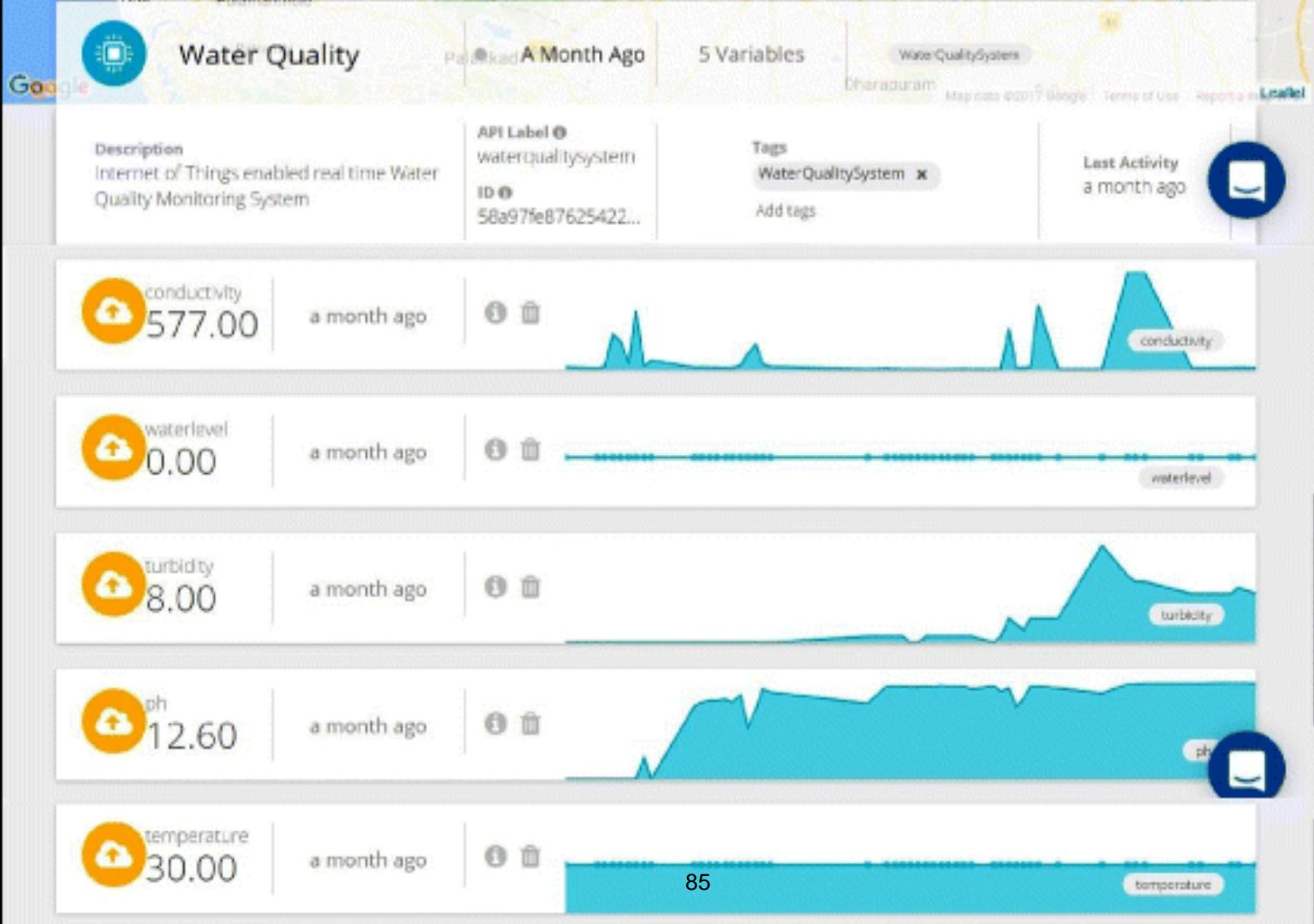


## Water Quality

09.Modern Water Analysis-Lab on a chip technology



gouthami





Variable turbidity is greater than 10

If turbidity value is > than 10.0 → send sms to +917708573211

Water quality is bad :conductivity

If conductivity value is > than 600.0 → send email to satheeshgouthami@gmail.com

Variable turbidity is greater than 10

If turbidity value is > than 10.0 → send email to satheeshgouthami@gmail.com

Variable ph is greater than 8.5

If ph value is > than 8.5 → send sms to +917708573211

Variable conductivity is greater than ...

If conductivity value is ... → send sms to ...

Add event

**11:44**

51465

Mon, 4/17/2017

Water quality bad:turbidity  
Recipient SIM2 Receive

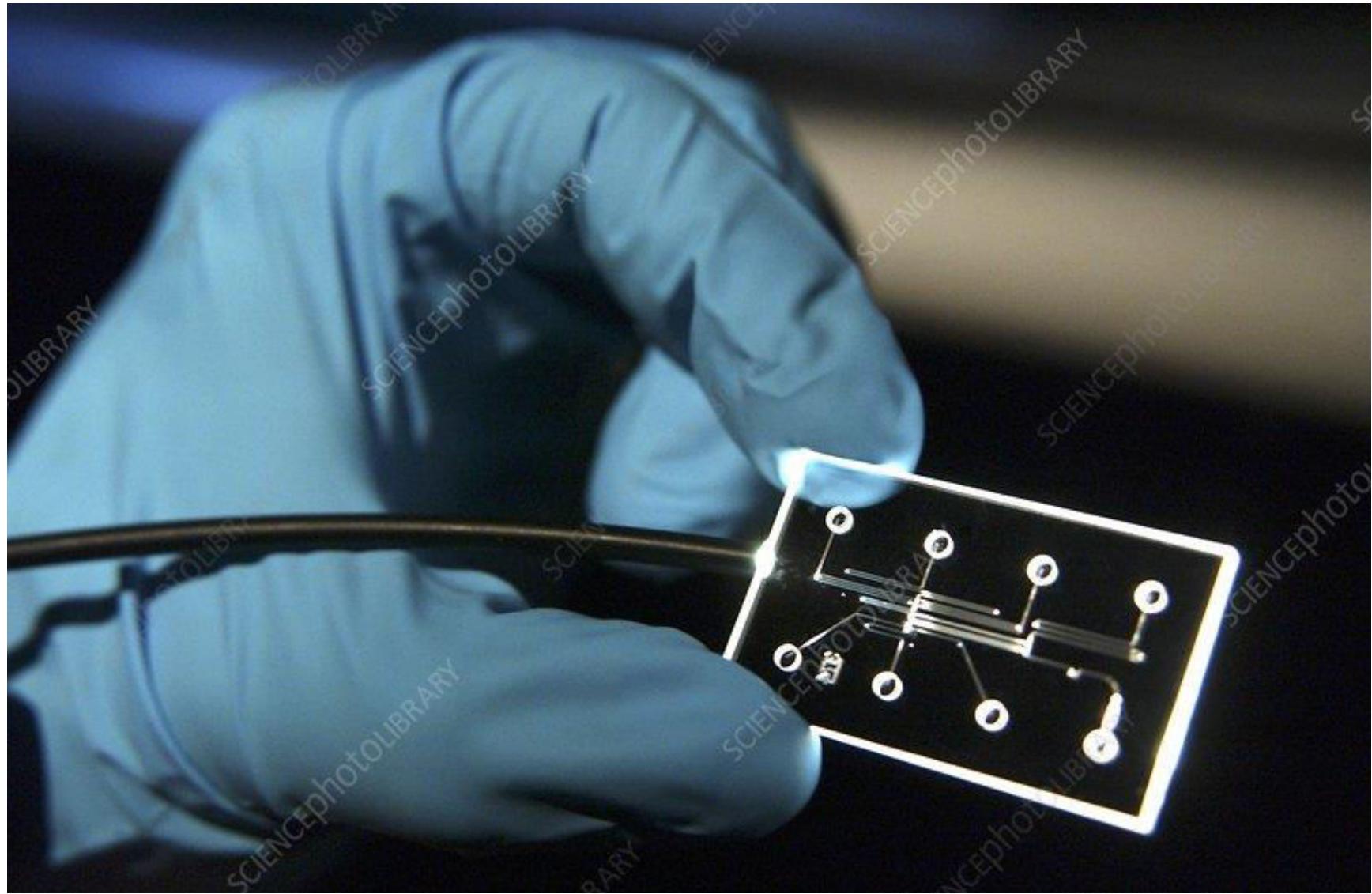
Bad water quality : conductivity  
Recipient SIM2 Receive

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+ Enter contents

SIM1 Send      SIM2 Send

# Lab on Chip – water quality monitoring





- A lab-on-a-chip (LOC) is a device that integrates one or several laboratory functions on a single integrated circuit (commonly called a "chip") of only millimeters to a few square centimeters to achieve automation and high-throughput screening
- Lab-on-a-chip devices are a subset of microelectromechanical systems (MEMS) devices and sometimes called "micro total analysis systems" ( $\mu$ TAS)
- LOCs may provide advantages, which are specific to their application. Typical advantages are:
  - a) low fluid volumes consumption (less waste, lower reagents costs, and fewer sample volumes)
  - b) faster analysis and response time due to short diffusion distance & high surface to volume ratio.
  - c) better process control because of a faster response of the system compactness of the systems due to the integration of much functionality and small volumes
  - d) lower fabrication costs, allowing cost-effective disposable chips, fabricated in mass production
  - e) safer platform for chemical, radioactive or biological studies because of integration of functionality, smaller fluid volumes, and stored energies



## Microfluidics and Lab-On-A-Chip for Water Analysis

- Microfluidics and lab-on-a-chip systems are advanced technologies that may replace the traditional methods of water analysis in the near future.
- Lab-on-a-chip technology employs microfluidics, which deals with very minute amounts of fluids in microchannels, to perform the analysis.
- The lab-on-a-chip device is a chip that resembles electronic chips, but with micro-channels instead of electrical circuits.
- It shrinks the lab to the chip size and can perform complete analysis or even series of analysis.

## Advantages of using lab-on-a-chip for water analysis:

- can reduce time and manpower in the sampling process because this technology can offer immediate, onsite results.
- In addition, this technique is much less expensive and offers higher accuracy, because of the small volumes analyzed and the possibility of eliminating the sampling process, which reduces the human error

# Components of Lab-on-a-chip systems



The main components of a lab-on-a-chip system for water analysis are; a liquid delivery system (injector and fluidic transporter), mixer, reactor, separator, and power supply.

- **The Injector** is used to deliver precise volumes into the chip. The most common types of the injectors are syringe pumps and robotic pipets.
- **Transporters** control all aspects of the flow. They can be active, which need an energy source, or passive, which are achieved by manipulating the geometries of the channels and do not require any energy source. The choice between the active and passive types is based on the application. There are multiple types of active transporters, but the most preferred is electrochemical pumping systems, such as microsyringe pumps, because they eliminate the design complexity.



# Components of Lab-on-a-chip systems

- **Mixers** are used to mix different fluids into the channels. Similar to the transporters, the types of mixers are divided into passive, which are achieved by design manipulation, and active, which require power.
- **The Reactor** is where the reaction takes place. There are three types of reactors used in lab-on-a-chip systems: gas phase, liquid phase, and packed-bed reactors.
- **Controllers** are used for controlling all types of activities in the chip as well as data acquisition and signal processing.
- **Power supplies**, such as batteries, are essential to run the lab-on-a-chip systems. Many research studies focus on finding more advanced power supplies because some types of lab-on-a-chip systems require high voltage.

## Module – 2

# Water Treatment

Module:2	Water Treatment	8 hours	SLO:1,14
Water softening methods: - Lime-soda, Zeolite and ion exchange processes and their applications. Specifications of water for domestic use (ICMR and WHO); Unit processes involved in water treatment for municipal supply - Sedimentation with coagulant- Sand Filtration - chlorination; Domestic water purification – Candle filtration- activated carbon filtration; Disinfection methods- Ultrafiltration, UV treatment, Ozonolysis, Reverse Osmosis; Electro dialysis.			

# Module – 2: Water Treatment



- Water softening methods: - Lime-soda, Zeolite and ion exchange processes and their applications.
- Specifications of water for domestic use (ICMR and WHO); Unit processes involved in water
- treatment for municipal supply - Sedimentation with coagulant- Sand Filtration - chlorination;
- Domestic water purification – Candle filtration- activated carbon filtration; Disinfection methods-
- Ultrafiltration, UV treatment, Ozonolysis, Reverse Osmosis; Electro dialysis.



## Internal conditioning methods

- i. Colloidal conditioning
- ii. Phosphate conditioning
- iii. Carbonate conditioning
- iv. Calgon conditioning
- v. Treatment with sodium meta aluminate

## External conditioning methods

- i. Lime Soda Process
- ii. Zeolite process
- iii. Ion exchange and mixed bed ion exchange process



# Internal Conditioning

Ion is prohibited to exhibit its original character by Complexing or converting them into more stable and soluble salts.

## i. Colloidal conditioning (*Low pressure boilers*)

Reagents Used - Kerosene, tannin and agar-agar.

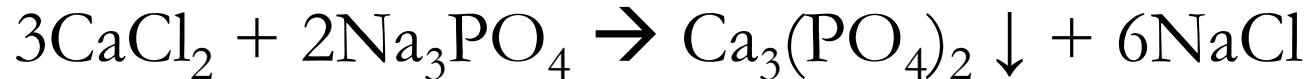
- Scale formation can be avoided by adding these substances
- Forms non-sticky loose precipitates → can be easily removed



# Internal Conditioning

## ii. Phosphate conditioning (*High-Pressure boilers*)

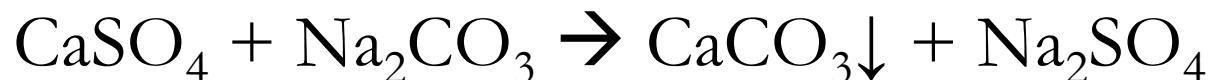
Reagent Used – Sodium Phosphate



(based on pH of the water)

## iii. Carbonate Conditioning (*Low-Pressure boilers*)

Reagent Used – Sodium Carbonate

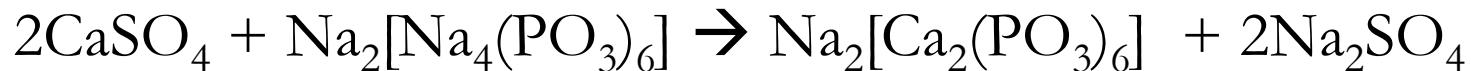




# Internal Conditioning

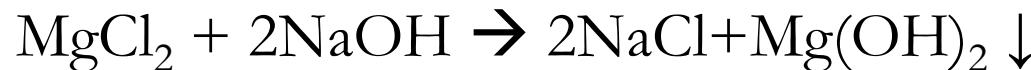
## iv. Calgon conditioning

Reagent Used – Sodium hexa-meta Phosphate



## v. Treatment with Sodium meta aluminate

Reagent Used – Sodium meta aluminate





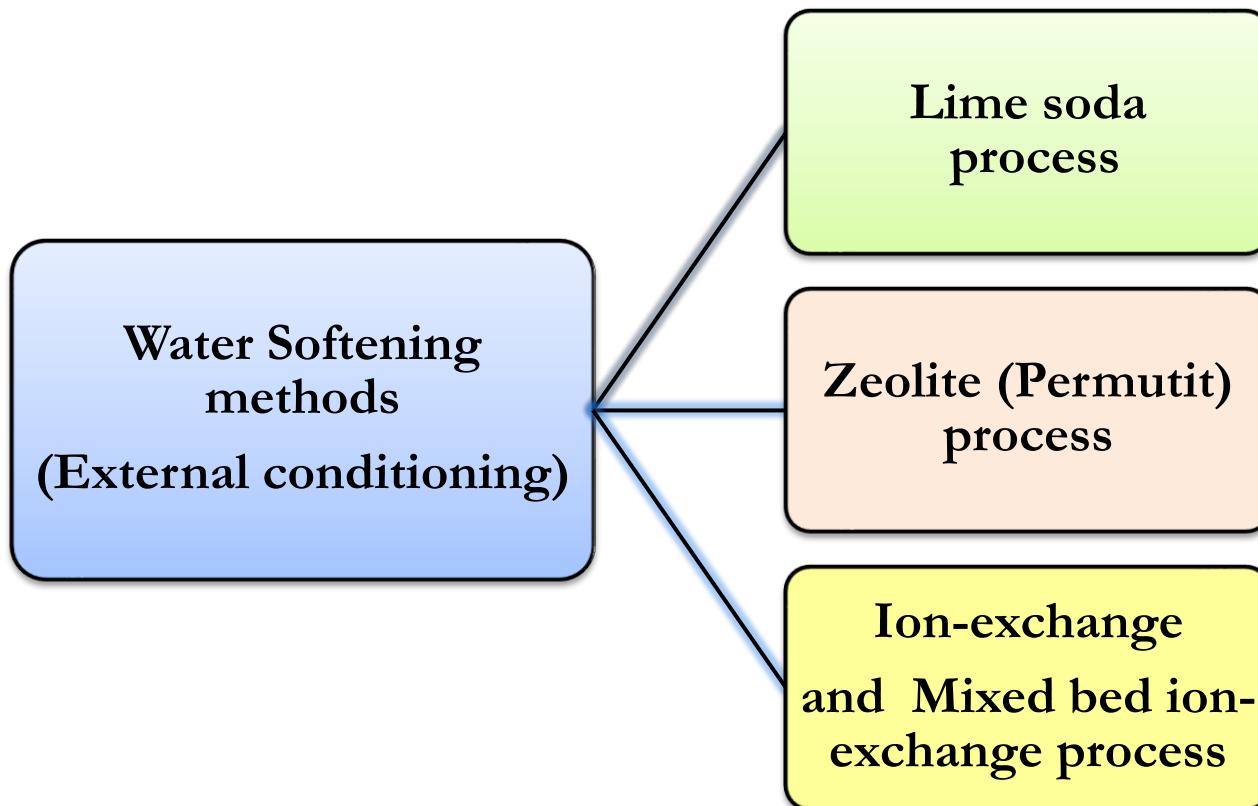
# Internal Conditioning

Method	Reagents used	Boiler type
<b>Colloidal Conditioning</b>	Kerosene, Agar-Agar, tannin	Low-Pressure
<b>Phosphate Conditioning</b>	Sodium Phosphate	High-Pressure
<b>Carbonate Conditioning</b>	Sodium Carbonate	Low-Pressure
<b>Calgon Conditioning</b>	Sodium hexa-meta Phosphate	
<b>Sodium meta Aluminate treatment</b>	Sodium meta Aluminate	

# Water Softening methods: External conditioning



- The process of removing the hardness producing substance from the water is called softening of water
- In Industry three main methods are employed for softening of water





## Water softening methods

### 1. Lime-Soda process

# Lime-Soda process



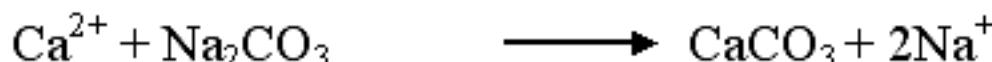
Soluble calcium and magnesium salts in water are chemically converted into insoluble compounds by adding calculated amount of **lime**  $[\text{Ca}(\text{OH})_2]$  and **Soda**  $[\text{Na}_2\text{CO}_3]$ . Calcium carbonate  $[\text{CaCO}_3]$  and Magnesium hydroxide  $[\text{Mg}(\text{OH})_2]$  so precipitated, are filtered off.

## 1. Lime-soda

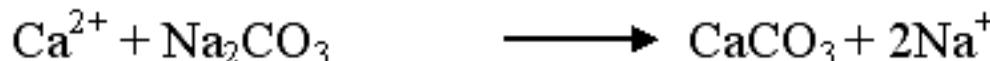
- I.    a) Batch process
- b) Continuous process
- II. - Cold lime-soda
- Hot lime-soda

# Lime Soda Process - Reactions of Lime and Soda

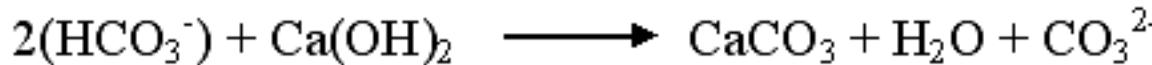
## Reaction of Perm. $\text{Ca}^{2+}$



## Reaction of Perm. $\text{Mg}^{2+}$



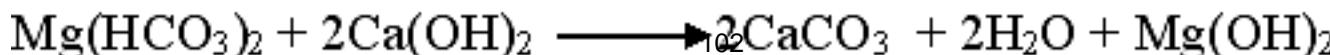
## Reaction of $\text{HCO}_3^-$ (ex. $\text{NaHCO}_3$ )



## Reaction of $\text{Ca}(\text{HCO}_3)_2$



## Reaction of $\text{Mg}(\text{HCO}_3)_2$



# Lime-Soda process



## Reaction of CO<sub>2</sub>



## Reaction of H<sup>+</sup>





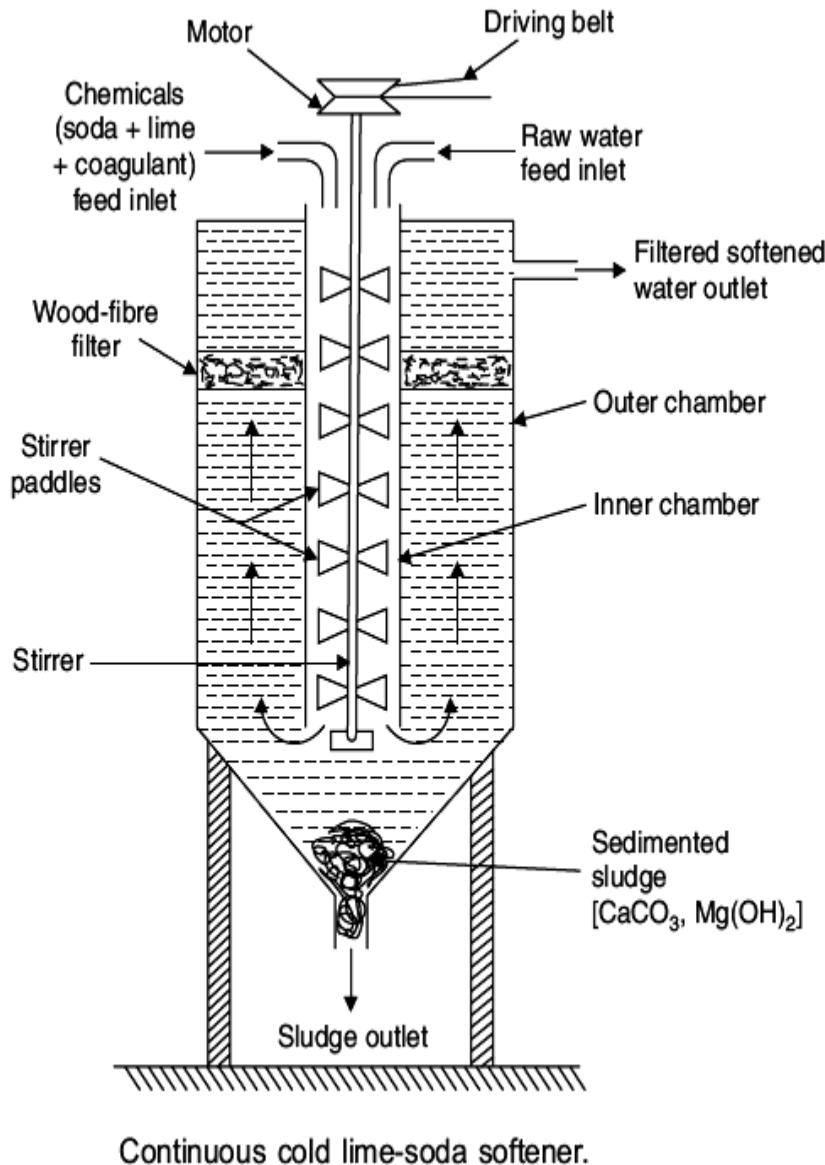
**Lime requirement for softening**

$$= \frac{74}{100} \left\{ \text{Temp } \text{Ca}^{2+} + 2 \times \text{Temp } \text{Mg}^{2+} + \text{Perm.} (\text{Mg}^{2+} + \text{Fe}^{2+} + \text{Al}^{3+}) + \text{CO}_2 + \text{H}^+ \right. \\ \left. + \text{HCO}_3^- - \text{NaAlO}_2 \right\}$$

**Soda requirement for softening**

$$= \frac{106}{100} \left\{ \text{Perm.} (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Fe}^{2+} + \text{Al}^{3+}) + \text{H}^+ - \text{HCO}_3^- \right\}$$

# Continuous cold lime-soda process



- Occurring at room temperature
- precipitate formed are finely divided hence do not settle down easily
- It is essential to add small amount of coagulant (alum, sodium aluminate)
- Coagulant hydrolyze to form gelatinous ppt. and entraps the fine ppt.
- $\text{NaAlO}_2 + \text{H}_2\text{O} \longrightarrow \text{NaOH} + \text{Al}(\text{OH})_3$
- It provides water with a residual hardness of 50 to 60 ppm

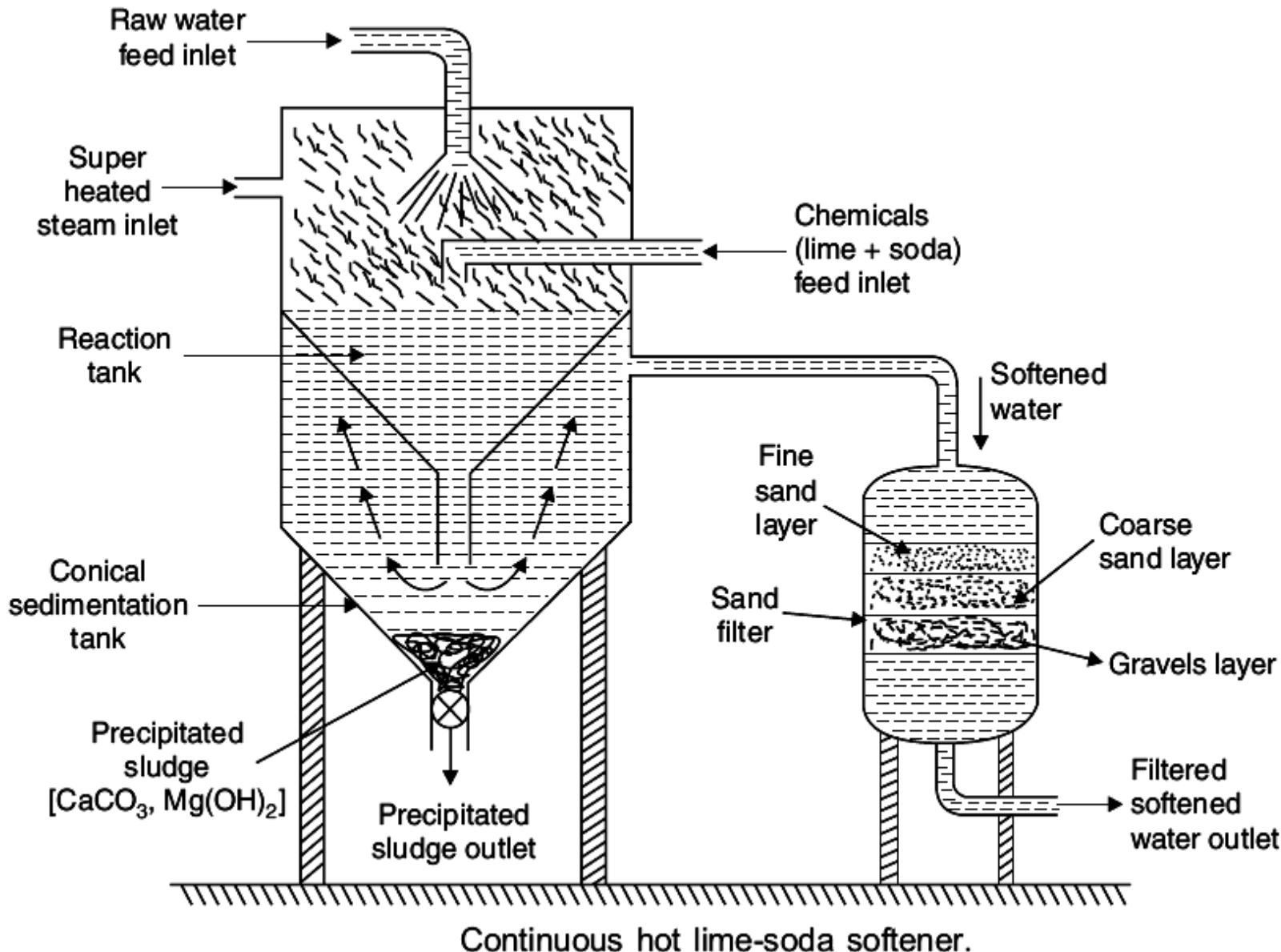
# Hot lime-soda process



**Hot lime-soda process consists of three parts:**

- a) Reaction tank to mix all ingredients
  - b) Conical sedimentation vessel where the sludge settles down
  - c) Sand filter where sludge is completely removed
- 
- **Occurring at 80 to 150 °C close to the boiling point of the solution**
  - **Reaction proceed faster**
  - **The precipitate and sludge formed settle down rapidly so no coagulant needed**
  - **Viscosity of the softened water is lower, so filtration of water becomes much easier**
  - **Produce water contain the residual hardness of 15 to 30 ppm**

## 10. Water Softening-Lime Soda Technology





## ***Hot Lime-Soda Process***

### ***Advantages***

- (i) the precipitation reaction becomes almost complete.
- (ii) the reaction takes place faster.
- (iii) the sludge settles rapidly.
- (iv) no coagulant is needed.
- (v) dissolved gases (which may cause corrosion) are removed.
- (vi) viscosity of soft water is lower, hence filtered easily.
- (vii) Residual hardness is low compared to the cold process.

Hot lime-soda process consists of three parts:

- (a) 'Reaction tank' in which complete mixing of the ingredients takes place.
- (b) 'Tonical sedimentation vessel' where the sludge settles down and
- (c) 'Sand filter' where sludge is completely removed.

The soft water from this process is used for feeding the boilers



# Hot & cold lime soda process

S. No.	Cold lime soda process	Hot lime soda process
1	It is carried out at room temperature (25-30 °C)	It is carried out at high temperature (80-150 °C)
2	It is a slow process	It is a rapid process
3	Use of coagulant is a necessary	No coagulant required
4	Filtration is not easy	Filtration is easy as viscosity of water is low
5	Residual hardness is 60 ppm	Residual hardness is 15-30 ppm
6	Dissolved gases are not removed	Dissolved gases are removed
7	It has low softening capacity <sup>109</sup>	It has high softening capacity

# Advantages & disadvantages of lime-soda process



## Advantages of Lime – soda process:

- Economical
- Process improves the corrosion resistance of water
- Mineral content of water is reduced
- pH of water raises thus reducing content of pathogenic bacteria
- No skilled labour is required

## Disadvantages of Lime – soda process:

- Huge amount of sludge is formed and its disposal is difficult
- Due to residual hardness, water is not suitable for high pressure boilers

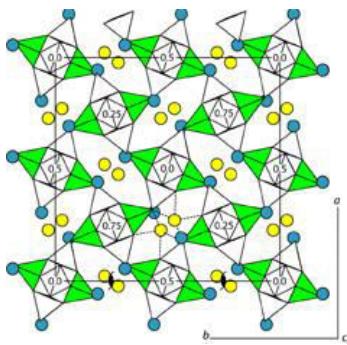
# Zeolite



- o Zeolite is hydrated sodium aluminium silicate having a general formula,  $\text{Na}_2\text{OAl}_2\text{O}_3 \cdot \text{xSiO}_2 \cdot \text{yH}_2\text{O}$ .

## 1) Natural zeolite:

- These are about 40 naturally occurring zeolites, forming in both volcanic and sedimentary rocks
- Natural zeolite are non-porous
- e.g. Natrolite, Mordenite, stillbite and so on



## 1) Synthetic zeolite:

- These are around 150 Synthetic (Artificial) zeolite which are designed for specific purposes.
- Synthetic zeolite are porous
- Such zeolites possess higher exchange capacity per unit weight than natural zeolites
- Prepared by heating china clay, feldspar and soda ash.
- e.g. Zeolite A (used as a laundry detergent), Zeolites X and Y (used for catalytic cracking) and ZSM-5 (pentasil-zeolite)



**China clay**  $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$

# Zeolite or Permutit Process



- o Common Zeolite is  $\text{Na}_2\text{OAl}_2\text{O}_3 \cdot 3\text{SiO}_2 \cdot 2\text{H}_2\text{O}$  known as natrolith.
- o Other gluconites, green sand (iron potassium phyllosilicate with characteristic green colour, a mineral containing Glauconite), etc. are used for water softening.
- o It exchanges  $\text{Na}^+$  ions for  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions.
- o Artificial zeolite used for water softening is Permutit.
- o These are porous, glassy particles having higher softening capacity compared to green sand.
- o They are prepared by heating china clay (hydrated aluminium silicate), feldspar ( $\text{KAlSi}_3\text{O}_8$ - $\text{NaAlSi}_3\text{O}_8$  –  $\text{CaAl}_2\text{Si}_2\text{O}_8$ ) are a group of rock-forming tectosilicate minerals which make up as much as 60% of the earth's crust) and soda ash ( $\text{Na}_2\text{CO}_3$ )

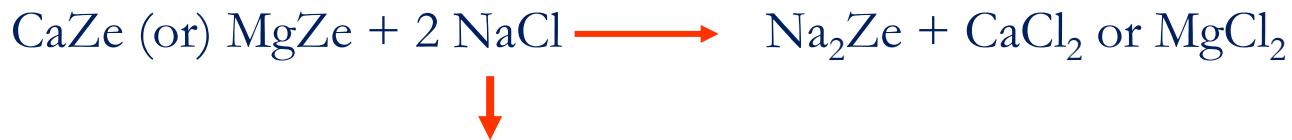


# Zeolite process

- o **Method of softening:**



- o **Regeneration of Zeolite:**

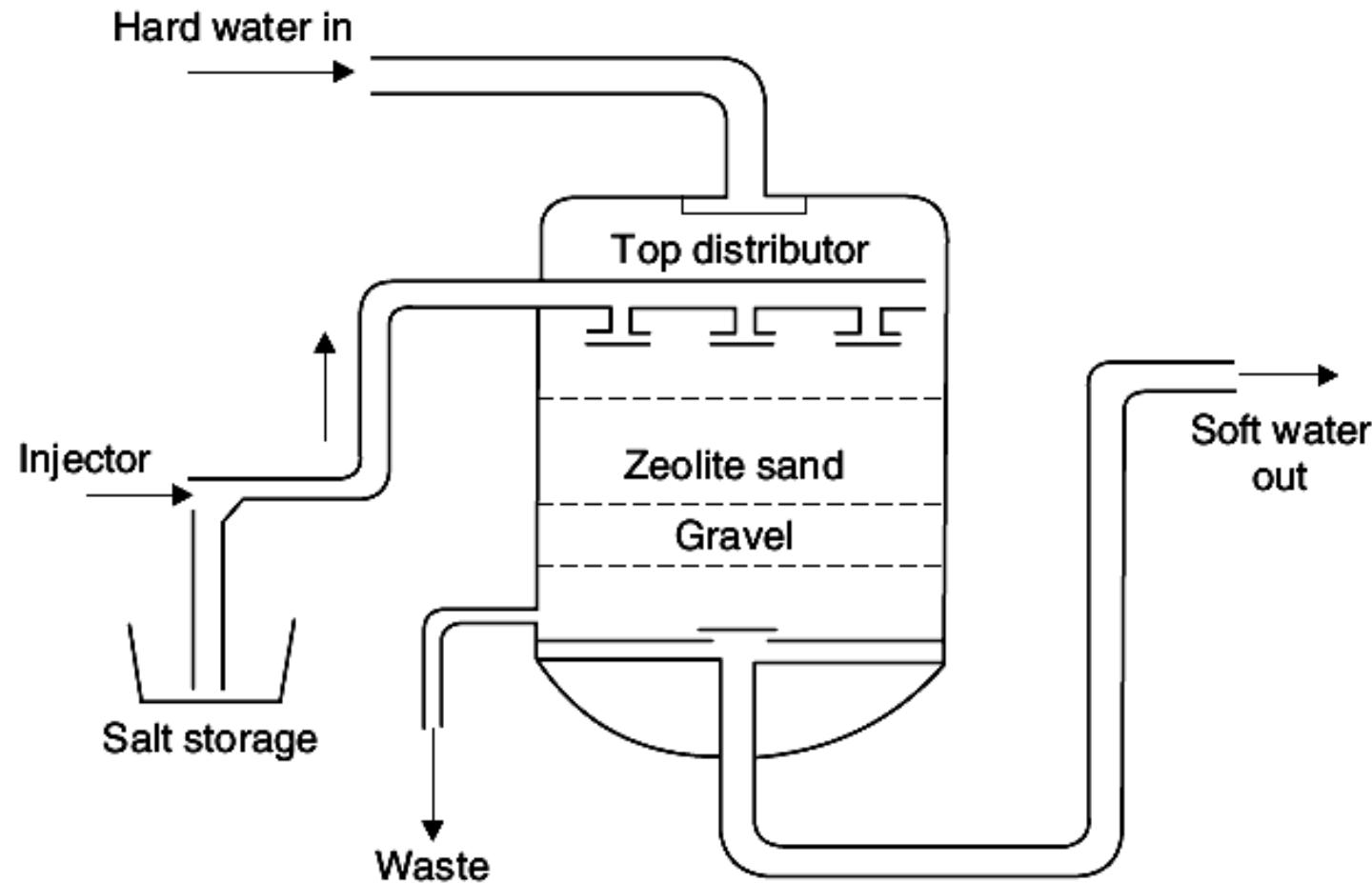


Brine solution

**Note:**

**\*Ze = Zeolite**

# Zeolite process equipment diagram



Softening of hard water by permutit process.

# Zeolite Process



## Advantages:

- Residual hardness of water is about 10 ppm only
- Equipment is small and easy to handle
- Time required for softening of water is small
- No sludge formation and the process is clean
- Zeolite can be regenerated easily using brine solution
- Any type of hardness can be removed without any modifications to the process

## Disadvantages:

- Coloured water or water containing suspended impurities cannot be used without filtration
- Water containing acidic pH cannot be used for softening since acid will destroy zeolite.



## Water softening methods

### 3. Ion-Exchange Process

# Ion-Exchange Resin Process



- ❖ Ion-exchange resins are insoluble, cross-linked, long chain organic polymers with a microporous structure and the functional groups attached to the groups are responsible for the ion-exchanging properties.
  - **Cation exchange resins** will exchange cations with  $H^+$
  - **Anion exchange resins** will exchange anions with  $OH^-$
  - Functional groups present are responsible for ion-exchange properties.
  - Acidic functional groups ( $-COOH$ ,  $-SO_3H$  etc.) exchange  $H^+$  for cations
  - Basic functional groups ( $-NH_2$ ,  $=NH$  etc.) exchange  $OH^-$  for anions.

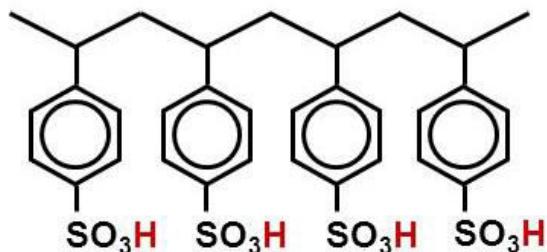


# Ion-Exchange Resin Process

## A. Cation-exchange Resins ( $RH^+$ ):

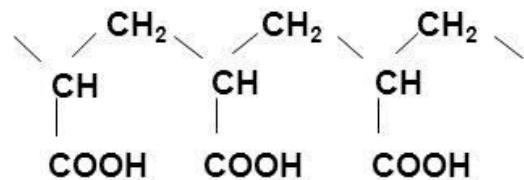
- Styrene divinyl benzene copolymers
- which on sulphonation or carboxylation, become capable to exchange their hydrogen ions with the cations in the water

**Strongly acidic cation exchange resin**



Sulphonic group

**Weakly acidic cation exchange resin (WAC)**



**Polycarboxylic acid, polyacrylic acid**

Amberlite IRC86



# Ion-Exchange Resin

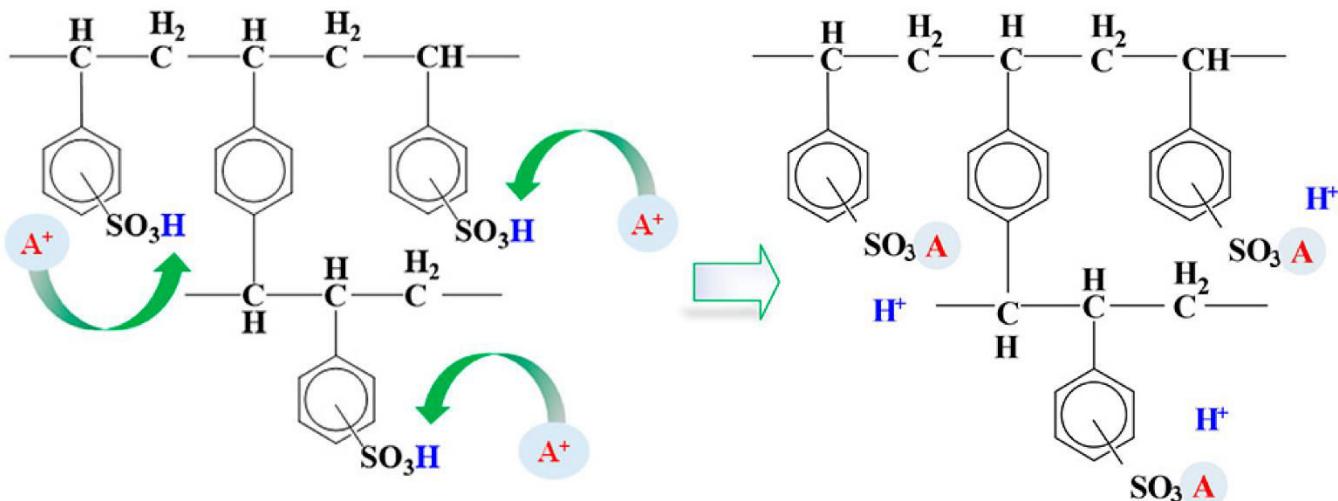
## Cation-Exchange Resin

- ❖ Cations exchanged with  $H^+$  ion



**Sulphonated polystyrene**  
= strongly acidic cation exchange resin (SAC)

Amberjet 1200 H, Amberlite IR120 H





# Ion-Exchange Resin Process

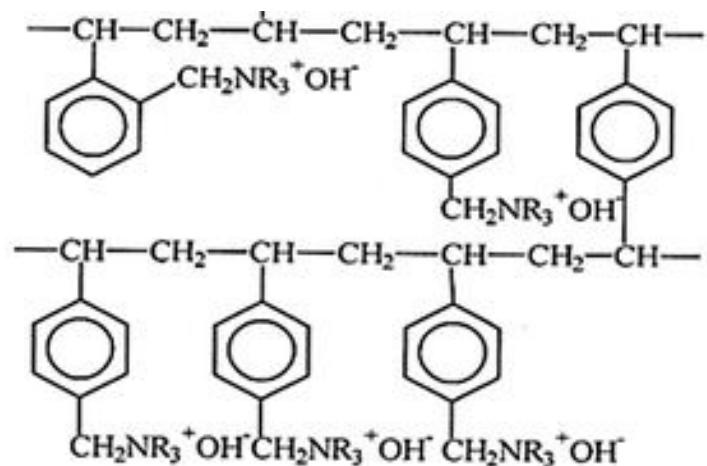
## B. Anion-exchange Resins ( $R'OH^-$ ):

- Styrene-divinyl benzene or amine-formaldehyde copolymers, which contain amino or quaternary ammonium or quaternary phosphonium or tertiary sulphonium groups as an integral part of the resin matrix.
- These after treatment with dil. NaOH solution capable to exchange their  $OH^-$  ions with the anions in the water

**Quaternary ammoniated ST-DVB copolymer**

**Anion exchange resin**

$R' = CH_3$  is known as Type-1 anion resin





# Ion-Exchange Resin Process

**The Process of Ion-exchange is:**



Finally,



**Regeneration of exhausted resins:**

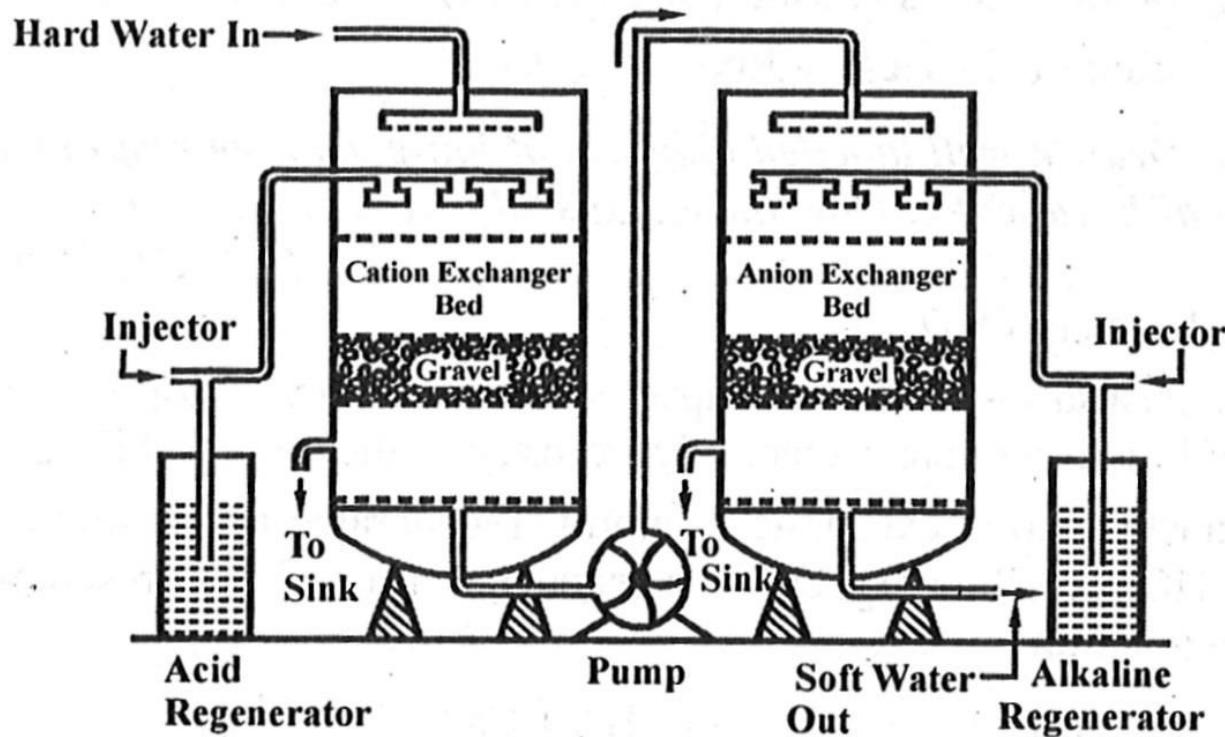
Saturated resins are regenerated by treating with strong mineral acid or alkali respectively



\***R** = Resin; **RH<sup>+</sup>** = Cation exchange resin; **R'OH<sup>-</sup>** = anion exchange resin



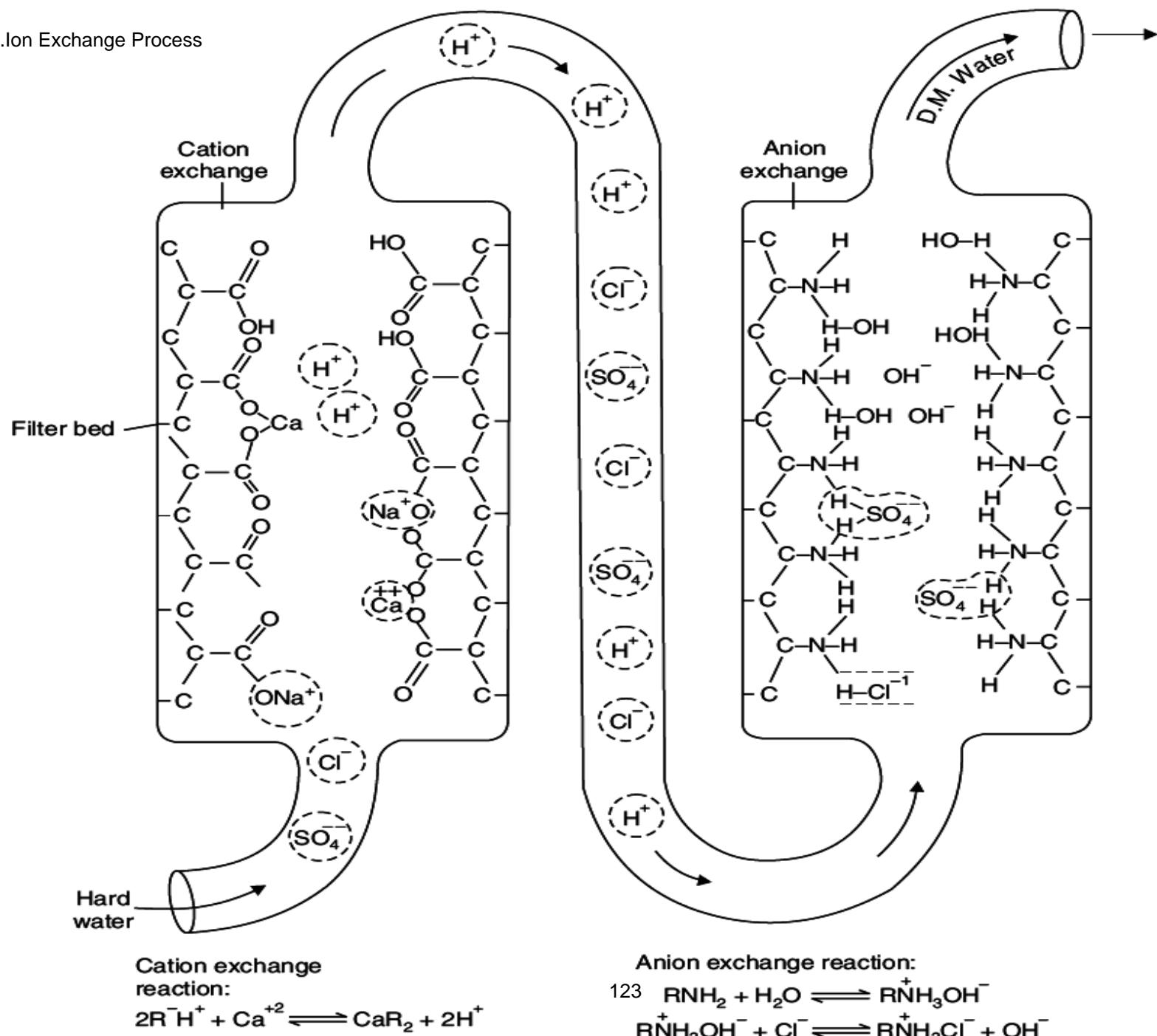
# Ion-Exchange Resin Process



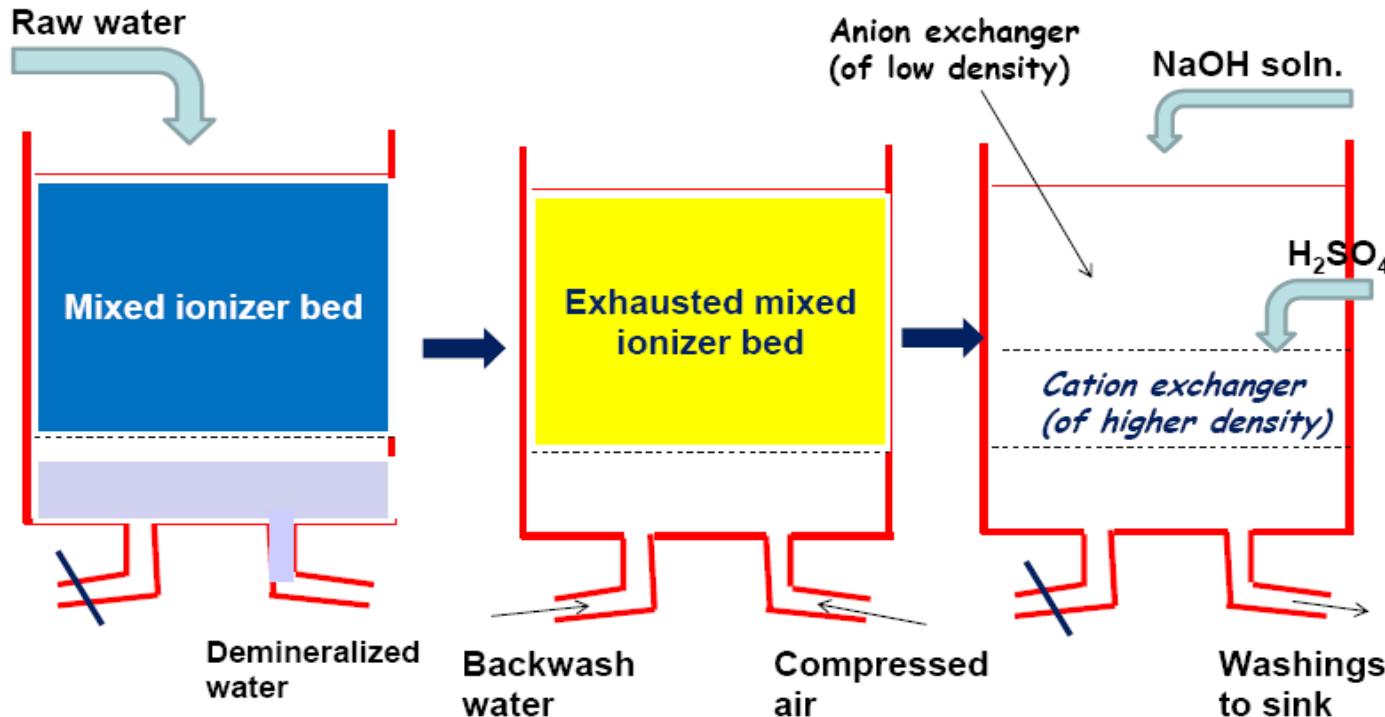
## Demineralisation of water

**Note:** Hard water should be first passed through the cation exchanger and then anion exchanger to avoid hydroxides of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  getting formed

## 12. Ion Exchange Process



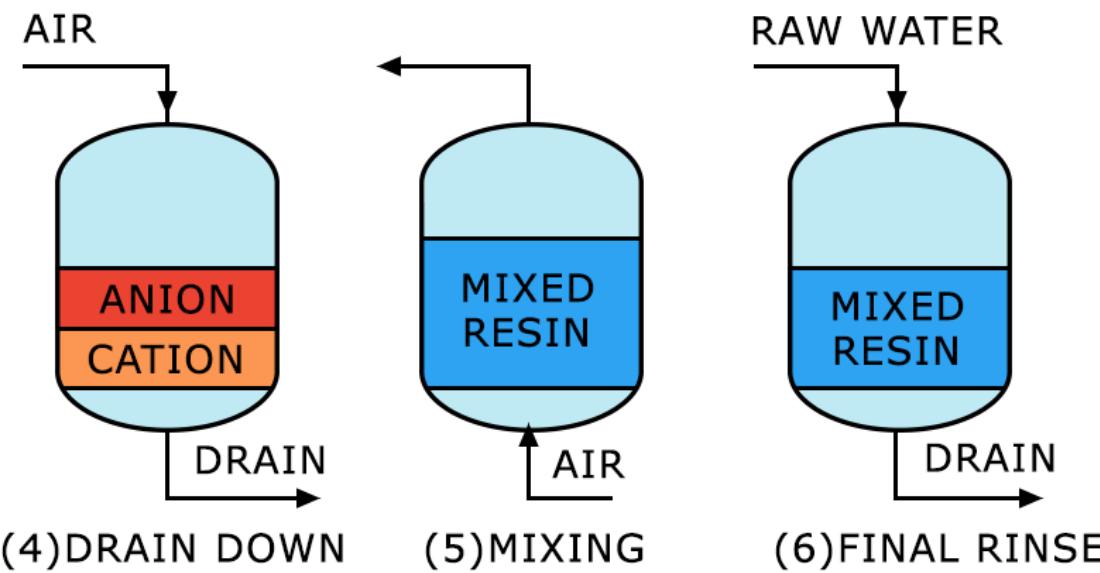
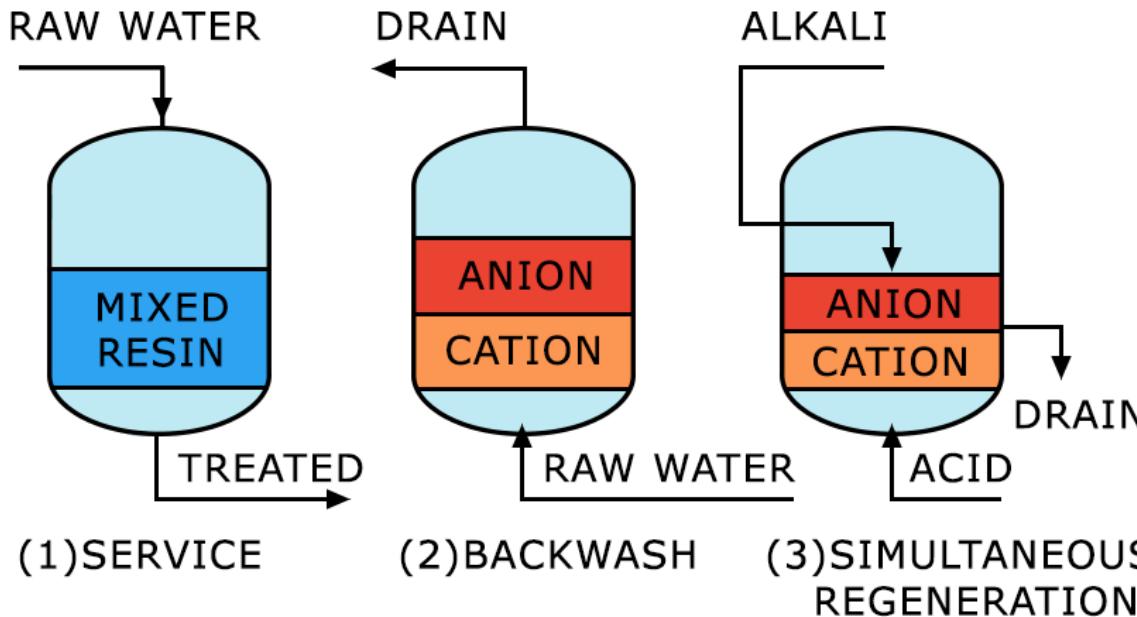
# Mixed Bed Deionizer



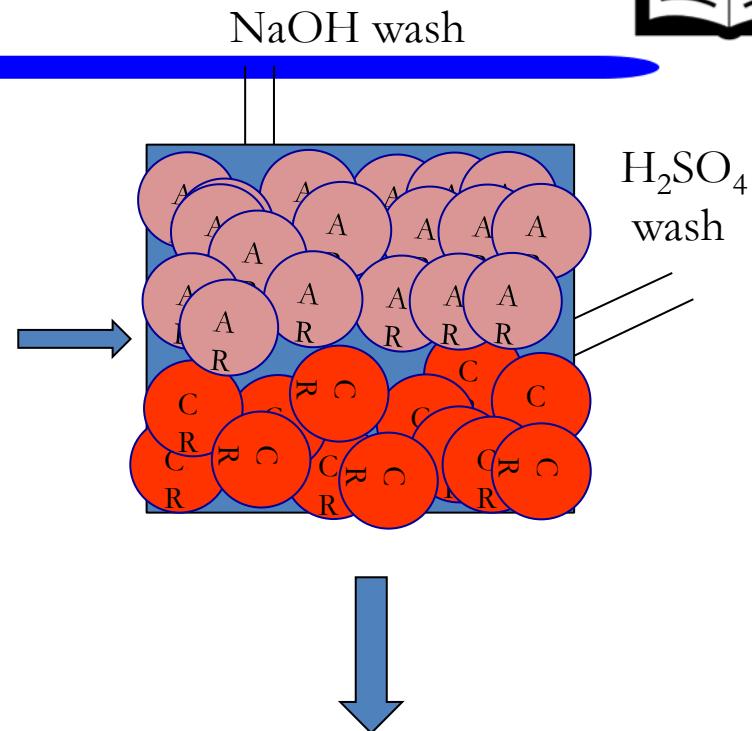
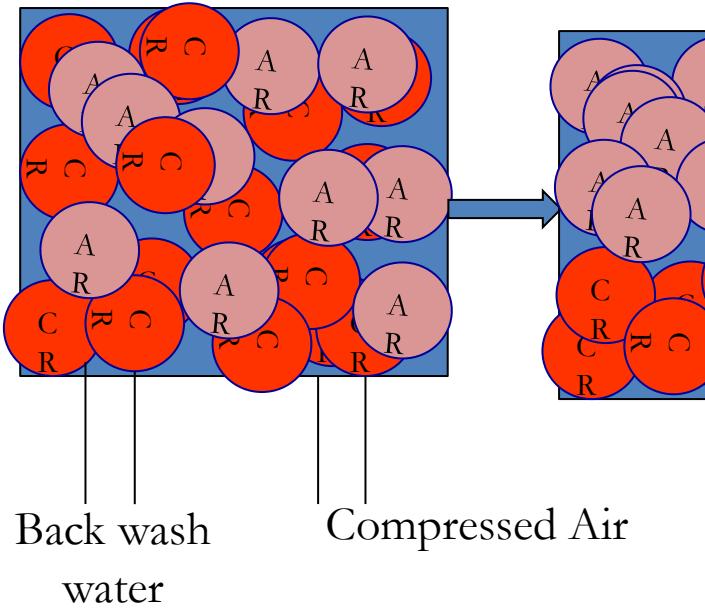
Containing an intimate mixture of hydrogen exchanger and strongly basic anion exchanger

The outgoing water from the mixed-bed contains even less than 1 ppm of dissolved salts

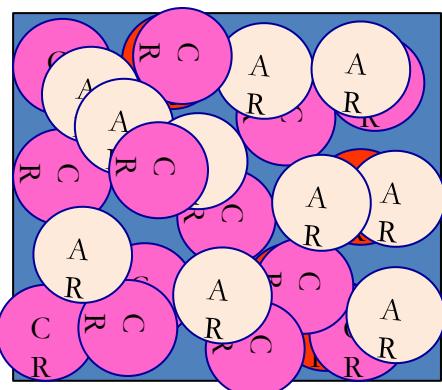
12.Ion Exchange Process



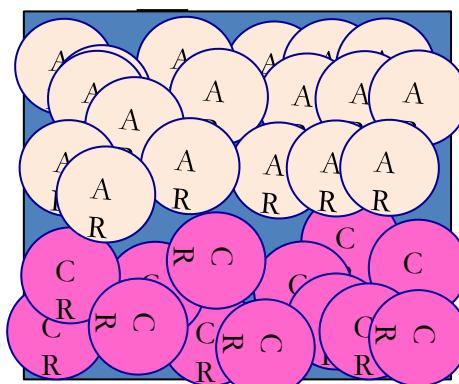
# Mix bed to be regeneration process



Forcing with  
Compressed air  
for mixing



Regenerated Mix bed read for use



After wash it is regenerated



- The mixed bed deionizer consist of cation and anion exchange resins mixed together in a single pressure vessel.
- When water is passed through mixed bed it comes in contact, a number of times, with the two kinds of exchanges alternatively. As a result the net effect of mixed bed exchanger is equivalent to passing water through a series of several cation and anion exchangers.
- The quality of water obtained from mixed bed is appreciably higher than the water produced from two bed plants.
- Mixed bed exchange produce water with hardness less than 1 ppm

## Regeneration:

- The mixed bed is back washed by forcing water in the upward direction. This separate the cation and anion exchanges from the mixed bed. Being lighter the anion resin occupies upper part and the denser cation at the bottom.
- Now these layers can be washed with NaOH and H<sub>2</sub>SO<sub>4</sub> respectively to regenerate anion and cation exchange resins. After regeneration again they are mixed by forcing compressed air.

**Generally soften water (e.g. RO, etc) will be further purified by this method**



## o Advantages:

- Can be used for highly acidic and highly alkaline water
- Residual hardness of water is as low as 1 ppm.
- Very good for treating water for high pressure boilers

## o Disadvantages:

- Expensive equipment and chemicals
- Turbidity of water should be  $< 10$  ppm. Otherwise output will be reduced; turbidity needs to be coagulated before treatment.
- Needs skilled labour

# Specifications of different materials in drinking water (ICMR and WHO)

S. No.	Parameter/Material	WHO Standards/ppm	ICMR/BIS Standards/ppm
1	Colour	Clear	Clear
2	Odour	Pleasant	Pleasant
3	Turbidity	2.5	2.5
4	pH	6.0 – 8.5	6.0 – 8.5
5	TDS	300	500
6	Total Hardness as CaCO <sub>3</sub>	200	300
7	Calcium	75	75
8	Chlorides	200	200
9	Sulphates	200	200
10	Fluoride	0.5	1.0
11	Mercury	0.006	0.001
12	Cadmium	0.003	0.01
13	Arsenic	0.01	0.02
14	Chromium as hexavalent	0.01	0.1
15	Lead	0.01	0.01
16	E.Coli	No colony Should be present in 100 mL water	No colony Should be present in 100 mL water

ICMR = Indian Council of Medical Research

BIS = Bureau of Indian Standards

WHO = World Health Organization

# Drinking water or Municipal water



***Should satisfy the following requirements***

1. It should be sparkling clear and odourless
2. Pleasant taste
3. Perfectly cool
4. Turbidity level should not exceed 10 ppm
5. Free from objectionable dissolved gases like  $H_2S$
6. Free from objectionable minerals such as lead, arsenic, chromium and manganese salts
7. Alkalinity should not be high ( $pH \sim 8$ )
8. It should be reasonably soft
9. Total dissolved solids should be less than 500 ppm
10. Free from disease producing micro-organisms

# Purification of Municipal Supply



**Screening**



**Coagulation**



**Flocculation**



**Sedimentation**



**Filtration**

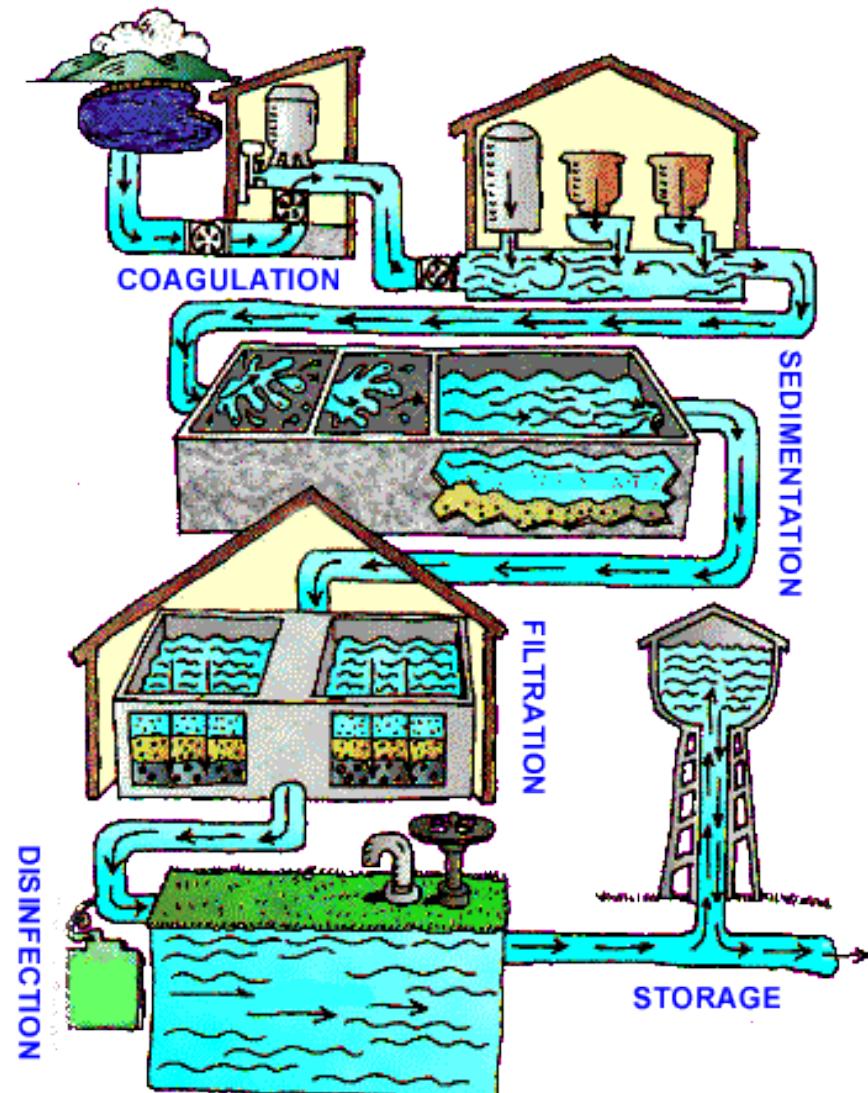


**Chlorination**



**Supplementary treatment**

131



# Purification of Municipal Supply



## Purification of water for domestic use

Removal of

- A. Suspended impurities;    B. Microorganisms

### Suspended Impurities

#### 1. Screening

- Water is passed through screens , having large number of holes

#### 2. Sedimentation

Allowing water to stand undisturbed in big tanks (~ 5 m deep)

Most of the suspended particles settles down at the bottom, due to the force of gravity

*when water contains fine clay particles and colloidal matter  
its necessary to apply sedimentation with coagulation*

## Sedimentation with coagulation

Removing suspended and colloidal impurities by the addition of requisite amount of chemicals (coagulants)

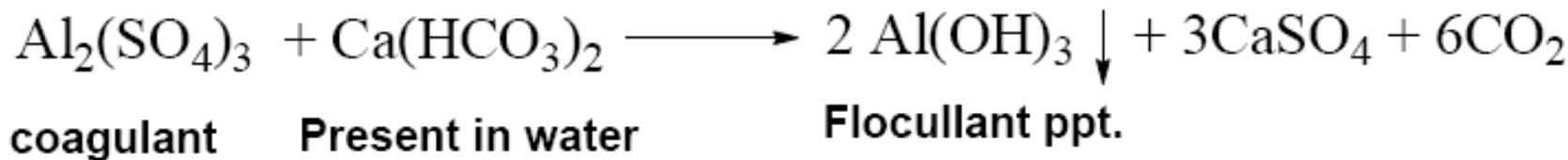
### *Coagulant (Alum or Ferrous sulphate)*

*When added to water , forms an insoluble gelatinous, flocculant precipitate, which descent through water, adsorbs and entangles very fine suspended impurities forming bigger flocs, which settle down easily*

#### 1. Alum ( $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$ )

Alum reacts in water in the presence of alkalinity of water.

If the water is not alkaline, sufficient amount of lime should be added

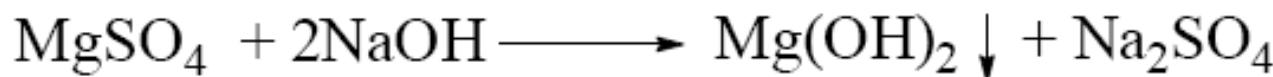


## 2. Sodium Aluminate ( $\text{NaAlO}_2$ )

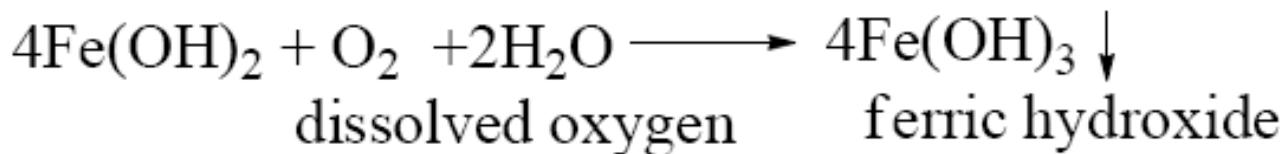
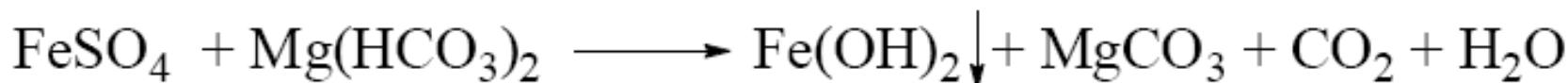
treating water having no alkalinity ( pH <7)



Gelationous  
flocculant



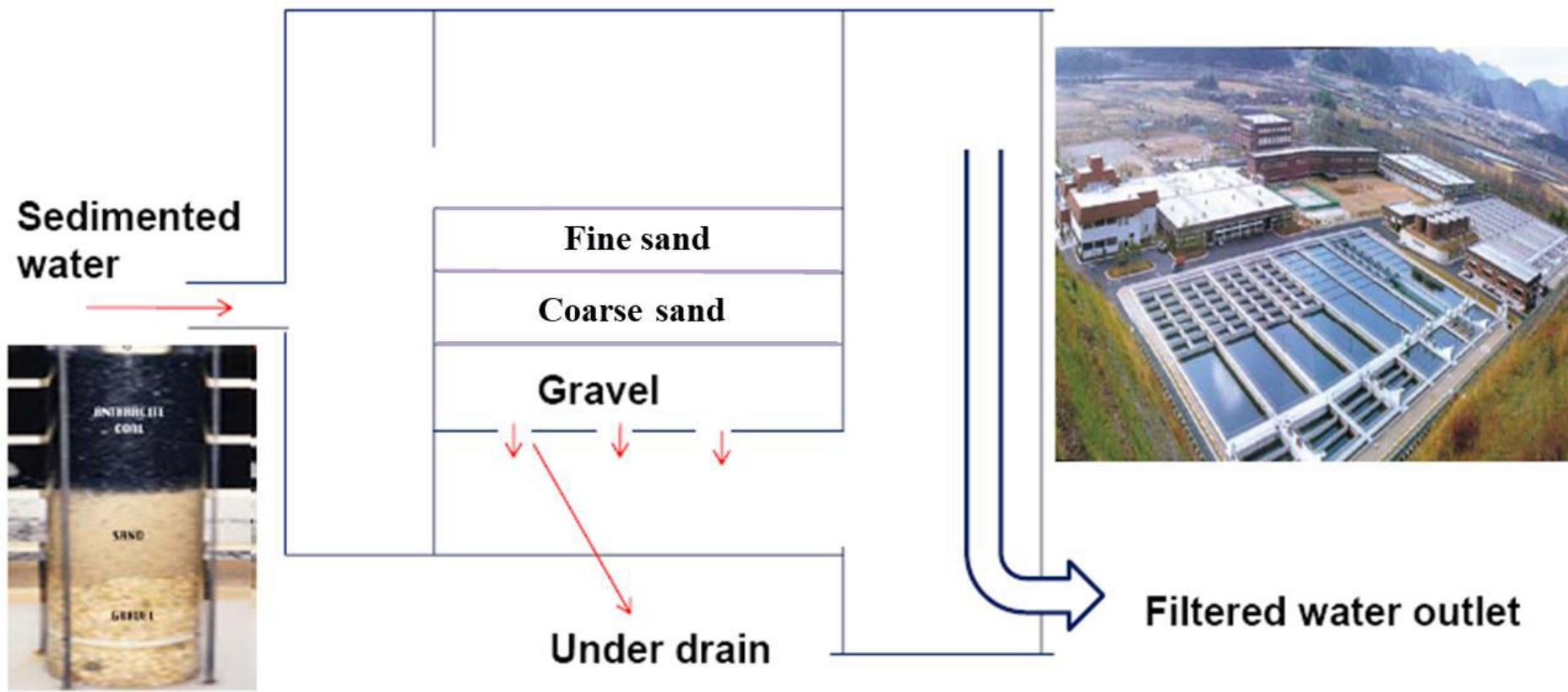
## 3. Copperas or Ferrous sulphate [ $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ ]



**Above pH = 8.5, if alkalinity is not present, lime should be added**

# Filtration

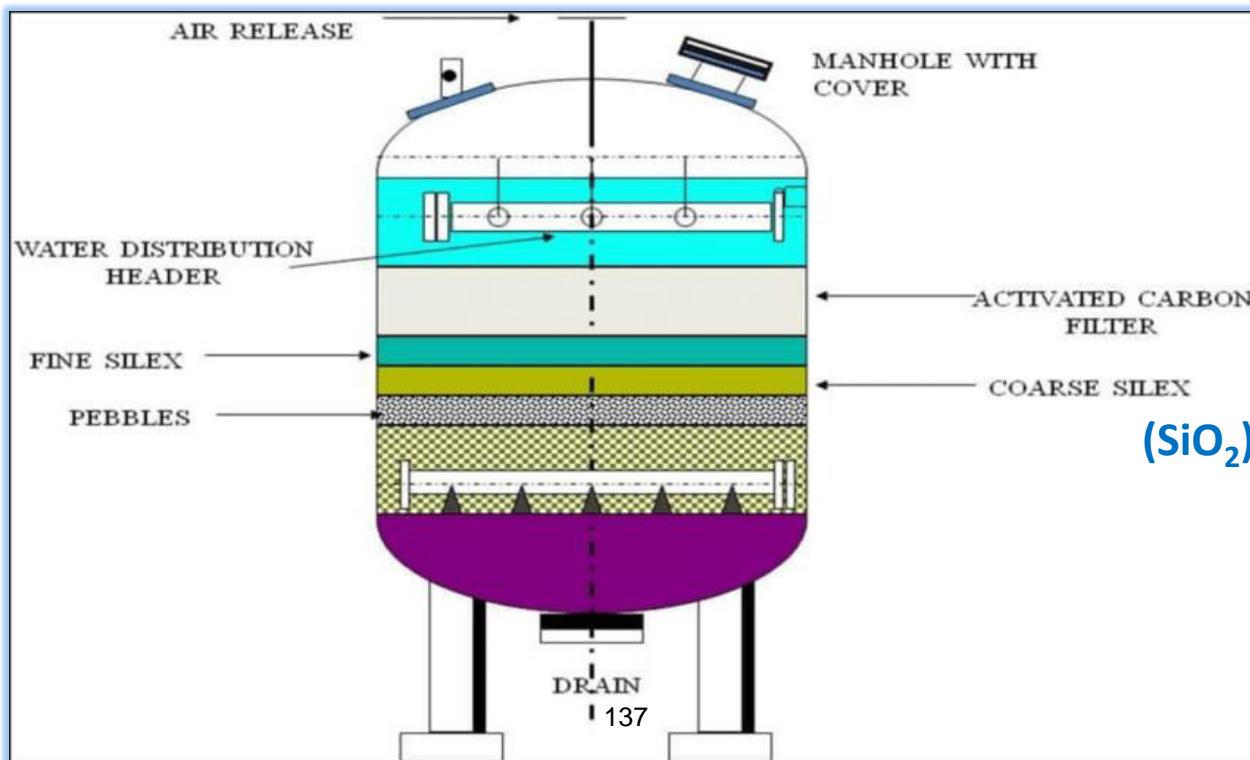
A process of removing colloidal matter and most of the bacteria, micro-organisms etc., by passing water through a bed of fine sand and other proper sized granular materials



# Activated Carbon Filtration



- Activated carbon filters are generally used in the process of removing organic compounds and/or extracting free chlorine from water.
- Coconut shells and coal (anthracite or bituminous) are both organic sources of activated carbon.





# Working Mechanism in the fabrication of Activated Carbon

- Carbon forms when an organic source is burned in an environment without oxygen. This process leaves only about 30% of the organic mass intact, driving off heavy organic molecules.
- Prior to being used for water treatment, the organic mass must then be "activated by either Steam Activation (800°C-1000°C) or Chemical Activation (a powerful dehydrating agent like phosphoric acid ( $P_2O_5$ ) or zinc chloride ( $ZnCl_2$ )."
- The process of activation opens up the carbon's massive number of pores and further drives off unwanted molecules. The open pores are what allow the carbon to capture contaminants, through **adsorption**.
- The rate of adsorption for a surface area of a just one pound (0.45 kg) of Activated Carbon is equal to 60-150 acres!

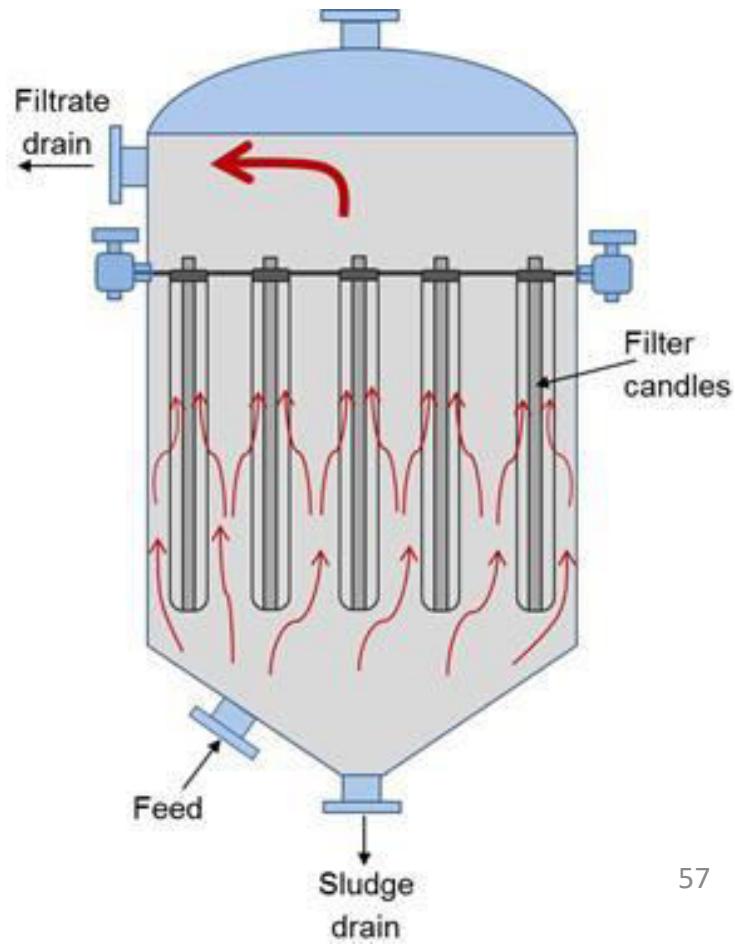
# Candle Filtration



The Candle Filters are, like all pressure filters, operating on a batch cycle and may be seen in process lines handling titanium dioxide, flue gas, brine clarification, red mud, china clay, fine chemicals and many other applications that require efficient low moisture cake filtration or high degree of polishing.

**The Candle Filter consists of three major components:**

- The vessel
  - The filtering elements
  - The cake discharge mechanism
- 
- **Candle Filters are very well suited for handling flammable, toxic and corrosive materials.**



# Candle Filtration



## Advantages

- Excellent cake discharge.
- Adapts readily to slurry thickening.
- Minimum floor space.
- Mechanically simple since there are no complex sealing glands or bearings.

## Disadvantages

- High headroom is required for dismantling the filtering elements.
- The emptying of the vessel in between cake filtration, washing and drying requires close monitoring of the pressure inside the vessel to ensure that the cake holds on to the candles.



# Disinfection

---

**The destruction or prevention of growth of microorganisms capable of causing diseases**

Disinfection is achieved by altering or destroying structures or functions of essential components within the pathogens

- proteins (structural proteins, enzymes, transport proteins, etc.)
- nucleic acids (genomic DNA or RNA, mRNA, tRNA, etc.)
- lipids (lipid bi-layer membranes, other lipids)

**Disinfectants include:**

- **Heat** – denatures proteins and nucleic acids
- **Chemicals** – uses a variety of mechanisms
- **Filtration** – physical removal of a pathogen
- **Radiation** – destroys nucleic acids

Some disinfectants also control taste and odor problems, organic matter, and metals such as iron and manganese

# Factors Influencing Disinfection



- Type of disinfectant
- Type of microorganism
- Disinfectant concentration and time of contact
- pH
- Temperature
- Chemical and physical interference, e.g., clumping of cells or adsorption to larger particles

# Common Disinfectants in Water Treatment



- Chlorine
- Ozone
- Ultraviolet light

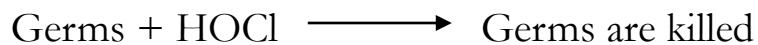
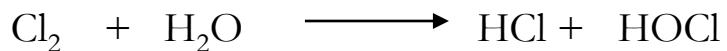
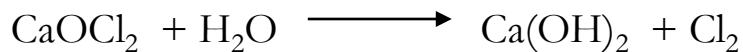
**Some filtration techniques such as RO etc.**



# I. Disinfectants of Water by Chlorination

## (a) bleaching powder

- In drinking water 1 mg/L of chlorine for 30 min is generally sufficient to reduce bacterial numbers. In wastewater with **interfering substances** up to 20-40 mg/L may be required.
  - Produces hypochlorous acid (powerful germicide)

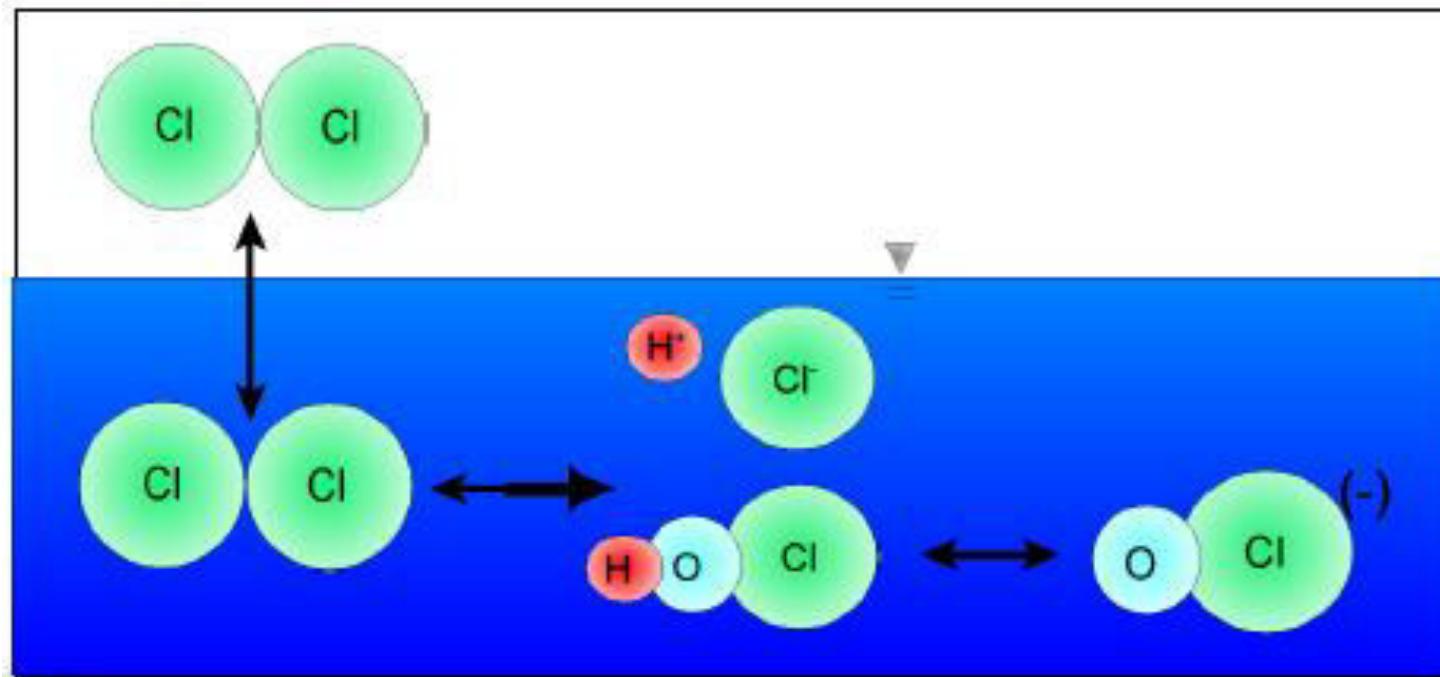


### Disadvantage

- Introduces Calcium in water, thereby making it more hard
- excess of it gives a bad taste and smell to treated water
- Chlorinated organic compounds (some of them are carcinogenic)



# Disinfection by HOCl



Produces hypochlorous acid (powerful germicide)

Hypochlorous acid weak acid

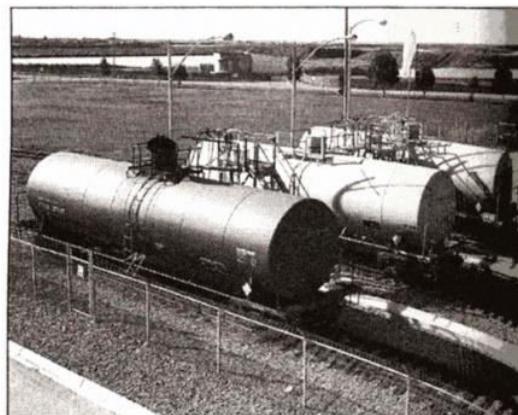
Neutral or weak acidic pH  $\text{HOCl}$  (stable)

Basic pH it forms  $\text{OCl}^-$  not a powerful germicide

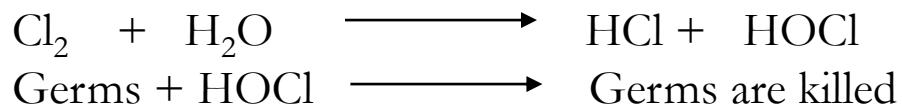
# I. Disinfectants of Water by Chlorination



## (b) Chlorine gas

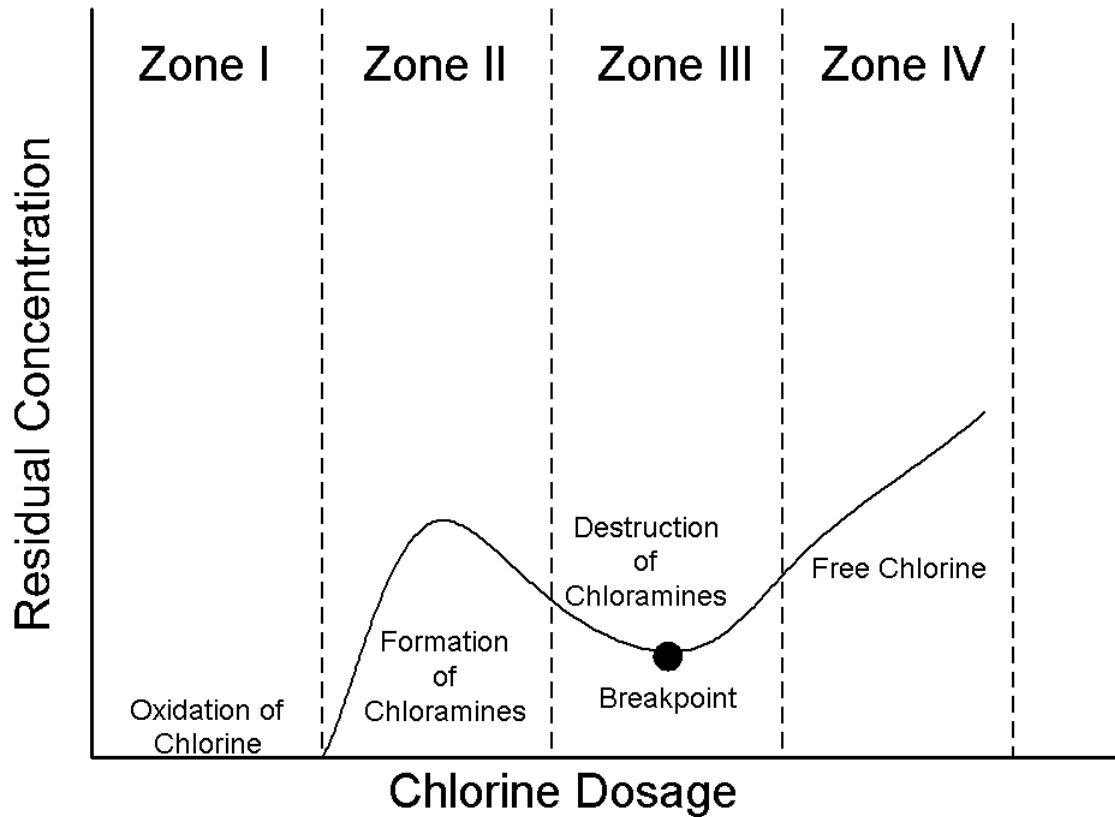


- Chlorine either gas or in concentrated solution form produces hypochlorous acid, which is a powerful germicide





# Break point chlorination or free-residual chlorination



Involves addition of sufficient amount of chlorine to oxidize organic matters, reducing substances, free ammonia leaving behind free chlorine to kill bacteria.

The addition of chlorine at the dip or break is called break-point chlorination

# Break point chlorination



The point at which near complete oxidation of nitrogen compounds are reached. Any point beyond breakpoint is mostly free chlorine ( $\text{HOCl}$  and  $\text{OCl}^-$ )

## (i) Amount of chlorine required

- **Theory:** 7.6 to 15 times the ammonia nitrogen content of the water
- **Practical:** up to 25 times the ammonia nitrogen content

## (ii) Beyond breakpoint

- 90% free residual chlorine ( $\text{HOCl}$  and  $\text{OCl}^-$ )
- 10% combined chlorine

## (iii) Why much breakpoint chlorination be reached

- Necessary for the production of free residual chlorination ( $\text{HOCl}$  and  $\text{OCl}^-$ )
- Reduces taste and odours
- Reduces chloramines

# Chlorination (advantages and disadvantages)



## Advantages

- Effective against all types of microbes
- Relatively simple maintenance and operation
- Inexpensive

## Disadvantages

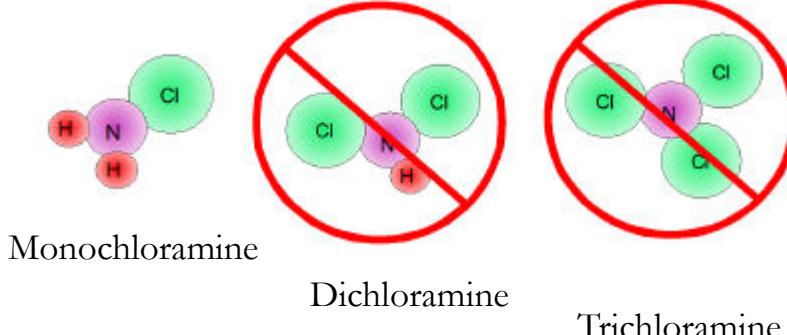
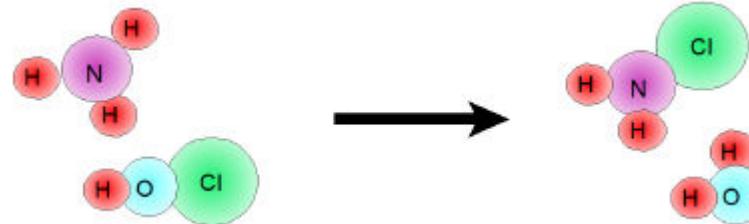
- Corrosive
- High toxicity
- High chemical hazard
- Highly sensitive to inorganic and organic loads
- less effective in higher pH values
- excess chlorine produces unpleasant taste and odour
- Formation of harmful disinfection by-products (DBP's)

# 1. Disinfectants of Water by Chlorination



- First used in 1905 in London, in Bubbly Creek in Chicago (in USA) in 1908
- Chlorine being replaced by alternative disinfectants after the discovery of its disinfection by-products (trihalomethanes and other chlorinated organics) during the 1970's

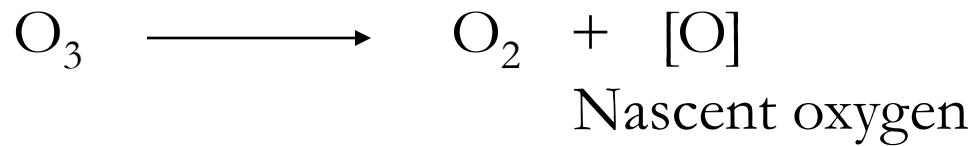
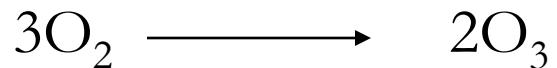
If ammonia present in the raw water, these reactions occur:



Formation is dependent on the pH and chlorine to ammonia ratio



## 2. Disinfection of water by Ozone ( $O_3$ )



- Very strong oxidant but has no residual disinfection power
- Generated by passing high voltage through the air between two electrodes
- More expensive than chlorination but does not produce trihalomethanes which are suspected carcinogens
- Widely used in Europe, limited use in U.S.



# Ozone - History and Background

- First used in 1893 at Oudshoorn, Netherlands and at Jerome Park Reservoir in NY (in USA) in 1906
- Used in more than 1000 WTPs in European countries, but was not so popular in USA
- Increased interest due to the discovery of chlorination disinfection by-products during the 1970's
  - an alternative primary disinfectant to free chlorine
  - strong oxidant, strong microbiocidal activity, perhaps less toxic DBPs



# Ozone - Chemistry

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## Ozone

- colorless gas
- relatively unstable
- highly reactive
  - reacts with itself and with  $\text{OH}^-$  in water

## The method of application

- generated by passing dry air (or oxygen) through high voltage electrodes (Ozone generator)
- bubbled into the water to be treated.



# Ozone (advantages and disadvantages)

## Advantages

- Highly effective against all type of microbes

## Disadvantages

- Expensive
- Unstable (must produced on-site)
- High toxicity
- High chemical hazards
- Highly sensitive to inorganic and organic loads
- Formation of harmful disinfection by-products (DBP's)
- Highly complicated maintenance and operation

### 3. Water disinfection by UV

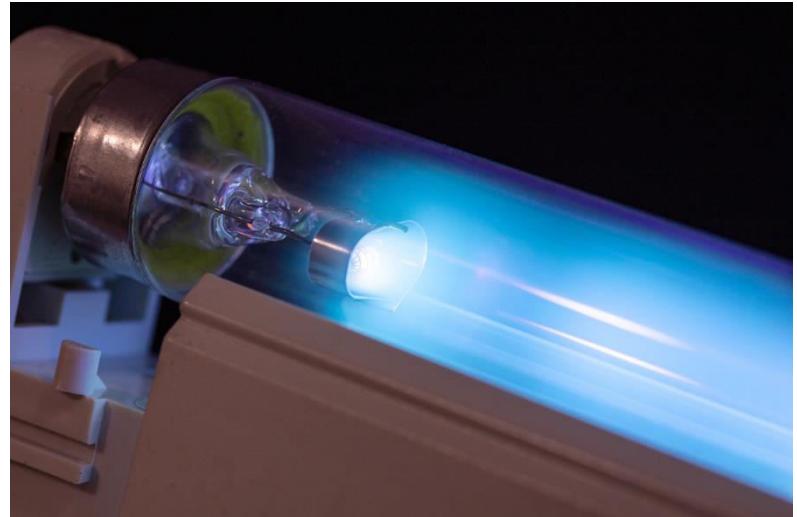


- Optimum ultraviolet light wavelength range for germicidal effect:  
250 nm - 270 nm
- Low pressure mercury lamps emit 253.7 nm
- Damages microbial/viral DNA and viral RNA by causing dimerization, blocking nucleic acid replication
- **Does not produce toxic by-products**
- Higher costs than chemical disinfection, no residual disinfection



# Ultraviolet irradiation

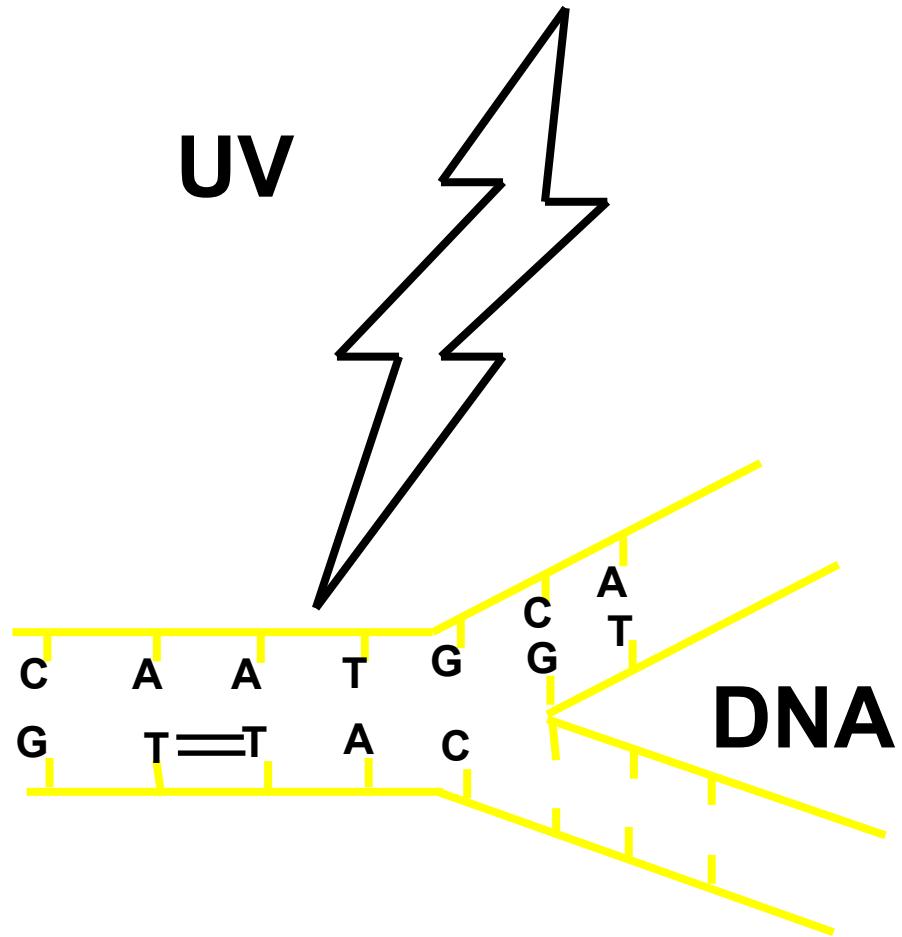
- Has been used in wastewater disinfection for more than 50 years
- Increased interest after the discovery of its remarkable effectiveness against *Cryptosporidium parvum* (diarrhea) and *Giardia lamblia* in late 1990's





# Ultraviolet irradiation

- physical process
- energy absorbed by DNA
  - pyrimidine dimers, strand breaks, other damages
  - **inhibits replication**



# Ultraviolet irradiation



The advantages of using UV, rather than chemical disinfection, include:

- Has no known toxic or significant nontoxic by-products
- Has no danger of overdosing
- Removes some organic contaminants
- Has no volatile organic compound (VOC) emissions or toxic air missions
- Has no onsite smell and no smell in the final water product
- Requires very little contact time (seconds versus minutes for chemical disinfection)
- Does not require storage of hazardous material
- Requires minimal space for equipment and contact chamber
- Improves the taste of water because of some organic contaminants and nuisance microorganisms are destroyed

# Ultraviolet irradiation



## Disadvantages of UV disinfection include

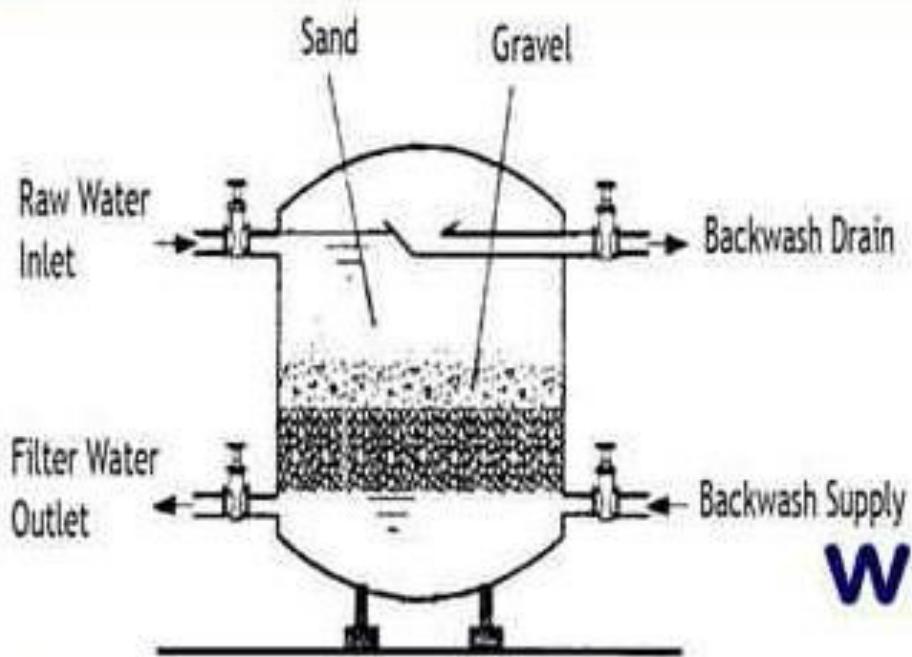
- No technical database exists on how well UV systems perform for various water quality conditions
- No standardized mechanism measures, calibrates, or certifies how well equipment works before or after installation

# Purification of Municipal water supply

- **Screening**
  - Water passes through screens with larger holes
- **Sedimentation**
  - Allow water to stand undisturbed in big tanks
- **Coagulation and/or flocculation**
  - Alum, Sodium aluminate, copper or Ferrous sulphate
- **Filtration**
  - Sand filtration – (Coarse & Fine sand bed)
  - Activated carbon filtration – (Adsorption)
  - Candle filtration – (Ceramic materials)
- **Disinfection – Factors influencing disinfection process**
  - Chlorination
    - Bleach or gaseous chlorine (break-point of chlorination)
  - Ozonation (Oxidation using [O])
  - Ultraviolet light irradiation (Higher energy – DNA strand breaks)
- **Supplementary treatment<sup>60</sup>**



# Water Purification by Filtration



**Filtration  
process  
in  
water treatment**

# What is filtration?



- **Filtration is a process of removing particulate matter from water by forcing the water through a porous media.**
- This porous media can be natural, like sand, gravel and clay, or it can be a membrane wall made of various materials.
- Sometimes, large particles are settled before filtration; this is called sedimentation.
- The size of materials that can be removed during filtration depends upon the size of the pores of the filter.

# Water Contaminants



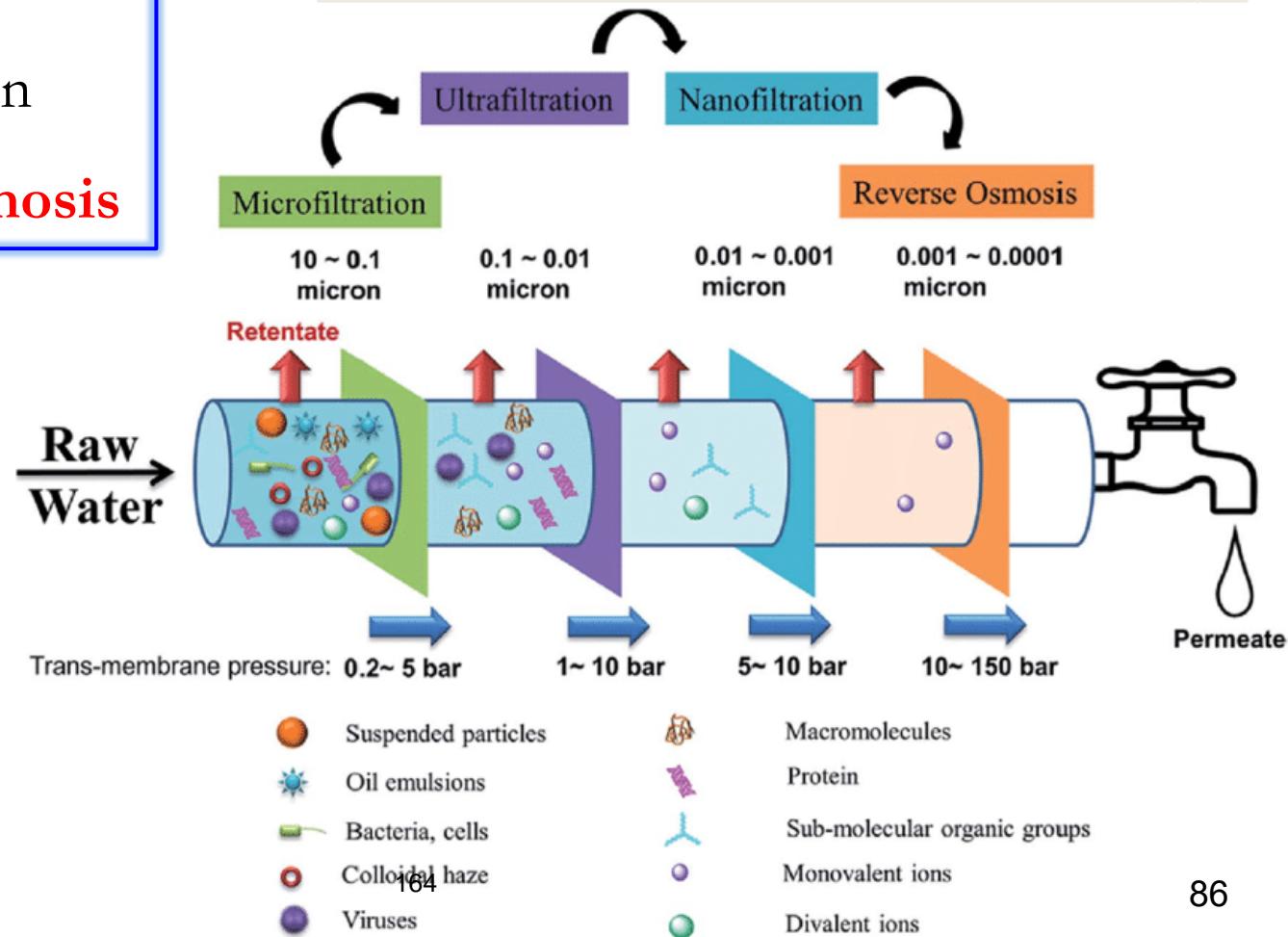
Class	Typical Example
Suspended solids	Dirt, clay, colloidal materials
Dissolved organics	Trihalomethanes, synthetic organic chemicals, humic acids, fulvic acids
Dissolved ionics (salts)	Heavy metals, silica, arsenic, nitrate
Microorganisms	Bacteria, viruses, protozoan cysts, fungi, algae
Gases	Hydrogen sulfide, methane, radon



# Different Kinds of Filtration

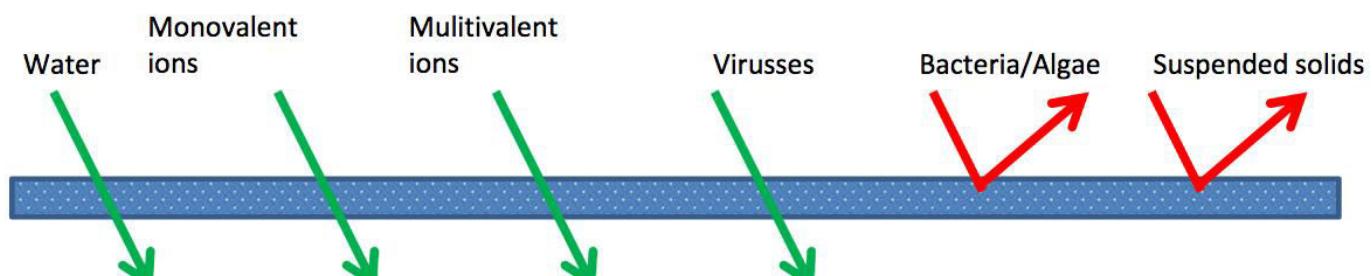
1. Micro filtration
2. Ultra filtration
3. Nano filtration
4. Reverse Osmosis

Membrane Processes are becoming popular because they are considered “Green” technology  
- no chemicals are used in the process.

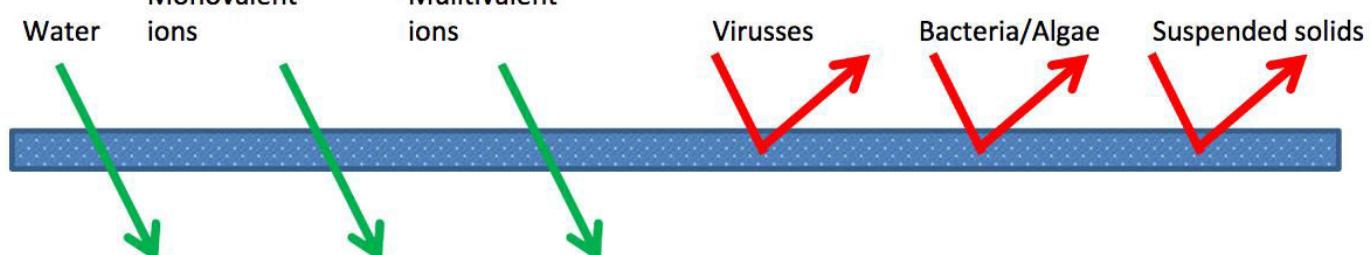


# Comparison membrane techniques

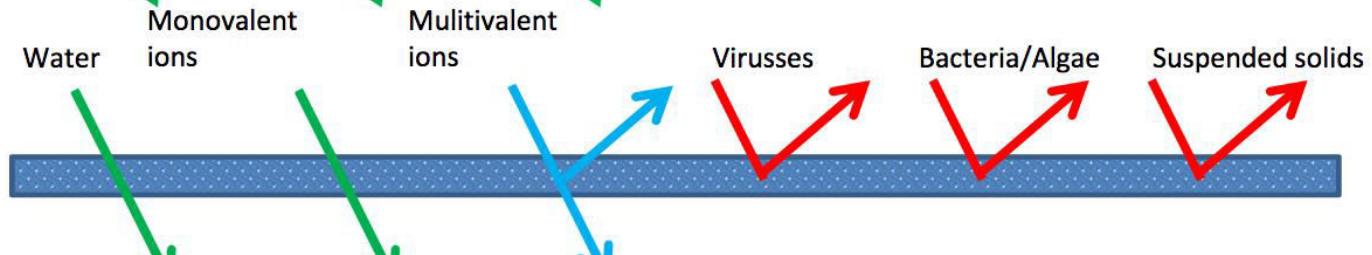
**Micro filtration MF**  
10µm – 0,1µm (100nm)



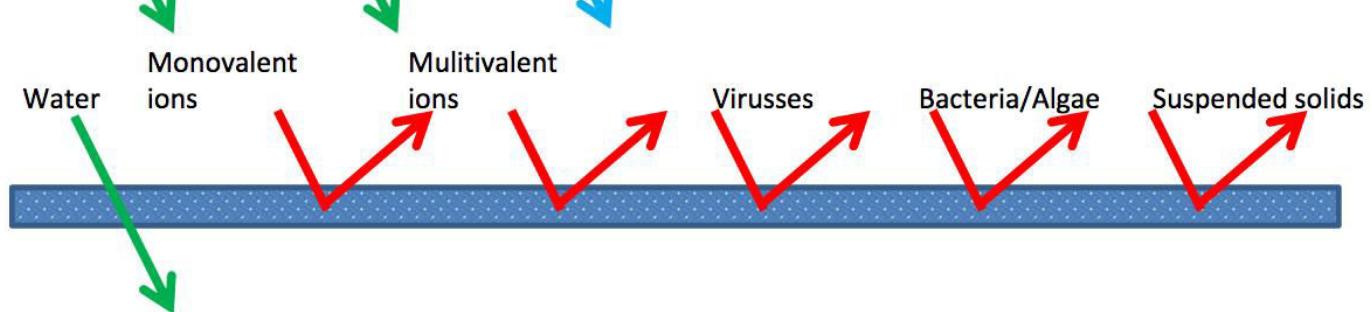
**Ultra filtration UF**  
0,1µm – 0,01µm (10nm)



**Nano filtration NF**  
10nm – 1nm



**Hyper filtration/  
Reverse osmosis**  
RO < 1nm



# Membrane Filtration comparison



Filtration type	Pore size	Impurities removed
Microfiltration	0.1-10 µm	Suspended Particles, Microorganisms
Ultrafiltration	0.1 – 0.01 µm	Suspended solids, solutes of higher molecular weight
Nanofiltration	1-10 nm	Multivalent Cations, Organic Impurities
Reverse Osmosis	0.1 nm (< 1nm)	Removes most of the impurities (bigger than 0.1 nm)



# 1. Microfiltration

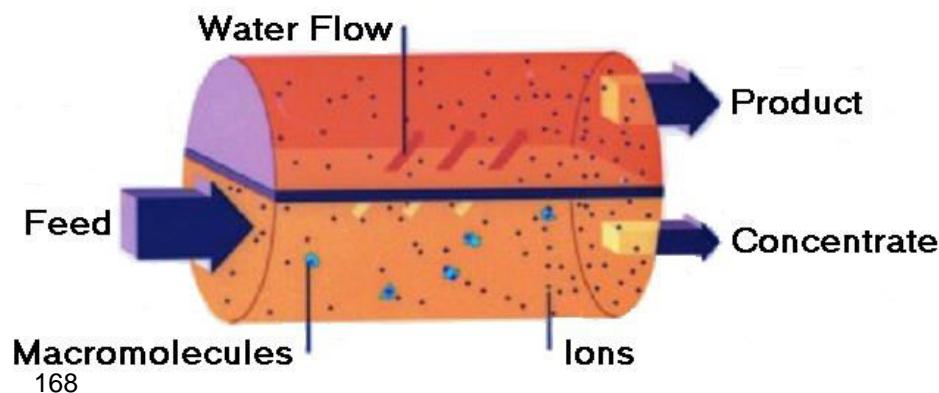
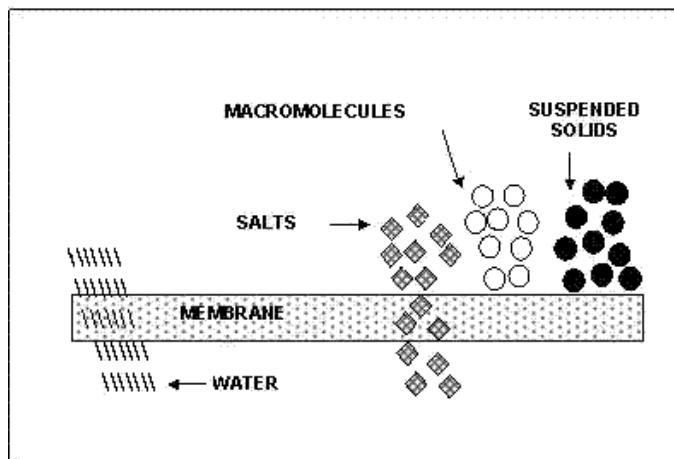
Microfiltration (MF) membranes are available in pore sizes ranging from **0.1 to 10 µm**. MF porosity is the highest in the membrane filtration family, with the result that MF membranes allow water, ions, dissolved organic material, small colloids, and viruses to pass through, while retaining larger contaminants such as:

- **Algae**
- **Bacteria**
- **Pathogenic protozoa**, including Giardia lamblia and Cryptosporidium
- **Sediment**, including sand, clay, and complex metals/particles

## 2. Ultrafiltration



- Ultrafiltration is basically a pressure driven separation process, governed by a screening principle and dependent on particle size
- Ultrafiltration membranes have a pore size between **10 nm and 100 nm**, this allowing retention of compounds with a molecular weight of 300-5,00,000 Daltons.
- The Ultrafiltration rejected water consist of sugars, biomolecules, polymers, colloidal particles and viruses.



## 2. Ultrafiltration



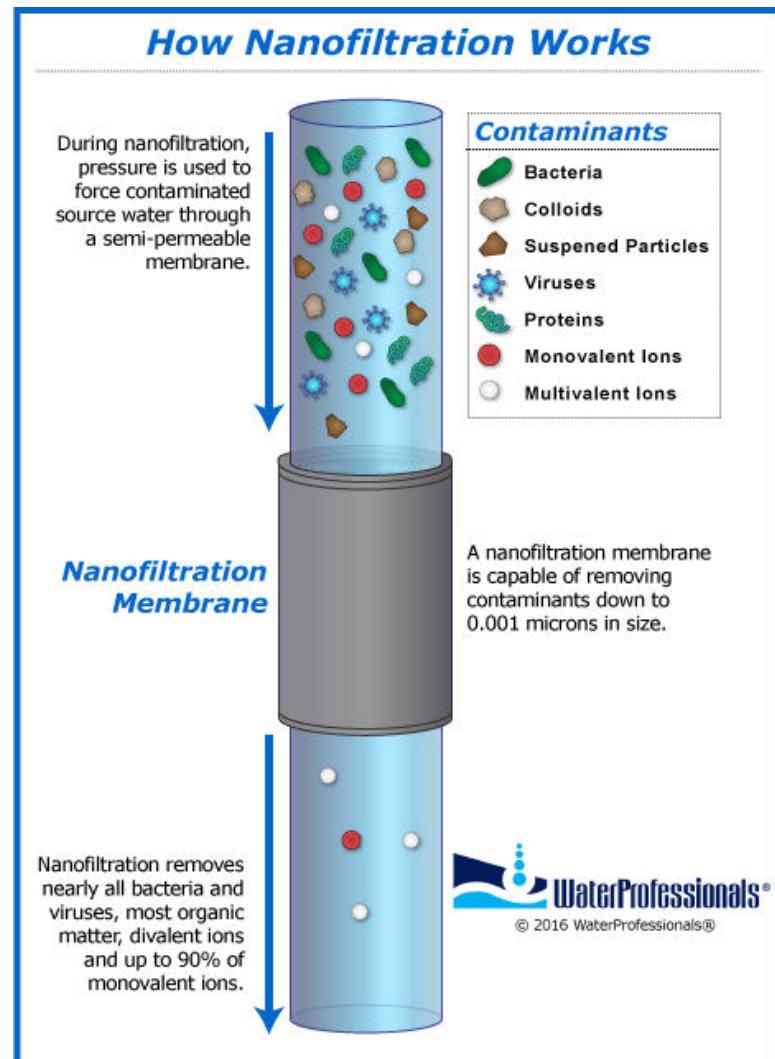
Most membranes are synthetic organic polymers (e.g. polysulfone, cellulose acetate).

- Microfiltration and ultrafiltration membranes are often made from the same materials, but they are prepared under different membrane formation conditions so that different pore sizes are produced.
- Membranes can also be prepared from inorganic materials such as ceramics or metals.
- Ceramic membranes are microporous, thermally stable, chemically resistant, and often used for microfiltration.
- However, disadvantages such as high cost and mechanical fragility have hindered their widespread use. Metallic membranes are often made of stainless steel and can be very finely porous.
- Their main application is in gas separations, but they can also be used for water filtration at high temperatures or as a membrane support.



### 3. Nanofiltration

- Nanofiltration (NF) is a membrane filtration – based method.
- Nanofiltration membranes have pore sizes from **1 to 10 nm**.
- NF membranes used are predominantly created from polymer thin films.
- Materials that are commonly use include polyethylene terephthalate or metals such as aluminium



### 3. Nanofiltration



#### Benefits of Nanofiltration

- ✓ Low cost of operation and low energy cost
- ✓ Comparatively lower discharge and less wastewater
- ✓ Reduction in heavy metals and reduction in water hardness
- ✓ Reduction/Removal of viruses, bacteria and pesticides

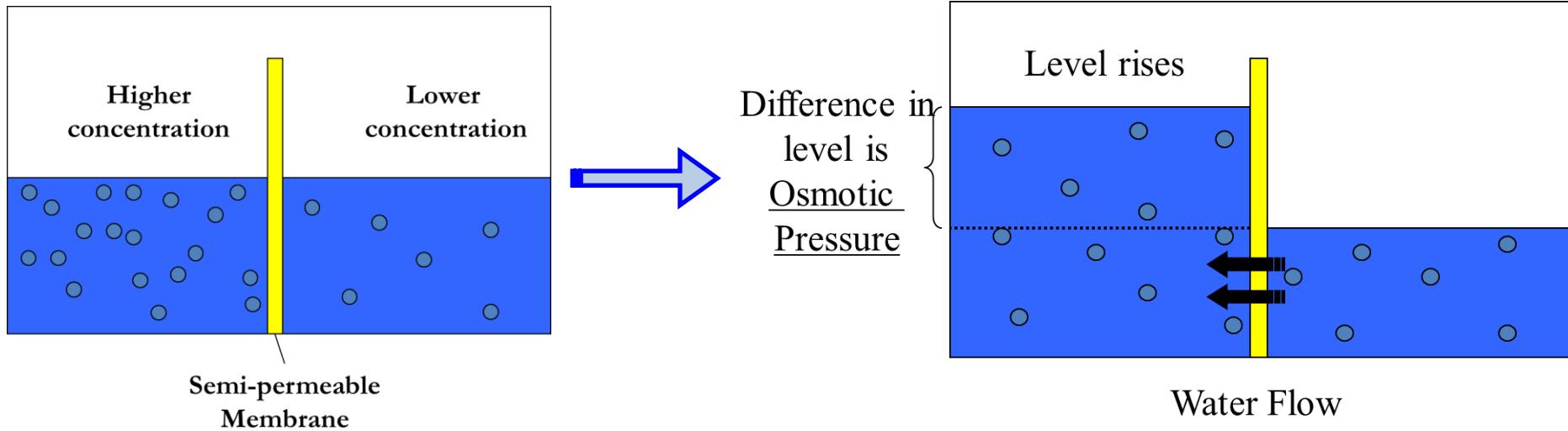
#### Drawbacks of the process of Nanofiltration

- ✗ Membrane fouling
- ✗ Treatment of concentrates
- ✗ Membrane lifetime and chemical resistance
- ✗ Insufficient rejection for individual components



## 4. Reverse Osmosis

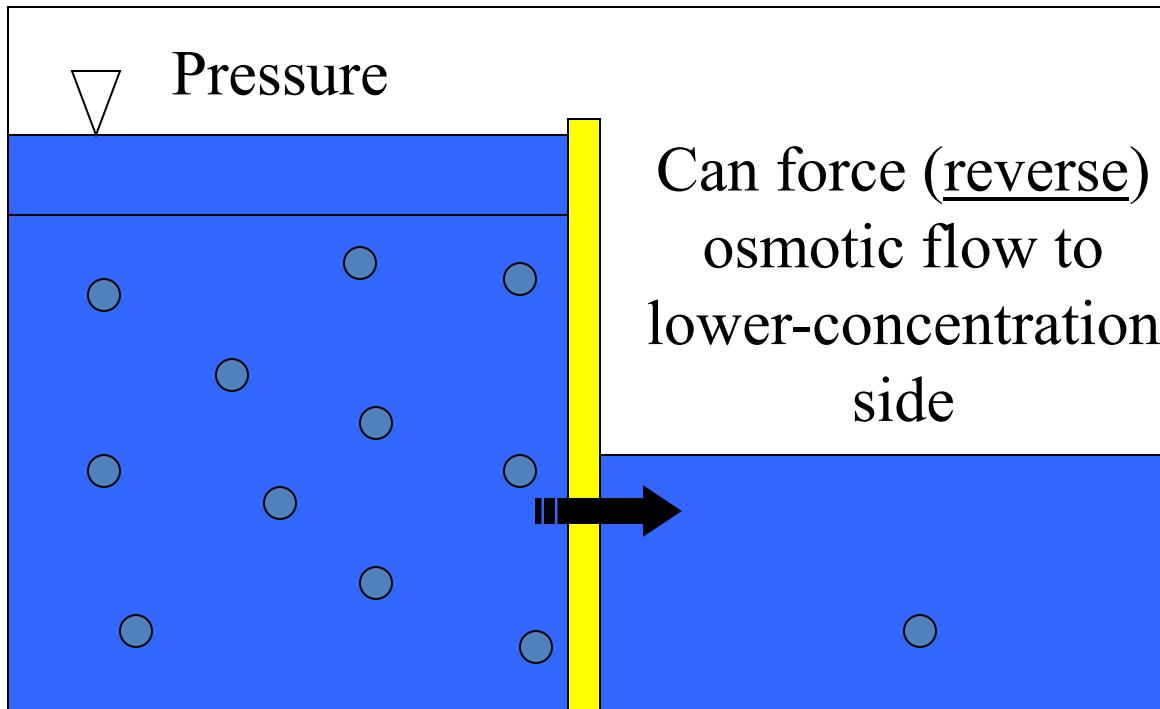
# Osmosis



- **Osmosis** is the movement of water or other solvent through a plasma membrane from a region of low solute concentration to a region of high solute concentration.
- **Osmosis** is passive transport, meaning it does not require energy to be applied.

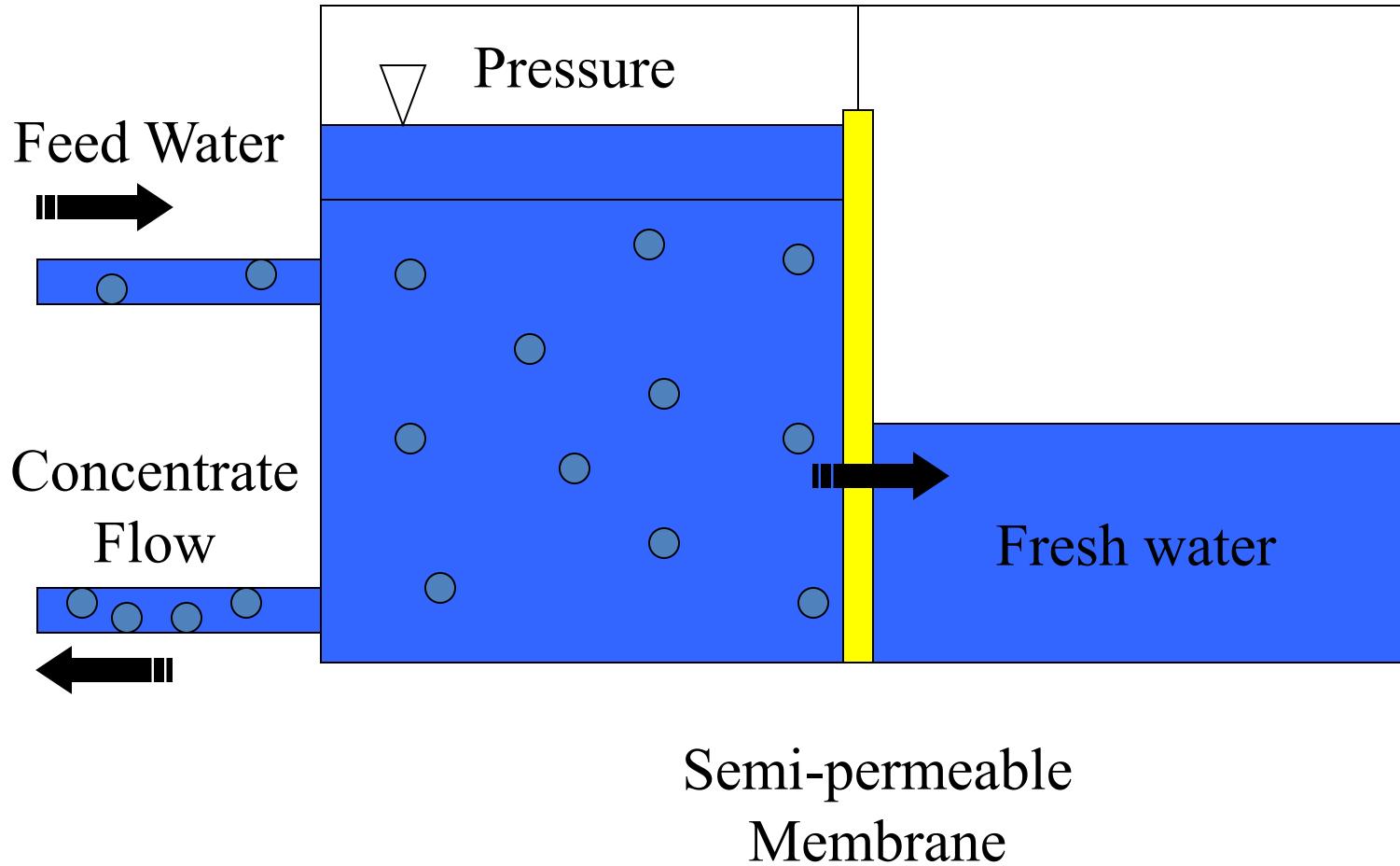


## 4. Reverse Osmosis



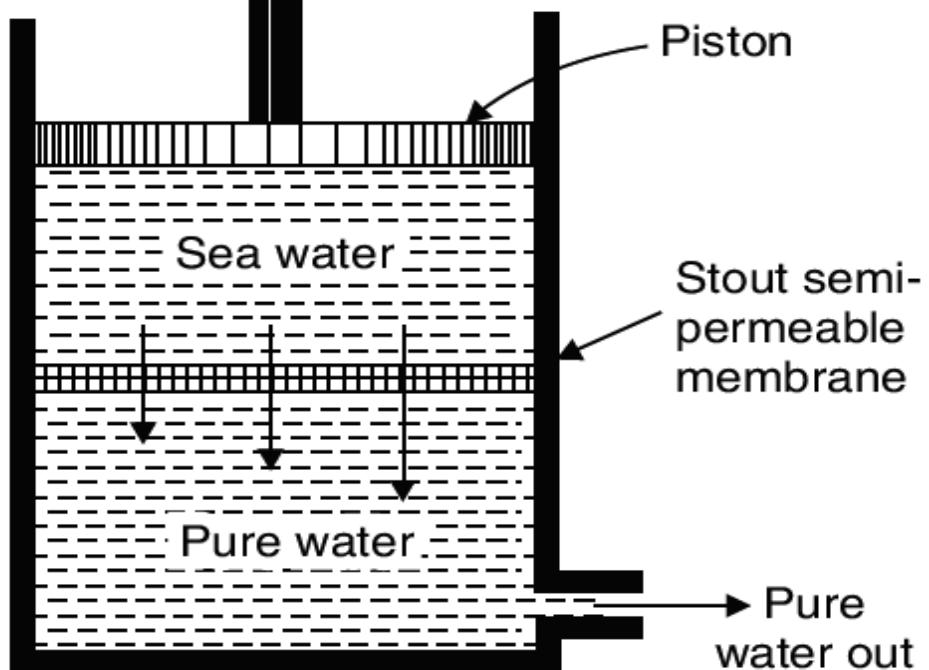
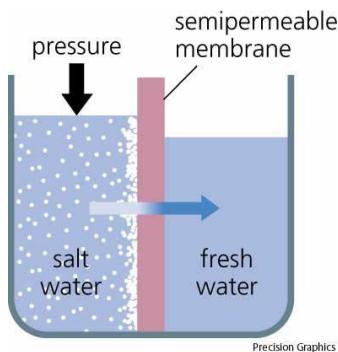
Semi-permeable  
Membrane

# Reverse Osmosis Applied





## 4. Reverse Osmosis



Reverse osmosis cell

- Super filtration
- 15-40 kg cm<sup>2</sup>
- Cellulose acetate
- Polysulfone
- Polysulfone amide
- Polyamide
- Poly-acrylonitrile

### Advantages

- Removes colloidal silica
- Long life
- Can be replaced within few minutes

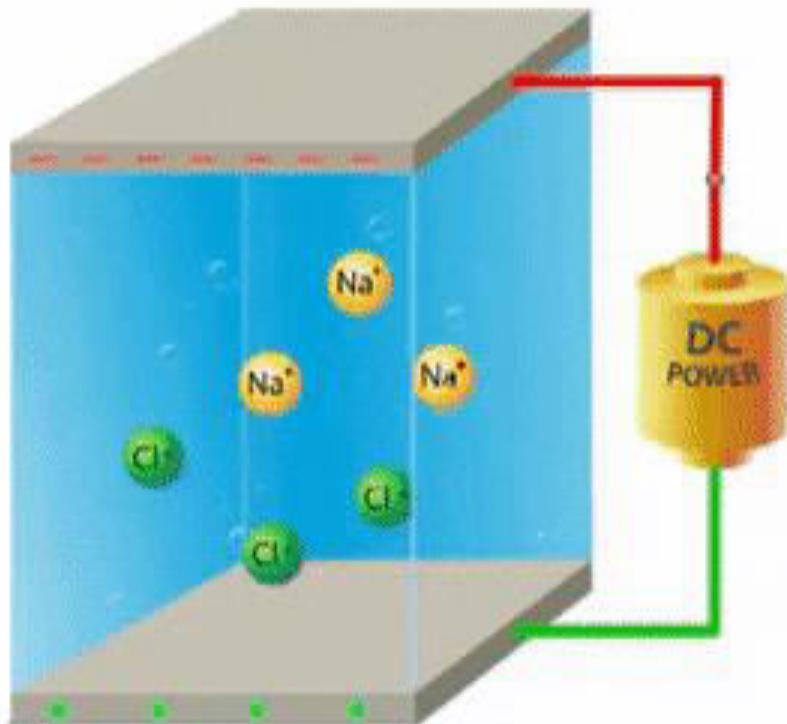


# Desalination of brackish water

- Water containing dissolved salts with a peculiar salty (brackish) taste is brackish water
- The process of removing common salt from water is desalination
- Electrodialysis consists of a large container with two membrane separators, one permeable to positive ions and the other permeable to negative ions.
- In the outer compartments anode and cathode are arranged to pass DC Voltage.
- When DC voltage/current is passed through the cell,  $\text{Na}^+$  will move towards cathode and  $\text{Cl}^-$  will move towards anode through the membrane.
- Hence, the concentration of salt decreases in the middle compartment and increases in the side compartments.
- Water from the middle compartment is collected and this water is desalinated water.

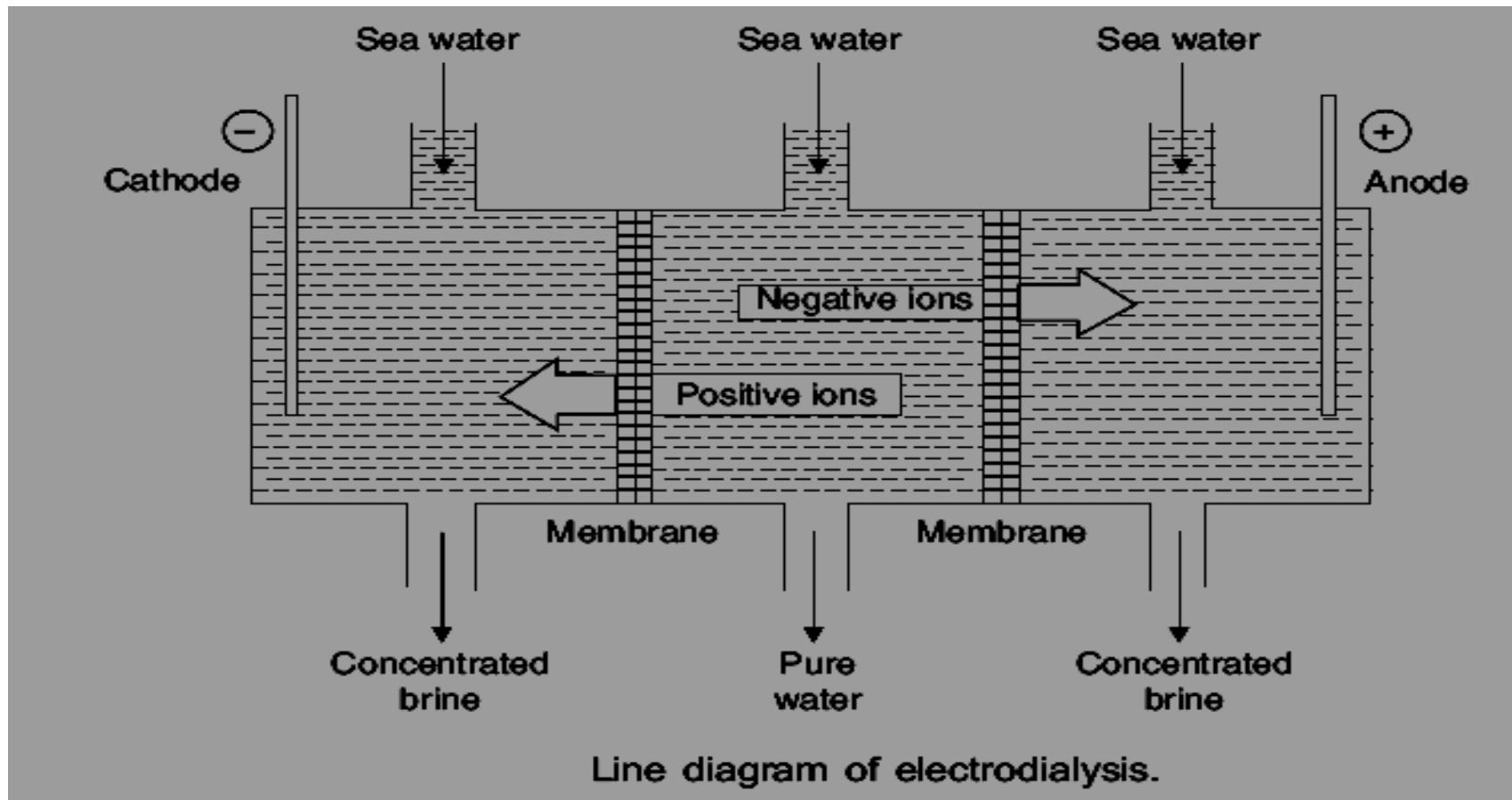


# Electrodialysis





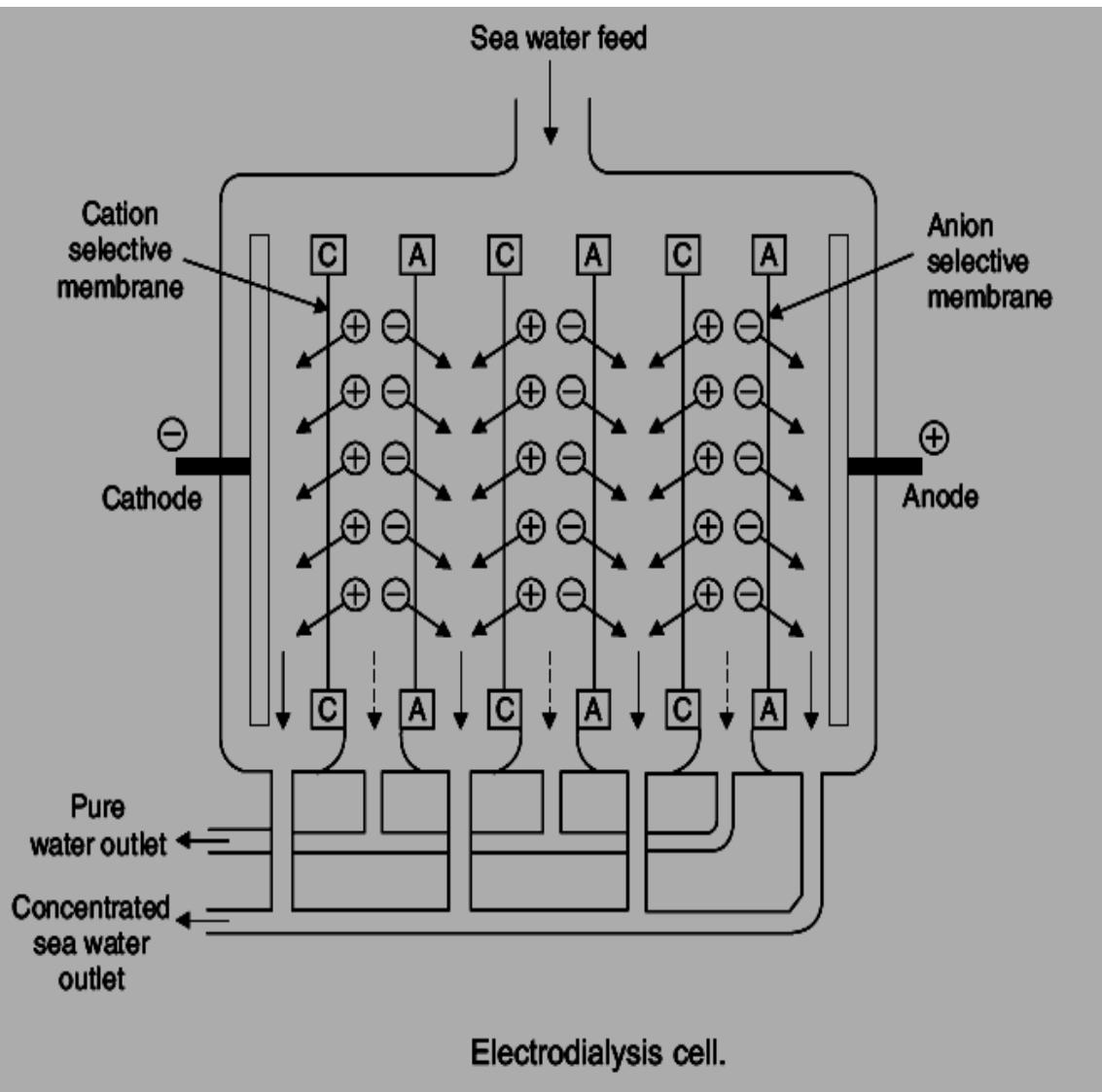
# Electrodialysis diagram



For efficient separation, ion-selective membranes are used which selectively allow cations or anions to pass through them.



# Electrodialysis cell



- Electrodialysis cell consists of Large number of pairs of rigid Plastic membranes.
- Saline water at a pressure of 5-6 kg/cm<sup>2</sup> is passed through the membrane pairs.
- DC current is applied perpendicular to the direction of water flow.

## Advantages are:

1. Unit is compact and installation is economical
2. Best suited if electricity is available.