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ENGINEERING CHEMISTRY (22CH101)

DEPARTMENT	ADS, CSD, CSE, IT
BATCH/YEAR	2022-23/I
CREATED BY	CHEMISTRY DIVISION
DATE	OCTOBER 2022

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COURSE OBJECTIVES

Objectives:

The goal of this course is to achieve conceptual understanding of the applications of chemistry in engineering and technology. The syllabus is designed to:

- To understand the water quality criteria and interpret its applications in water purification
- To gain insights on the basic concepts of electrochemistry and implement its applications in Chemical Sensors
- To acquire knowledge on the fundamental principle of energy storage devices and relate it to Electric Vehicles
- To identify the different types of smart materials and explore its applications in Engineering and Technology
- To assimilate the preparation, properties and applications of nanomaterials in various fields

COURSE CODE	ENGINEERING CHEMISTRY Theory Course with Laboratory Component (Common to all except CE, ME and CB)	L	T	P	C
22CH101		3	0	2	4

UNIT I WATER TECHNOLOGY **15**

Sources of water – Impurities - Drinking water quality parameters – Hardness and its types, problems - Municipal water treatment and disinfection (chlorination - break-point chlorination, UV, Ozonation). **Boiler troubles** - Scales and sludges, Boiler feed water: Requirements - Internal treatment (phosphate, colloidal, sodium aluminate and Calgon conditioning). External treatment – Ion exchange demineralization - Principle, process and fouling.

Desalination of brackish water: Reverse osmosis – principle -types of membranes, process and fouling. (Theory-9)

1. Determination of total, temporary and permanent hardness of water by EDTA method.
2. Determination of chloride content of water sample by argentometric method.
3. Determination of alkalinity in water sample. (Laboratory-6)

UNIT II ELECTROCHEMISTRY AND SENSORS **15**

Introduction- Conductance- factors affecting conductance – Electrodes – origin of electrode potential – single electrode potential, standard electrode potential – measurement of single electrode potential –over voltage - reference electrodes (standard hydrogen electrode, calomel electrode)-ion selective electrode- glass electrode - Nernst equation (derivation), numerical problems, Electrochemical series and its applications.

Chemical sensors – Principle of chemical sensors – Breath analyzer – Gas sensors – CO_2 sensors- Sensor for health care – Glucose sensor. (Theory-9)

1. Determination of the amount of NaOH using a conductivity meter.
2. Determination of the amount of acids in a mixture using a conductivity meter.
3. Determination of the amount of given hydrochloric acid using a pH meter. (Laboratory-6)

UNIT III ENERGY STORAGE DEVICES AND ENERGY SOURCES 15

Batteries – Primary alkaline battery - Secondary battery - Pb-acid battery, Fuel cell - $H_2 – O_2$ fuel cell.
Batteries used in E- vehicle: Ni-metal hydride battery, Li-ion Battery, Li-air Battery
Nuclear Energy – Nuclear fission, fusion, differences, characteristics – nuclear chain reactions – light water nuclear reactor – breeder reactor. (Theory-9)

1. Determination of single electrode potential of the given electrode.
2. Estimation of the iron content of the given solution using a potentiometer.
3. Determination of electrochemical cell potential (using different electrodes/ different concentrations of electrolytes) (Laboratory-6)

UNIT IV SMART MATERIALS FOR ENGINEERING APPLICATIONS 15

Polymers – Definition – Classification – smart polymeric materials - Preparation, properties and applications of Piezoelectric polymer - Polyvinylidene fluoride (PVDF), Electroactive polymer- Polyaniline (PANI) and Biodegradable polymer - Polylactic acid (PLA).
Polymer composites: Definition, Classification – FRP's – Kevlar.
Shape Memory Alloys: Introduction, Shape memory effect – Functional properties of SMAs – Types of SMA - Nitinol (Ni-Ti) alloys - applications.
Chromogenic materials: Introduction – Types - applications. (Theory-9)

1. Determination of the molecular weight of polymer using Ostwald viscometer.
2. Application of polymeric fibers in 3D printing. (Laboratory-6)

UNIT V NANOCHEMISTRY 15

Introduction – synthesis – top-down process (laser ablation, chemical vapor deposition), bottom-up process (precipitation, electrochemical deposition) – properties of nanomaterials – types – nanotubes -carbon nanotubes, applications of CNT - nanocomposites – General applications of nanomaterials in electronics, information technology, medical and healthcare, energy, environmental remediation, construction and transportation industries. (Theory-9)

1. Determination of concentration of $BaSO_4$ nanoparticles by conductometric titrations.
2. Preparation of ZnO nanocrystal by precipitation method. (Laboratory-6)

COURSE OUTCOMES

COs	Outcomes
CO 1	Interpret the water quality parameters and explain the various water treatment methods.
CO 2	Construct the electrochemical cells and sensors.
CO 3	Compare different energy storage devices and predict its relevance in Electric Vehicles
CO 4	Classify different types of smart materials, their properties and applications in engineering and technology.
CO 5	Integrate the concepts of nano chemistry and enumerate its applications in various fields.

Course Outcome mapping with POs / PSOs

COs	PO1	PO2	PO3	PO 4	PO5	PO 6	PO7	PO 8	PO 9	PO10	PO11	PO12
CO1	3	2				2	2					1
CO2	3	2				1	1					1
CO3	3	2				2	1					1
CO4	3	2				1	1					1
CO5	3	2				1	1					1

LECTURE PLAN

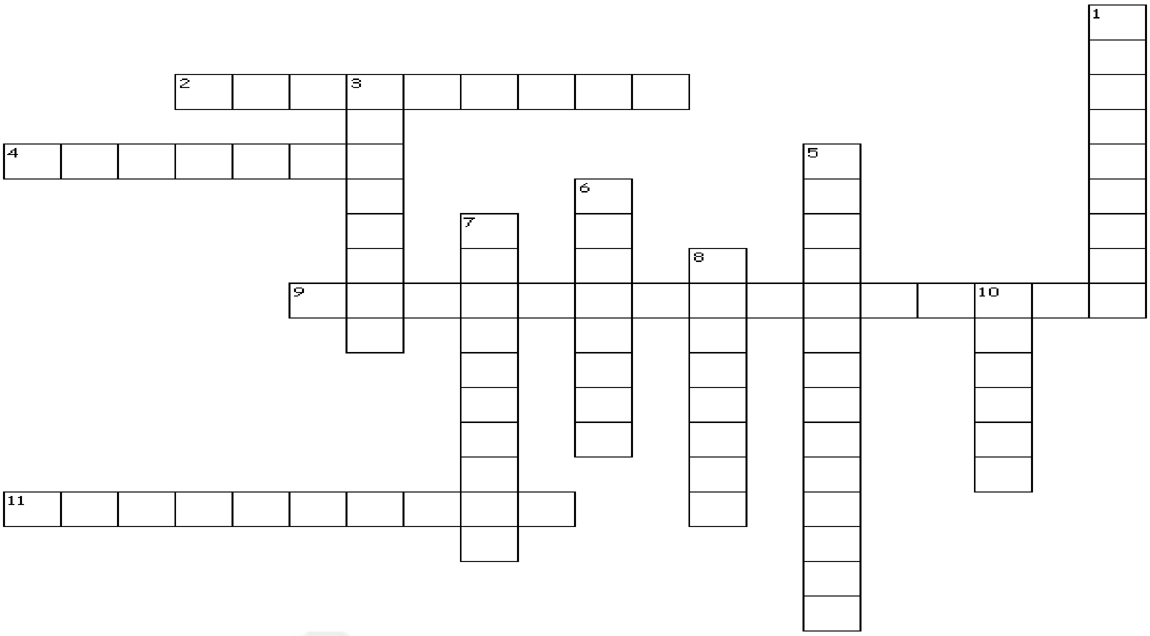
S.No.	Topics to be covered	No. of periods	Proposed date	Actual lecture date	CO	Taxonomy level	Mode of delivery
1	Sources of Water – Impurities – Drinking Water quality parameters	1					
2	Hardness and its types, Problems based on hardness	1					
3	Municipal water treatment and disinfection	1					
4	Boiler troubles - scales and sludges, Boiler feed water: Requirements	1					
5	Internal treatment (phosphate, colloidal, sodium aluminate and Calgon conditioning)	1					
6	External treatment demineralization process	1					
7	Fouling - causes, Types and control	1					
8	Desalination of brackish water – Reverse Osmosis	1					
9	Membrane Fouling and pretreatment	1					

Activity Based Learning

Activity	Topic	Outcome
Crossword Puzzle	Drinking water	Students will get familiarized with terminologies
Do and learn (hands-on experience)	Testing of Hardness	Students will learn about Hardwater and soft water
Bring out the process of different Ion exchange process by pictorial representation.	1. Zeolite 2. Montmorillonite 3. Clay 4. Soil Humus	Students will be able to apply their concept of water treatment through various ion exchangers.

Activity 1: Drinking Water Crossword Puzzle

Activity: Use the Drinking water glossary and water words below to complete this puzzle



CLUES

Across:

2. The amount of cloudiness of a normally clear liquid due to the suspension of solid particles.

4. Life or natural processes that require an environment with oxygen.

9. The amount of molecular oxygen dissolved in water.

11. A separate sewer that carries rain and melted snow from street runoff

Down:

1. The biological decomposition of organic matter in sludge by anaerobic or aerobic microorganisms in the wastewater.

3. Single--celled microscopic organisms that may be used in a variety of biological treatment processes.

5.Microscopic animals and plants of simple cell structure that feed on the wastes in wastewater to remove organic pollutants.

6. Wastewater flowing into a treatment process or treatment plant

7.The used water and solids that flow to a treatment plant.

8. The process of adding air in wastewater treatment to provide oxygen for microorganisms and to keep solids in suspension.

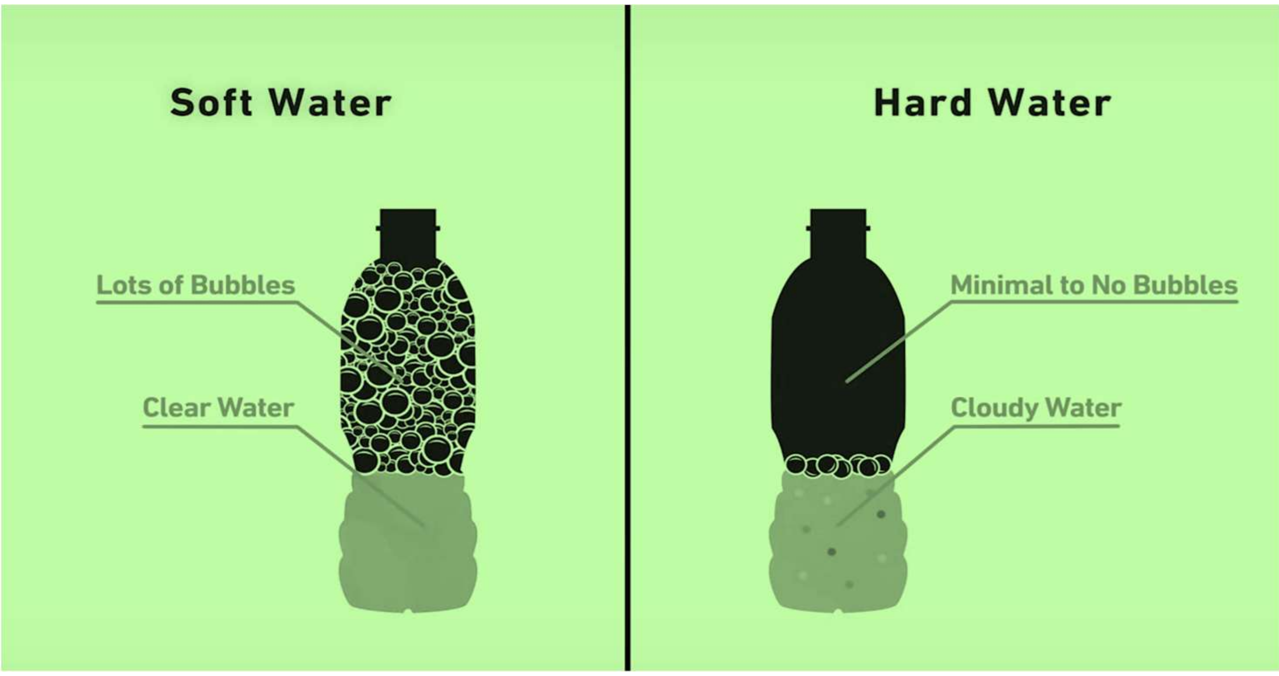
10. Oily or fatty matter.

Activity 2: Do and Learn

Testing of hardwater

1. How do you test for soft water?

If you have soft water, **your bottle should still be filled a third of the way with water and two-thirds filled with bubbles from the soap**. If you have hard water, the water in the bottle will be cloudy and there will be a thin layer of bubbles.



HARD WATER

The sample of hard water must be treated with buffer solution and EBT indicator which forms unstable, wine-red colored complex s with Ca^{2+} and Mg^{2+} present in water.

SOFT WATER

The sample of water must be treated with buffer solution and EBT indicator which forms blue-colored complex s indicating the absence of Ca^{2+} and Mg^{2+} in water.

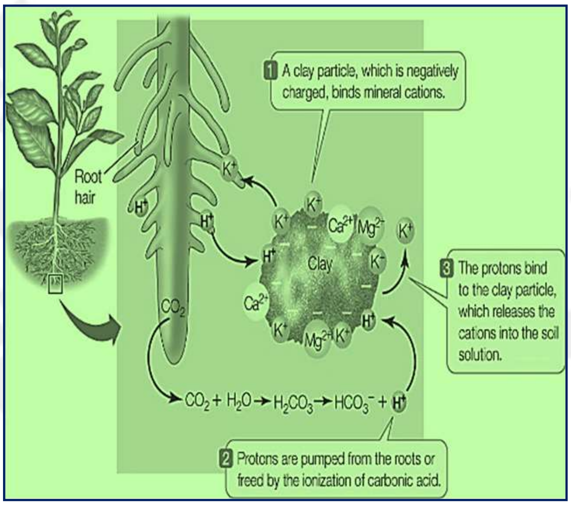
Activity 3: Bring out the process of different Ion exchange process by pictorial representation.

2. Give the role and significance of following Ion exchangers in water treatment with a neat sketch:

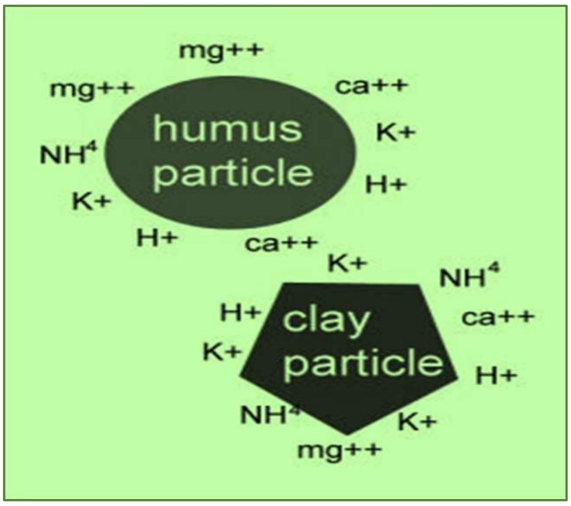
1. Zeolites

2. Montmorillonite

3. Clay



4. soil humus

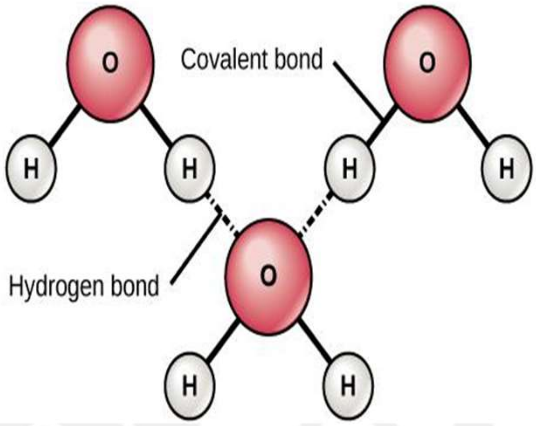


UNIT – I

WATER TECHNOLOGY

1.1 Water - Introduction:

- Water (H_2O), a transparent, tasteless, odorless, and colorless chemical substance, is capable of existing in gaseous, liquid and solid states. Every aspect of life involves water as food, as a medium in which to live, or as the essential ingredient of life.



The anomalous properties of pure water are:

a) High specific heat capacity, High latent heat of fusion, High latent heat of evaporation, highest surface tension etc.

(b) Fresh water and dilute seawater have a maximum density at temperatures above the freezing point.

(c) The dissolving power of water has obvious implications in both physical and biological phenomena.

- This unique property of water makes it inevitable for life and various domestic and industrial applications.

Water is one of the most abundant commodities in nature, at the same time it is the most polluted one. Although earth is a blue planet and 80% of its surface is covered by water, about 97% of it is locked in the oceans which is too saline which cannot be used for drinking as well as for the direct use of agricultural or industrial purpose. About 2.4% is trapped in polar ice caps and glaciers. Only less than 1% of water is used by man for various developmental, industrial, agricultural, steam generation and domestic purposes.

DO YOU KNOW?

The solid state of any substance is denser than the liquid state; thus, the solid would sink to the bottom of the liquid. The fact that ice floats on water is exceedingly important in the natural world, because the ice that forms on ponds and lakes in cold areas acts as an insulating barrier that protects the aquatic life below. If ice were denser than liquid water, ice forming on a pond would sink, thereby exposing more water to the cold temperature. Thus, the pond would eventually freeze throughout, killing all the life-forms present.

Ice float in water because it occupies more volume than liq water, which lowers the density. The reason is hydrogen bonding in water molecule leads to cage like arrangements creating voids or gaps.

1.1.1 Sources of Water

The main sources of water are:

1.Surface water: It includes flowing water (streams and rivers) and still water (lakes, ponds and reservoirs).

2. Underground water: It includes water from bore wells and springs.

3. Rain water: It is pure form of water.

4. Estuarine and sea water: Highly saline water.

Among the various sources of water, the rain water is the purest form of water but is difficult to collect whereas the sea water is the most impure form. So, surface and underground water are normally used for domestic and industrial purpose.

1.1.2 Types of Impurities Present in Water:

- Being a universal solvent, water can dissolve every naturally occurring substance on the earth, to some degree. This solvency power of water poses a major threat to its applications. In agriculture, the impurities enter into the food chain causing serious threats to the living beings. In industries, the impurities may get deposited in machine parts, clog the flow of the liquids, corrode the machinery and thus affect the overall performance and efficiency of the industrial operations. These impurities may be classified as given below:

1) **Dissolved impurities:** The substances dissolved in water may be classified as given below.

Dissolved gases: The water generally contains dissolved gases like O_2, CO_2, H_2S etc.

Inorganic salts: The main impurities of ground water is dissolved inorganic salts from rocks beneath the earth. They are classified as given below :

(i) **Cations:** E.g. Ca^{2+}, Mg^{2+}, Na^+, K^+, Fe^{2+}, Al^{3+} etc.

(ii) **Anions:** E.g. CO_3^{2-}, Cl^-, $SO^2{}_4{}^-$, NO_3^- etc.

2) **Organic matters:** Natural impurities from decay of vegetable and animal matter. E.g. Cellulose, starch, proteins, polyphenolic substances, etc.

3) **Suspended impurities:** Surface water is generally contaminated with suspended impurities. It may be further classified as follows

Inorganic impurities: E.g. Clay and sand.

Organic impurities: E.g. Oil globules, vegetables, and animal material.

Colloidal impurities: Finely divided clay and silica $Al(OH)_3$, $Fe(OH)_3$, organic waste products, coloring matter, amino acids, etc.

4) **Micro Organisms:** E.g. Bacteria, algae, fungi etc.

1.1.3 Drinking Water Quality Parameters:

- Water quality standards are important because they help to identify the water quality, problems caused by improper treatment of waste water discharge, run off, addition of fertilizers, chemicals from agricultural areas and so on. The parameters for water quality are decided according to its use.
- The water quality parameters or characteristics for which analysis is carried out generally fall into three groups

➢ Physical characteristics

➢ Chemical characteristics

➢ Biological characteristics

Drinking Water Quality Parameters

Physical

1. Turbidity
2. Colour
3. Taste and Odour
4. Temperature
5. Electrical conductivity

Chemical

1. Total dissolved solids
2. pH
3. Hardness
4. Alkalinity
5. Dissolved Oxygen
6. BOD,COD
7. Fluoride
8. Chlorides
9. Sulphates
10. Nitrates

Biological

1. Pathogenic
2. Bacteria
3. Non Pathogenic

Physical characteristics

These are the characteristics that respond to touch, taste, sight, etc. These include turbidity, temperature, odour, colour and taste.

- **Turbidity :** Turbidity in water is due to the presence of fine suspended impurities (Clay, Sand, decomposed vegetable and animal matters) that interferes with the passage of light through the water. Turbidity in water is measured on turbidmeter and Nephelometer. Turbidity in drinking water should be less than 5 units.
- **Colour :** Clean water should be colourless. The presence of colour in water indicates the presence of various minerals, decomposed organic matter like leaves, roots, organic and inorganic wastes, waste from textile mill, paper pulp industries, food processing industries, domestic wastes, wastes from laundry, dyeing, etc.
- **Taste and odour** : Water should be odorless and should have a fairly good taste. There are no specific units to measure these parameters but generally decaying organic matter imparts odor and bad taste to water.

The minimum odor that can be detected is called threshold odor number (TON). The value of TON is determined as follows

$$\text{TON} = \frac{A+B}{A}$$

A= Volume of sample in ml: B = Volume of distilled water (i.e., odor-free water in ml)

- **Temperature :** It is an important water quality parameter. High temperature indicates thermal pollution and disturbs ecosystem by reducing the dissolved oxygen in water.
- **Electrical conductivity :** It gives idea about the dissolved solids in water. Greater the amount of dissolved solids, Higher will be the conductivity. It can be measured easily with the help of conductivity meter. The average value of conductivity for portable water should be less than 2 μmho/cm.

Chemical Characteristics

Some important chemical characteristics are pH, hardness, alkalinity, total dissolved solids, chlorides, fluorides, sulphates, phosphates, nitrates, metal, etc.

- **Total dissolved solids (TDS):** The maximum permissible limit is 500 mg/l. TDS includes both organic and inorganic dissolved impurities. It can be measured by evaporating a sample to dryness and then weighing the residue.
- **pH :** The pH of normal drinking water is 6.5-8.5. It can be measured with the help of pH meter using a combined electrode (a glass electrode and a calomel electrode as reference electrode). pH scale ranges from 0 to 14. pH 7 indicates neutral solution, less than 7 is acidic, whereas greater than 7 signifies alkaline or basic water.
- **Hardness :** Hardness of water is due to the dissolved salts such as chlorides, sulphates and bicarbonates of calcium and magnesium. It can be determined by EDTA method. Total hardness of drinking water should be less than 125 ppm.
- **Alkalinity :** Alkalinity in water is due to the presence of bicarbonates, carbonates and hydroxides of Ca, Mg, Na and K.

Alkalinity is measured by titrating the water sample with a standard acid usually N/50 H_2SO_4 using phenolphthalein and methyl orange indicator. Determination of alkalinity in water is needed in water softening, chemical treatment of waste water and in boiler water analysis.

- **Dissolved oxygen :** It is an important quality parameter. Higher the amount of DO better is the quality of water. Normal water contains 4.7 mg/l of DO. Lesser amount of DO in water indicates pollution in water. Wrinkler or iodometric methods using membrane electrode is used for measuring DO in water.

- The **Biochemical Oxygen Demand (BOD)** and the **Chemical Oxygen Demand (COD)** tests are the main methods used in the determination of the concentration of organic matter in a sample of water. **BOD** is defined as the quantity of oxygen required by bacteria for the oxidation of organic matter present in water under aerobic conditions at 20° C for 5 days. **COD** is defined as the amount of oxygen required for the oxidation of organic matter as well as oxidisable inorganic matter.

- **Chlorides :** Its amount in water should be less than 250 ppm. High percentage of chloride in water harms metallic pipes as well as agriculture crops.

- **Fluorides :** Maximum permissible limit is 1.5 ppm. The amount of fluoride in water sample can be determined using an ion metre. Excess of fluoride causes discoloration of teeth, bone fluorosis and skeletal abnormalities.

- **Sulphates :** Permissible limit is 250 ppm. These are generally found associated with calcium, magnesium and sodium ions. It leads to scale formation in boilers, causes discoloration of teeth, bone fluorosis and skeletal abnormalities.

- **Nitrates :** Its concentration in drinking water should not exceed 45 mg/l. Excessive nitrates in drinking water causes methemoglobinemia or blue baby syndrome in infants. Nitrates dissolve in water because of leaching of fertilizers from soil and nitrification of organic matter.

Biological characteristics

Water should be free from all types of bacteria, viruses, protozoa and algae. The coliform count in any sample of 100 ml should be zero.

Drinking Water Quality Parameters as given by WHO

S. No.	Parameters	Water quality WHO standard Desirable limit
1	Turbidity	5 NTU
2	colour	15 HU
3	Temperature	Max 31° C Min 20° C
4	Electrical conductivity	500 µs/Cm
5	TDS	500 mg/l
6	pH	6.5 – 8.5
7	Hardness	> 125 mg/l
8	Alkalinity	200 mg/l
9	DO	4-6 mg/l
10	Chlorides	250 mg/l
11	Fluorides	1.5 mg/l
12	Sulphates	250 mg/l
13	Nitrates	50 mg/l

1.2 Hardness of water:

Hard water: Water which does not produce lather with soap solution, but produces white precipitate (scum) is called hard water. This is due to the presence of dissolved Ca and Mg salts.

$$2C_{17}H_{35}COONa + MgSO_4 \longrightarrow (C_{17}H_{35}COO)_2Mg\downarrow + Na_2SO_4$$

Soap (Sodium stearate) (from hard water) Magnesium stearate (Insoluble scum)

Soft water:

- Water which produces lather readily with soap solution is called soft water.

$$C_{17}H_{35}COONa + H_2O \longrightarrow \text{Lather}$$

- Soft water contains salt of sodium ions and is free of calcium and magnesium ions. It is not harsh on the skin, clothes and dishes.

Hardness of water

- It is the property of water which prevents lathering with soap due to the presence of calcium and magnesium salt impurities.
- Based on the ease with which the hardness is removed, hardness is classified into two types:
  - Temporary Hardness or Carbonate Hardness
  - Permanent or Non-carbonate Hardness

Temporary Hardness or Carbonate Hardness

- Temporary hardness of water is due to the presence of dissolved bicarbonates of calcium, magnesium and other heavy metals or carbonate of iron. It is easily removed by mere boiling of water. When the water is boiled, the bicarbonates are decomposed yielding insoluble carbonates or hydroxides which are deposited as a crust or scales at the bottom of the vessel, while carbon dioxide formed escapes out.

$$\underset{\text{Soluble}}{Ca(HCO_3)_2} \rightarrow \underset{\text{Insoluble}}{CaCO_3\downarrow} + H_2O + CO_2\uparrow$$

$$\underset{\text{Soluble}}{Mg(HCO_3)_2} \rightarrow \underset{\text{Insoluble}}{Mg(OH)_2} + 2CO_2\uparrow$$

Permanent or Non-carbonate Hardness

- Permanent hardness is due to the presence of chlorides, sulphates of calcium, magnesium, iron and other heavy metals.
- It cannot be removed by boiling.
- It is removed only by using softeners or chemical treatment.
- Permanent hardness can be removed by:

1) Chemical Methods:

Lime Soda Process: Hard water is treated with $Ca(OH)_2$ and Na_2CO_3 to convert hardness salts into precipitates.

$$MgCl_2 + Ca(OH)_2 \rightarrow Mg(OH)_2 \downarrow + CaCl_2$$

$$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 \downarrow + 2NaCl$$

2) Physical method or Ion-Exchange Methods: Zeolite process, Demineralisation process etc.

Testing of Hardness:

- To test whether the given sample of water is hard or soft, the following two simple methods can be used.
- **Test 1:**Treat a sample of water with soap solution and shake well. If it produces lather it is soft water. The scum or precipitate it is hard water.
- **Test 2:**To the water sample add 5 ml of ammonia and ammonium chloride buffer and 2 drops of EBT indicator. If the colour changes to wine red, the water is said to be hard water.

Expression of Concentration of Hardness:

- The concentration of hardness as well as non-hardness causing ions is expressed in terms of an equivalent amount of $CaCO_3$. The choice of $CaCO_3$, in particular is due to
  - Its molecular weight is 100 (equivalent wt. is 50) which makes the calculation easier.
  - It is the most insoluble salt that can be precipitated in the water treatment easily. The equivalents of $CaCO_3$ of a salt is

$$CaCO_3 \text{ equivalent hardness} = \frac{\text{Weight of hardness producing substance}}{\text{Molecular Weight of hardness causing substance}} \times 100$$

Total hardness

The sum of temporary hardness and permanent hardness

Molecular Weights of few hardness causing salts:

Salt	Molecular Weight	Salt	Molecular weight
$Mg(HCO_3)_2$	146	$CaCl_2$	111
$Ca(HCO_3)_2$	162	$CaSO_4$	136
$MgCl_2$	95	$Mg(NO_3)_2$	148
$MgSO_4$	120	$MgCO_3$	85

Units of hardness - Units used to express hardness are:

Unit	Definition
Parts per million (ppm)	The number of parts of $CaCO_3$ equivalent hardness per 10^6 parts of water. 1 ppm = 1 part of $CaCO_3$ equivalent hardness in 10^6 parts of water
Milligrams per litre (mg/l)	The number of milligrams of $CaCO_3$ equivalent hardness per litre of water. 1 mg/l = 1 mg of $CaCO_3$ equivalent hardness in 1 L of water
Degree Clarke(°Cl)	The number of parts of $CaCO_3$ equivalent hardness in 70,000 parts of water. 1˚Cl = 1 part of $CaCO_3$ equivalent hardness in 70,000 parts of water.
Degree French (°Fr)	The number of parts of $CaCO_3$ equivalent hardness per 10^5 parts of water. 1°Fr = 1 part of $CaCO_3$ equivalent hardness in10^5 parts of water.

Relationship between Units of Hardness

1ppm = 1mg / l = 0.07 ^{O}Cl = 0.1^{O} Fr

Problems based on Hardness of water

1. A sample of water contains 150 mg of $MgSO_4$ per litre. Calculate the hardness in terms of calcium carbonate equivalence.

Solution:

Molecular mass of $MgSO_4$ =120

$CaCO_3$equivalents of Hardness causing substance =

$$\frac{\text{Weight of hardness producing substance}}{\text{Molecular Weight of hardness causing substance}} \times 100$$

$$= \frac{150}{120} \times 100 = 125 \text{ mg/l}$$

2. **Calculate the carbonate and non-carbonate hardness of a water sample in ppm from the following results:**

$Mg(HCO_3)_2$ – 16.8 mg/l, $MgCl_2$ – 19 mg/l, $MgSO_4$ – 20 mg/l, and KCl – 74.5 mg/l

Solution:

$CaCO_3$equivalents of Hardness causing substance = $\frac{\text{Weight of hardness producing substance}}{\text{Molecular Weight of hardness causing substance}} \times 100$

Salt	**$CaCO_3$ equivalent**
$Mg(HCO_3)_2$	$\frac{16.8}{146} \times 100 = 11.50$ mg/l
$MgCl_2$	$\frac{19}{95} \times 100 = 20$ mg/l
$MgSO_4$	$\frac{20}{120} \times 100 = 16.66$ mg/l

***KCl does not contribute to hardness**

- Carbonate hardness = $Mg(HCO_3)_2$ = 11.50 ppm
- Non carbonate Hardness = $MgCl_2$ + $MgSO_4$ = 20 + 16.66 = 36.66 ppm
- Total hardness = 11.50 + 36.66 = 48.16 ppm

3. Calculate the temporary and permanent hardness of a water sample, having the following on analysis.

$Mg(HCO_3)_2$ – 73 mg/l, $Ca(HCO_3)_2$ – 204 mg/l, $CaSO_4$ – 130 mg/l, $MgCl_2$ – 81mg/l, $CaCl_2$ – 100 mg/ and NaCl – 100 mg/l

Solution:

$CaCO_3$ equivalents of Hardness causing substance =

$$\frac{\text{Weight of hardness producing substance}}{\text{Molecular Weight of hardness causing substance}} \times 100$$

Salt	$CaCO_3$ equivalent
$Mg(HCO_3)_2$	$\frac{73 \times 100}{146} = 50 mg/l$
$Ca(HCO_3)_2$	$\frac{204 \times 100}{162} = 126 mg/l$
$CaSO_4$	$\frac{130 \times 100}{136} = 95.5 mg/l$
$MgCl_2$	$\frac{81 \times 100}{95} = 85.3 mg/l$
$CaCl_2$	$\frac{100 \times 100}{146} = 68.5 mg/l$

***NaCl does not contribute to hardness**

- Temporary hardness = $Mg(HCO_3)_2 + Ca(HCO_3)_2$

  = 50 + 126 = 176 mg/l or ppm

- Permanent Hardness = $CaSO_4 + MgCl_2 + CaCl_2$

  = 95.5 + 85.3 + 68.5

  = 249.3 mg/l or ppm

- ∴ Total hardness = Temporary hardness + Permanent hardness

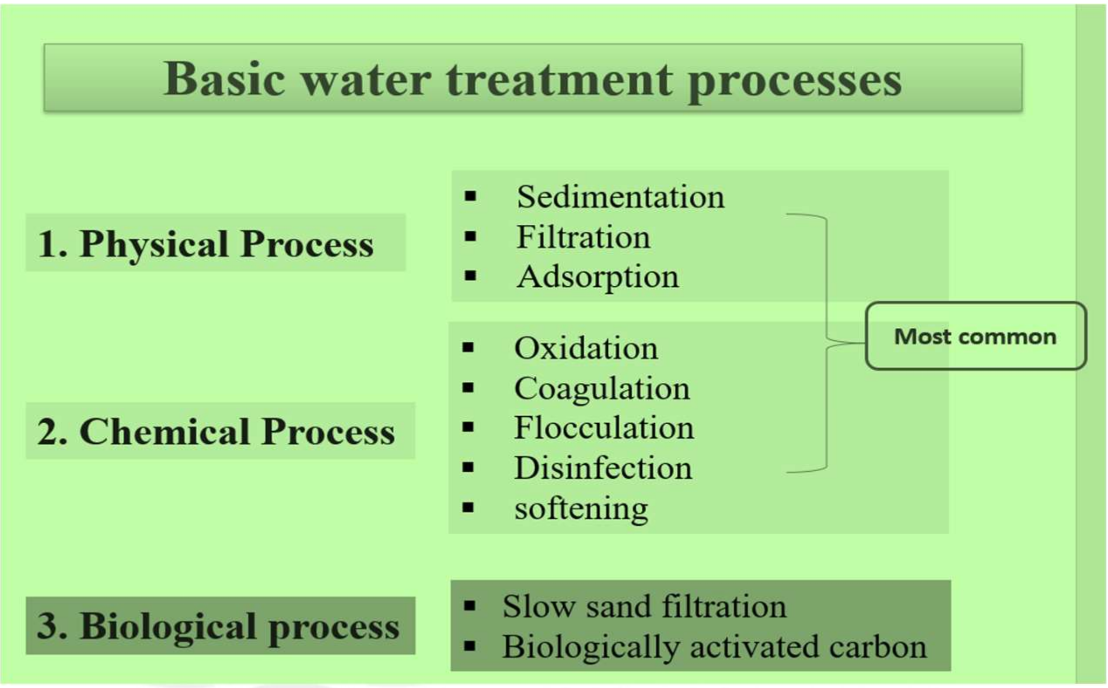
  = 176 + 249.3 = 425.3 mg/l or ppm

1.3 MUNICIPAL WATER TREATMENT

Water treatment processes

▪To remove all water contaminants, water treatment involves physical, chemical and biological processes

▪The most common treatment processes in potable water treatment are chemical and physical processes



Removal of suspended matter:

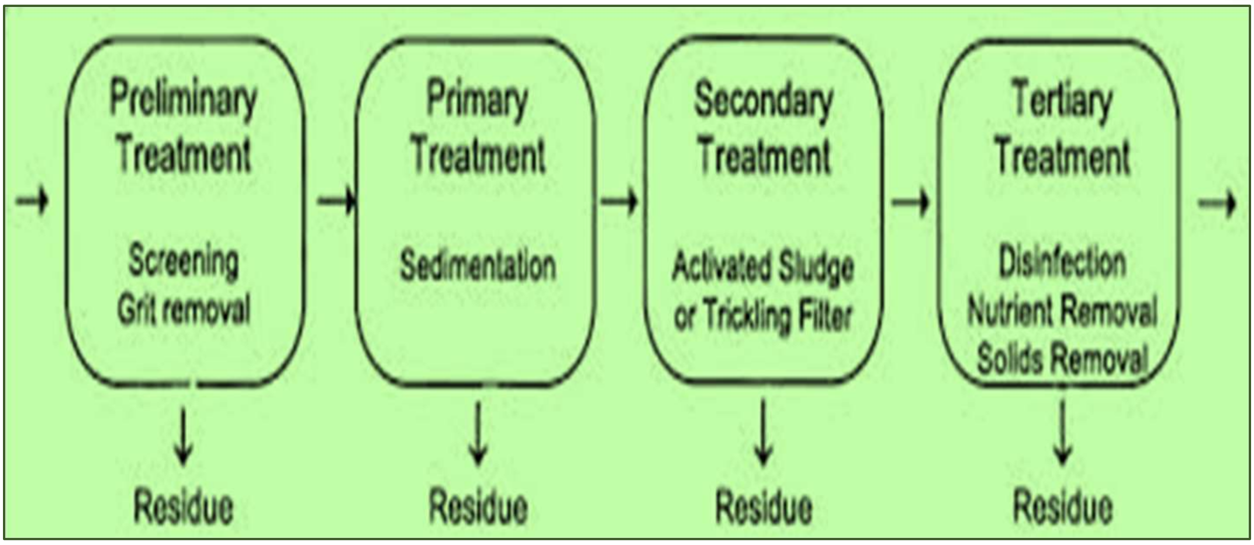
Screening:

The raw water is passed through screens which contain large number of holes where floating matter is retained.

Sedimentation with Coagulation:

- Suspended impurities are removed by allowing the water to stand undisturbed for few hours (about 2-8 hours) in big tanks (5m deep).
- Due to force of gravity most of the particles settles down at the bottom of the tank.
- About 70-75% of the suspended matter can be removed.
- Plain sedimentation can’t remove finely divided silica, clay and organic matter on with coagulation.

Municipal Water Treatment



- Sedimentation with coagulation is a process of removing fine particles by addition of chemicals (coagulants) before sedimentation.
- Commonly used coagulants are Alum ($K_2SO_4\ Al_2(SO_4)_3.24H_2O$), Sodium aluminate ($NaAlO_2$) etc.

$$Al_2\ (SO_4)_3 + H_2O \rightarrow 2Al\ (OH)_3 \downarrow + 3\ H_2SO_4$$

$Al(OH)_3$ acts as flocculent (due to its enormous surface area) and removes the impurities either by neutralizing the charge or by adsorption and mechanical entrainment.

- Coagulant (lime, fuller's earth, poly electrolytes) are added to increase the efficiency of the process.
- Generally, coagulants are added in solution form with the help of mechanical flocculators for thorough agitation.
- Substantial reduction of bacteria also takes place during this process. (O_2 released by some coagulants destroys bacteria, breaks up some organic compounds, partial removal of color & taste producing organisms.)

Filtration:

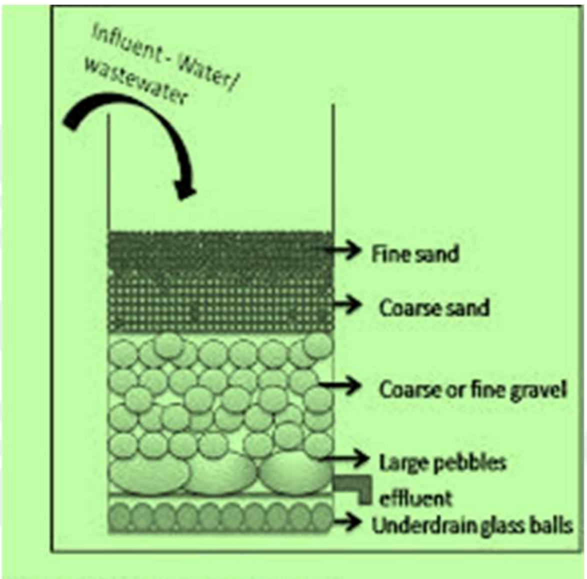
It is the process of clarification of water by passing the water through a porous material, which is capable of retaining coarse impurities on its surface & in the pores. [Porous material used – filtering media, equipment used – filter]

Common materials used as filtering media:

1. Quartz sand (0.5- 1.0mm)
2. Crushed anthracite(0.8-1.5mm)
3. Porous clay

Slow sand filtration is generally employed in municipal water treatment

Typical Sand Filter



2. Schematic view of a SSF column.

Process:

- A typical sand filter consists of a tank with a bed containing fine sand (top layer), coarse sand, coarse gravel (bottom layer).
- It is provided with inlet for sedimented water and under drain channel at the bottom for exit of filtered water
- Sedimented water is distributed uniformly over the bed and flows slowly through various layers.
- Rate of filtration slowly decreases due to retention of impurities in the pores.
- Top layer is scrapped and replaced with clean sand to increase the efficiency of process.

Removal of microorganisms- Disinfection:

Removal of pathogen (Disease causing microorganism) is known as disinfection.

Boiling

When water is boiled the harmful bacteria and virus cannot survive at this temperature.

But this process can be applicable only on house hold, municipalities cannot apply.

By adding bleaching powder

$CaOCl_2 + H_2O \rightarrow Ca(OH)_2 + Cl_2\uparrow$

$Cl_2 + H_2O \rightarrow HCl + HOCl$ (Hypo chlorous acid kills germs)

When bleaching powder is added to water first Cl_2 is liberated along with $Ca(OH)_2$

Cl_2 reacts with water & forms HCl & HOCl (Hypochlorous acid). HOCl is a germicide which kills bacteria or germs present in water.

Limitations:

It is unstable, difficult to store.

It introduces calcium in water which increases hardness of water when used in excess.

Addition of chlorine – (Chlorination)

Disinfection is done by addition of liquid chlorine or gaseous chlorine. Chlorine produces hypochlorous acid [HOCl] which kills microorganisms.

$Cl_2 + H_2O \rightarrow HCl + HOCl$

$HOCl \rightarrow H^+ + OCl^-$

HOCl $\rightarrow$ Kills Germs

Initially it was found that nascent oxygen [O] from HOCl [Hypochlorous acid] kills the microorganisms, but later it was found that HOCl also causes death of micro-organisms. Chlorine is s good disinfectant at a pH of 6.5.

Chlorination depends upon

- **Time of contact :** Number of Micro-organisms destroyed by chlorine per unit time is proportional to number of microorganisms remaining alive. So death rate is maximum at starting.

➢ **Temperature of water :** Higher the temperature, the rate of reaction is faster & killing of microorganisms increase.

➢ **pH value of water:** Lower the pH value ,the reaction is faster & a small contact period is required.

Advantages:

- Effective & economical
- It requires very little space.

Disadvantages:

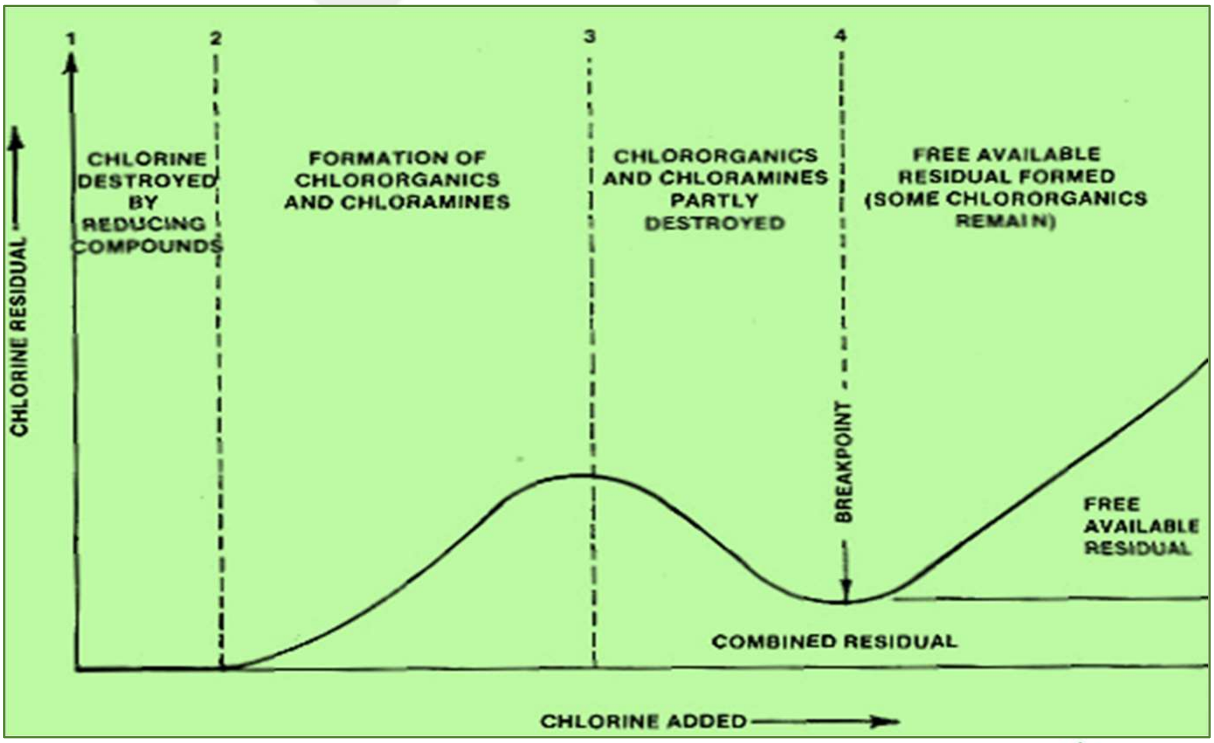
- Excess of chlorine produces unpleasant odour & taste.
- Free chlorine should not exceed 0.1-0.2ppm
- It is more effective below 6.5 & less effective at higher pH values**.**

Break point chlorination or Dip point (Free residual chlorine):

The addition of sufficient amount of chlorine to oxidize Organic matter, reducing substances, free ammonia leaving behind free chlorine killing pathogenic bacteria is called break point chlorination.

The addition of sufficient amount of chlorine to satisfy chlorine demand is called break point chlorination.

- When a graph is drawn between the added chlorine to residual chlorine a dip or break is formed in the graph called break point chlorination.



The addition of chlorine at the dip or break is called as Breakpoint chlorination. After this dip or break point chlorination, free residual chlorine is present. The addition of chlorine beyond the breakpoint creates presence free available chlorine i.e., uncombined chlorine that can act as a disinfecting agent.

The following equation is used to determine the amount of combined chlorine present:

Combined Chlorine = Total Chlorine - Free Available Chlorine

Usually all tastes and odors disappear at break point.

Advantages:

Break point chlorination gives an idea about the amount of chlorine that is required to add for chlorination. It

1) Oxidizes completely organic matter, NH_3 and reducing agents.
2) Removes colours in water.
3) Destroys completely all the disease producing bacteria.
4) Removes odour from water.
5) Prevents growth of weeds in water.

Disadvantages:

1) If excess chlorine is added it releases residual or free chlorine which imparts bad taste and odour.
2) Dechlorination must be done in order to remove free chlorine. Dechlorination is done by passing SO_2 & sodium sulphite.

By using chloramines

When chloramines are added into water they produce HOCl which act as germicide. Chloramines can be prepared by passing chlorine gas into ammonia chamber. Now a day's municipalities are using this process.

$Cl_2+NH_3 \rightarrow NH_2Cl+HCl$

$NH_2Cl+H_2O \rightarrow HOCl + NH_3$

UV Treatment:

UV Disinfection System is an extremely effective way to combat microbial contamination in water. However, microbes have to be exposed to UV light in the proper amount in order to effectively disinfect the water. UV Disinfection Systems are used in different applications ranging from the purification of drinking water in individual homes to disinfecting the water in industrial wastewater treatment. UV treatment for water is recognized as a safer and more cost-effective way to disinfect water for industrial applications

Ultraviolet light of wavelength 253.7 nanometers is used for the disinfection of bacteria, viruses, molds, algae, and other microorganisms, which multiply and grow. UV disinfection technology destroys the DNA of microorganisms which leaves them dead and unable to grow further. The technology can be used for wastewater disinfection, and surface disinfection.

Benefits of UV treatment

- Natural
- Environmentally Friendly
- Effective
- Economical
- Safe and Chemical-Free

Disinfection by ozone (OZONATION).

By sending raw water through ozonizer, where the nacent oxygen liberated from ozone act as a germicide and kills the microorganisms. Ozone is unstable so easily decomposes to

$$O_3 \rightarrow [O] + O_2$$

Advantages:

It removes chlorine odour (smell) taste etc. if ozone is in excess, it is not harmful.

Disadvantages :

Equipment is Expensive

1.4 Boiler troubles

The water fed into the boiler for the production of steam is called boiler feed water. If the boiler feed water contains hardness and other impurities, it reduces the efficiency of the boiler and causes trouble in steam production. Thus water needs to be purified. In modern high pressure boilers and laboratories, water purer than the distilled water is required. Some of the boiler troubles caused by the use of hard water are

1. Scale and Sludge Formation
2. Priming and Foaming
3. Caustic Embrittlement
4. Boiler Corrosion

Sludge and Scale formation in boilers

In boilers, because of continuous evaporation of water, the concentration of salts increase progressively and as the saturation point is reached, they are thrown out as precipitate leading to formation of scales and sludges.

Sludge

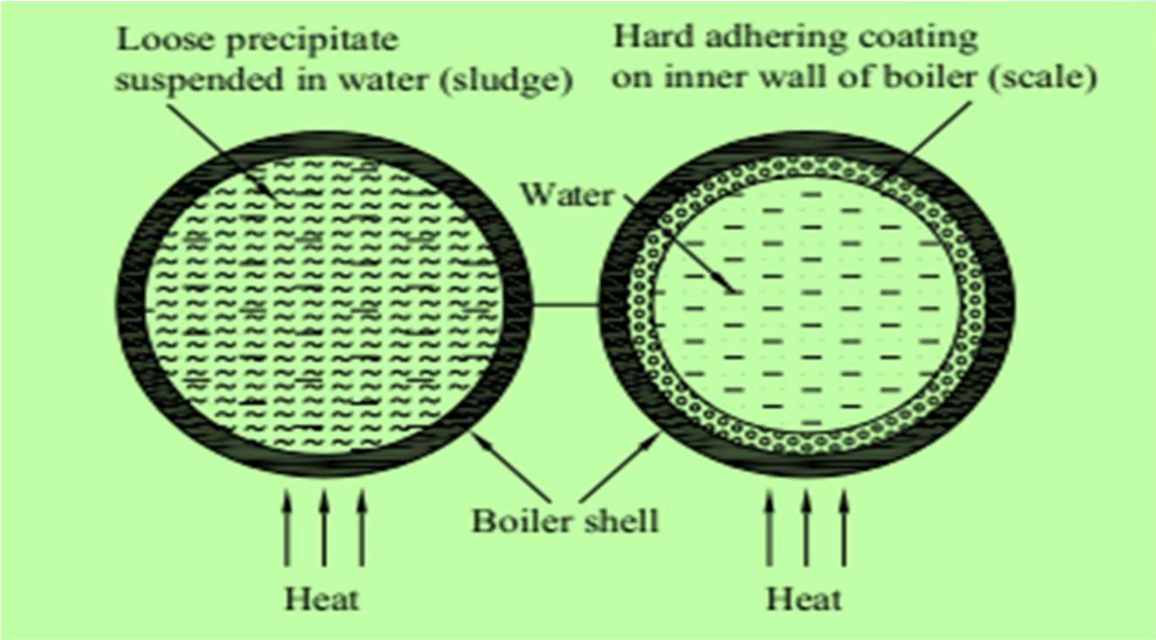
Sludge is a soft, loose and slimy white precipitate formed within the boiler. It is formed at comparatively colder portions of the boiler and collects in the area where flow rate is slow. These are formed by substances which have greater solubilities in hot water than in cold-water. Example: $MgCO_3$, $MgCl_2$, $CaCl_2$, $MgSO_4$, etc.

Disadvantages

1. As the sludges are poor conductors of heat they cause loss of heat and increase in fuel consumption.

2. The working of the boiler is disturbed because of chocking of pipes by the sludge.

3. Sludges gets entrapped with scales and deposits as scale.



Sludge **Scale**

Prevention

1. By using well softened water.

2. By periodic blow down operation i.e. drawing off a portion of concentrated water periodically and replacing with fresh water.

Scales

Scales are hard, adhering precipitates deposited on the inner walls of the boilers. They stick very firmly on to the inner wall surface and are difficult to remove .The scale forming salts are $CaSO_4$, $Mg(OH)_2$, etc.

Causes of scale formation

a. Decomposition of Calcium bicarbonate:

$$Ca(HCO_3)_2 \longrightarrow CaCO_3\downarrow + H_2O + CO_2$$

In low pressure boilers, $CaCO_3$ precipitate causes scale formation. In high pressure boilers, $CaCO_3$ precipitate is soluble.

$$CaCO_3 + H_2O \longrightarrow Ca(OH)_2\downarrow + CO_2\uparrow$$

b. Deposition of Calcium sulphate: The solubility of $CaSO_4$ in water decreases with rise of temperature. In super heated water $CaSO_4$ is insoluble and forms strong, hard and adhering deposits in the boiler walls. This is the main cause for scale formation in high-pressure boilers.

c. Hydrolysis of Magnesium salts:

Dissolved magnesium salts undergo hydrolysis forming $Mg(OH)_2$ precipitate. They form soft scale. $MgCl_2 + 2H_2O \rightarrow Mg(OH)_2 \downarrow + 2HCl$

d. Presence of Silica: Silica present in small quantities deposits as silicates like $CaSiO_3$ and $MgSiO_3$. These are very difficult to remove.

Disadvantages

- **Wastage of fuel:** The scale formation causes decrease in heat transfer. As a result over heating is required. This cause more consumption of fuel.
- **Lowering of efficiency:** Scales sometimes deposits in valves and condensers of boilers and choke them partially and thereby reducing the efficiency.
- **Danger of Explosion:** The hard scale cracks because of uneven expansion of the metal due to overheating. Water suddenly comes in contact with overheated Iron plates. This leads to the formation of large amount of steam suddenly. This results in high pressure causing boiler to burst or explode.

Prevention

1. External treatment of water
2. Internal treatment of water

S.No	Sludge	Scale
1	Loose, slim, non adherent precipitate.	Hard, thick, adherent deposit.
2	Formed due to salts like $MgSO_4$, $MgCl_2$.	Formed due to salts like $CaSO_4$, $Ca(HCO_3)_2$.
3	They decrease the boiler efficiency due to choking in the pipelines	They decrease the boiler efficiency leading to boiler explosion and reduce fuel economy.
4	It effect can be reduced by "blow down" operation periodically	It can be prevented by i) External treatment of ion exchange and ii) Internal treatment followed by blow down operation.

1.5 Boiler feed water

In Industries, the main use of water is the generation of steam from boilers. The water used in boilers for the production of steam is called boiler–feed water. The steam so generated should be pure and uncontaminated and may be used for power generation, sterilization, drying, etc. The presence of impurities like dissolved and suspended salts and dissolved gases cause boiler problems.

Requirements of Boiler Feed Water

- Boiler feed water should be free from oil and turbidity.
- It should have zero hardness.
- It should be free from dissolved gases like O_2, CO_2, H_2S etc.
- It should be free from total dissolved solids.
- It should be free from suspended impurities.
- It should be free from dissolved salt and alkalinity.

Softening or conditioning methods:

The process of removal of hardness producing salts from hard water is known as softening or conditioning of hard water. This can be done by two methods.

S. No.	Softening methods	Definition
1	Internal conditioning	• It is a process of treating the water inside the boilers by adding suitable chemicals. • It removes traces of hardness causing substances (which were not removed in external treatment) either by converting it into sludge or as into soluble complex. • Internal conditioning is followed by blow down operation
2	External conditioning	• It is a process of removing hardness from water before feeding it to the boilers. E.g. Demineralisation process.

1.6 Internal treatment

- **Principle:** The internal treatment involves the addition of chemicals directly to the water in the boilers to convert scale forming impurities into sludges followed by periodic blow down operation compounds which are highly soluble in water.

Different types of internal treatment are:

1. Colloidal conditioning: Organic substances like kerosene and agar-agar are added to water which prevents the scales from adhering to the walls of the boiler tube thereby forming non sticky precipitates which is thus removed by blow down operation.

2. Phosphate conditioning: Phosphates react with hardness producing salts in water and a soft, silky sludge is formed which can be easily removed by periodic blow-down operation. Scale formation can be avoided by adding sodium phosphate in high pressure boilers.

$$3CaSO_4 + 2Na_3PO_4 \longrightarrow Ca_3(PO_4)_2 \downarrow + 3Na_2SO_4$$

Advantages: Phosphate conditioning is better because, if present in excess does not lead to caustic embrittlement of boiler parts.

Phosphates	Nature	used
Tri sodium phosphate Na_3PO_4	Alkaline	used for highly acidic water.
Disodium hydrogen phosphate - Na_2HPO_4	weakly alkaline	used for slightly alkaline and weakly acidic water.
Sodium dihydrogen phosphate - NaH_2PO_4	Acidic	used for alkaline water.

3. Calgon conditioning

Sodium Hexa meta phosphate (calgon) is added to boiler water to prevent scale by the formation of the highly soluble complex. It is the best method since it does not lead to the formation of sludge and it takes a long time interval for blow down operation.

$$2CaSO_4 + Na_2[Na_4(PO_3)_6] \longrightarrow \underset{\text{Highly soluble complex}}{Na_2[Ca_2(PO_3)_6]} + 2Na_2SO_4$$

4. Sodium Aluminate

When boiler water is treated with sodium aluminate ($NaAlO_2$), it gets hydrolysed to give NaOH and $Al(OH)_3$

$$NaAlO_2 + 2H_2O \longrightarrow \underset{\text{precipitate}}{Al(OH)_3} + NaOH$$

The NaOH, so –formed reacts with magnesium salts to form $Mg(OH)_2$ sludge.

$$MgCl_2 + NaOH \longrightarrow Mg(OH)_2 + 2NaCl$$

The precipitate of $Al(OH)_3$ and $Mg(OH)_2$ produced inside the boiler, entraps all the finely suspended impurities. The loose precipitate can be removed by blow-down operation.

Problems of using hard water in industries:

Hard water, when used in industries cause troubles such as

- corrosion,
- scales and sludge formation,
- caustic embrittlement
- Priming and foaming etc.

These troubles lead to loss of efficiency of the boilers, fuel wastage and may cause boiler explosion. Hence, removal of hardness causing salts is important

1.7 External Treatment:

Demineralization process:

- This process removes almost all the ions (both anions and cations) present in the water. Deminerlised water does not contain both anions and cations.
- Thus, '**soft water is not a demineralized water where as a demineralized water is a soft water**'. Soft water may contain sodium and potassium salt.

Ion exchange Resins

- These are long chain, cross linked, insoluble organic polymers with micro porous structure and having replaceable functional group. They are of two types,

Cation Exchanger: They contain acidic functional groups (-COOH, -SO_3H) and are capable of exchanging their H^+ ions with cations of hard water. They are represented by RH_2. E.g. sulphonated coals, sulphonated polystyrene etc.

Anion Exchanger: They contain basic functional groups (-OH) are capable of exchanging their OH^- ions with anions of hard water. They are represented by $R'(OH)_2$. E.g. Cross linked quaternary ammonium salts, Urea formaldehyde resins etc.

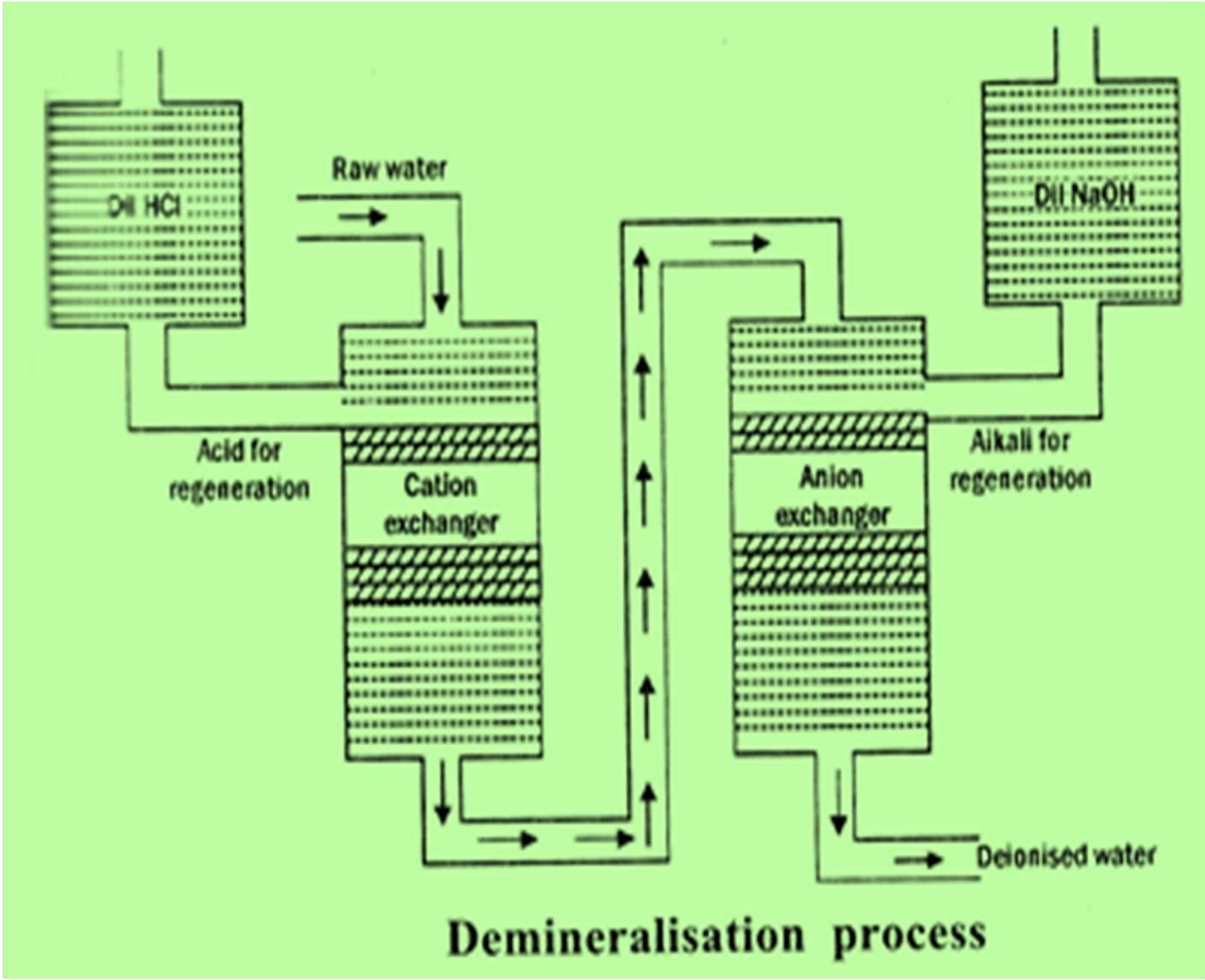
Process

- Hard water is first passed through a cation exchange column. All the cations like Ca^{2+}, Mg^{2+}, Na^+, K^+ etc., exchange with H^+ ions.

$$RH_2 + CaCl_2 \longrightarrow RCa + 2HCl$$

$$RH_2 + MgSO_4 \longrightarrow RMg + H_2SO_4$$

Diagram:



- The cation free water is then passed through the anion exchange column. This exchange all the anions like SO_4^{2-}, Cl^-, CO_3^{2-}, HCO_3^- etc., present in the water with OH^- ions.

  $R'(OH)_2 + 2HCl \longrightarrow R'Cl_2 + 2H_2O$

  $R'(OH)_2 + H_2SO_4 \longrightarrow R'SO_4 + 2H_2O$

- Now the water coming out of the anion exchanger is completely free from both anions and cations. Therefore it is called demineralized water or deionized water.

Regeneration

When the resin gets exhausted by the active site or exchangeable ionic site, it can be regenerated by treating with acids for cation exchanger and base for anion exchanger.

The cation exchanger resin can be regenerated with dilute acid.

$RCa + 2HCl \longrightarrow RH_2 + CaCl_2$

$RMg + 2\ HCl \longrightarrow 2RH_2 + MgCl_2$

- The anion exchanger resin can be regenerated with dilute NaOH.

$R'Cl_2 + 2NaOH \longrightarrow R'(OH)_2 + 2\ NaCl$

$R'SO_4 + 2NaOH \longrightarrow R'(OH)_2 + Na_2SO_4$

Advantages

- Alkaline and acidic water can be treated.
- Produces water with very low hardness (0 – 2 ppm)

Disadvantages

- Equipment is costly.
- Resins are expensive.
- Fe, Mn containing water cannot be treated because they exchange H from resin and form permanent bonding, thus blocking the active sites. It hence reduces the efficiency of the unit.
- Turbid water cannot be treated as it blocks the pores and reduces the rate of the process.

1.8 RESIN FOULING

Resin can become fouled with contaminants that hinder the exchange process. The resin can also be attacked by chemicals that cause irreversible destruction. Some materials, such as natural organics foul resins at first and then degrade the resin as time passes. This is the most common cause of fouling and degradation in ion exchange systems.

Adsorption or ion exchange of other chemical elements that are not easily removed by the normal regeneration procedures can cause gradual fouling of the resin.

Causes

- Fouling by bacteria and algae
- Fouling by iron and manganese
- Fouling by organic species
- Fouling by oil

Control

- Regular cleaning treatment can reduce fouling and extend resin life.
- Increased regenerant quantities, regeneration frequency and elevated regeneration temperature may reduce fouling by preventing foulants from gaining a permanent hold.
- A good operating practice is to ensure that all resin in the ion exchange units is regularly contacted with sufficient regenerant and subject to a regular cleaning procedure.

S. No.	Types	Sources and Effect	control
1	Fouling by bacteria and algae	Under certain conditions, resin can become fouled either by bacteria or algae when contaminated water sources are fed to ion exchange systems	1.Peracetic acid, a derivative of hydrogen peroxide, is a good treatment against a wide variety of microbes. 2. Bacteria and algae fouling can also be treated with sodium hypochlorite.
2	Fouling by iron and manganese	Iron is present in several different forms within the water. For example, in the case of unaerated borehole water,	1. Iron present in the ferric state is removed by cation resin operated in either the sodium or hydrogen forms.

		iron can be present in the ferrous form (Fe^{2+}), but on oxidation, it is converted into the ferric form (Fe^{3+}).	2. Iron and calcium fouling of both weak and strong acid cation resins (WAC and SAC) can be prevented by treating the resin periodically with citric acid.
3	Fouling by organic species	Anion resins are susceptible to fouling by humic and fulvic acids sometimes found in surface waters. These organic species become trapped within the resin matrix due to their large molecular weights.	1.Treat the resin at the end of the normal exhaustion cycle. 2. Prepare three bed volumes of 10% w/v brine solution containing 2% w/v caustic soda. Temperate of the solution should be between 95 °F (35 °C) and 140 °F (60 °C) to ensure optimal organic elution effect.
4	Fouling by oil	Oil in feed water or regeneration solutions will lead to fouling of ion exchange resins. Oil-based resin fouling results in deterioration of resin kinetics and treated water quality, as well as reduced operating capacity. Cleaning resins fouled by oil is extremely difficult	Low foaming, non-ionic surfactant and is recommended for lightly fouled ion exchange resins and inert polymers. Thoroughly backwash the fouled resin

1.9 Desalination of Brackish Water:

- The process used for the removal of total dissolved salts from the brackish or saline water and converting it into safe potable or usable water is called desalination. Based on the dissolved salt content, water can be classified into

1. Fresh water (<500 ppm or <0.5%)
2. Brackish water (>500 to <35000 ppm or (0.5% - 3.5%)
3. Sea water (>35000 ppm or >3.5%)

Reverse Osmosis (RO):

Osmosis:

- When two different concentrated solutions are separated by a semi permeable membrane, solvent spontaneously flows from a region of lower concentration to higher concentration by osmotic pressure is called Osmosis.

Reverse Osmosis (RO):

- When two different concentrated solutions are separated by a semipermeable membrane, solvents are made to flow from a region of higher concentration (salt water) to a lower concentration (freshwater) by applying pressure higher than the osmotic pressure is called reverse osmosis. For brackish water desalination, the operating pressures range from 250 to 400 psi, and for seawater desalination, it ranges from 800 to 1000 psi. Reverse osmosis is also known as super filtration or hyperfiltration.

Membrane Technology:

- The RO process uses membranes for separation; hence it is also called as Membrane Technology method. This method is more advantageous as this technology works without the usage of any chemical salts.
- Based on the removal of particle size, this membrane technology method can be further classified into
  - Microfiltration (Remove the impurities up to the particle size of 100 nm)
  - Ultrafiltration (Remove the impurities up to the particle size of 10 nm)
  - Nanofiltration (Remove the impurities up to the particle size of 1 nm)
  - Reverse osmosis (super filtration or hyperfiltration)- (Remove the impurities less than the particle size of 1 nm)

Process:

- The water which is fed into the chamber undergoes pretreatment, where the suspended particles are removed to avoid the damage of the membrane. The pump then increases the pressure of the pretreated feed water to an operating pressure appropriate to the membrane. When a pressure greater than osmotic pressure is applied the solvent (water) flows from concentrated side to diluted side leaving behind the solute (dissolved salts) particles. Two of the most popular configurations of the membrane used are spiral wound and hollow fine fiber membranes. The membranes used are generally made of cellulose acetate, aromatic polyamides, and thin film polymer composites. Finally the product water from the membrane assembly undergoes pH adjustment and degasification before being transferred to the distribution system for use as drinking water.

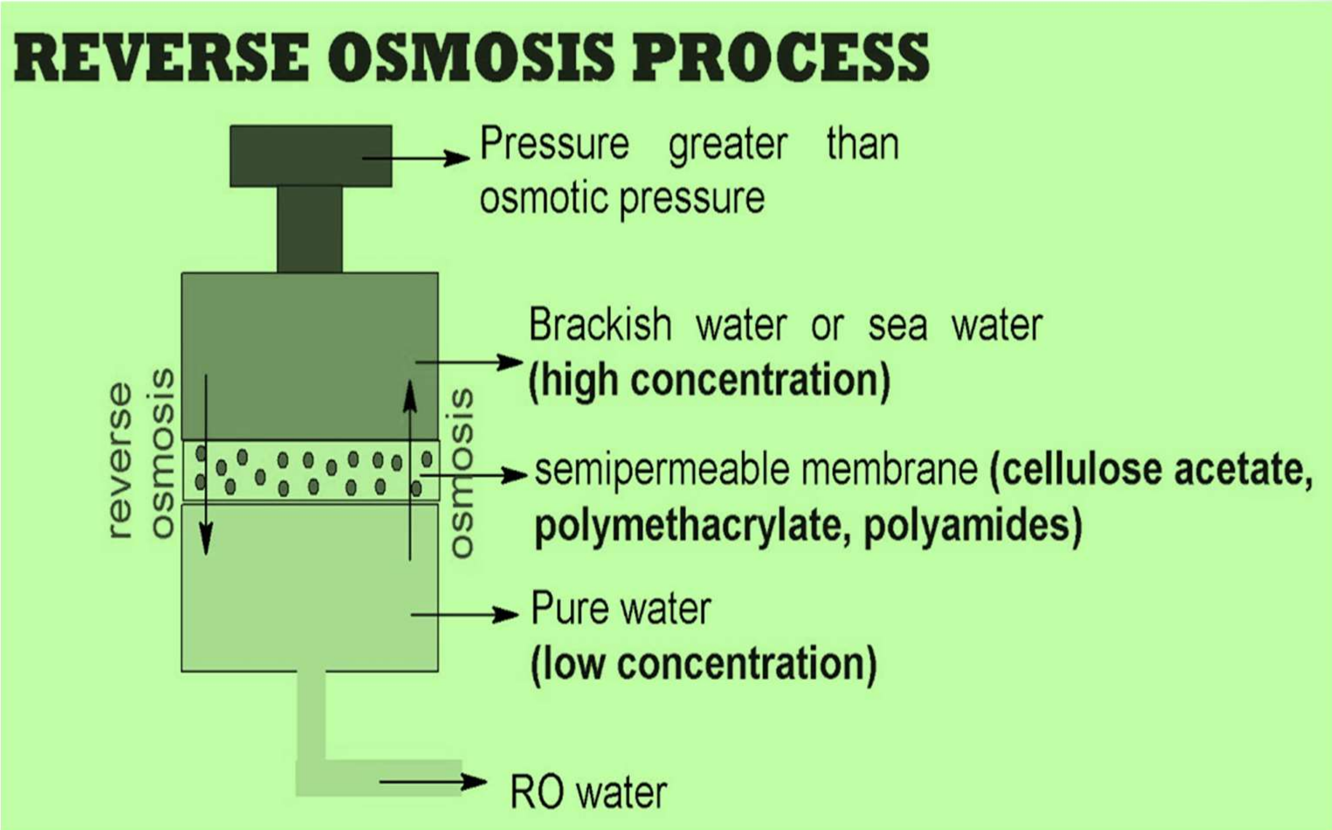
Advantages:

1. Removes all types of impurities like ionic, non-ionic and colloidal impurities.
2. The lifetime of the membrane is high (2 years).
3. The replacement time of the membrane is less.
4. Low energy consumption.
5. Cost of purification of water is less and maintenance cost is also less.
6. This water is mostly used for high pressure boilers.

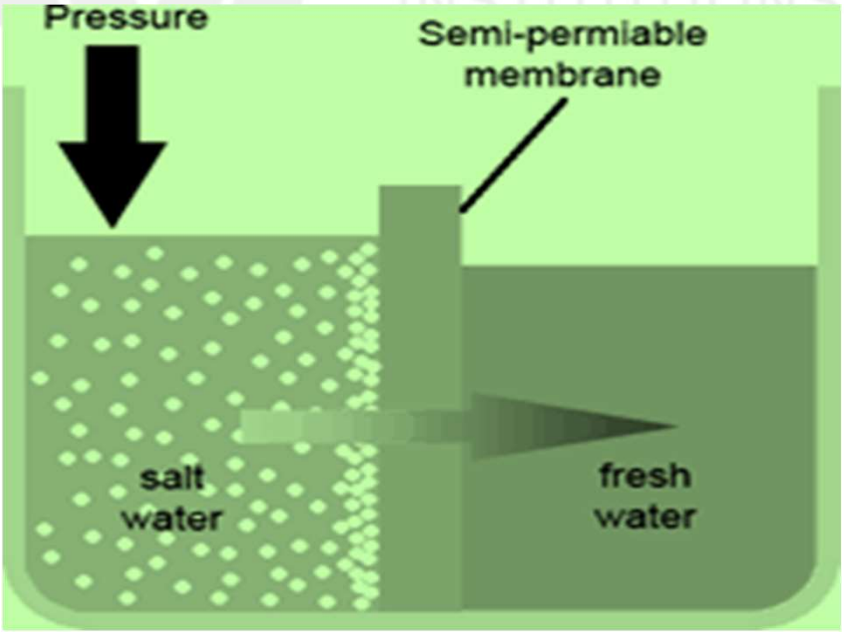
Disadvantages:

1. The membrane is costly.
2. The membranes are sensitive
3. It must be capable of withstanding pressure of the order of 20-100 atm.
4. The feed water usually needs to be pre-treated to remove particulates. (To increase the life of the membrane)

Vertical



Horizontal



1.10 Membrane Fouling

Membrane fouling is one of the most frequent issues affecting reverse osmosis (RO), microfiltration (MF), ultrafiltration (UF), or nanofiltration (NF).

Types	Causes	Effect
Particulate and colloidal fouling Particulate fouling occurs when suspended solids and/or colloidal material clog the holes of a membrane or adhere to its surface.	Particulate/colloid fouling is caused by the presence of non-biological and inorganic particles (e.g. silt or clay) in the feed water, especially when the stream is sourced from a body of surface water.	RO systems, as these have the smallest pores of any membrane filtration systems and are consequently much more vulnerable to particulate fouling.
Biological and microbial fouling Biofouling is a process where microorganisms, plants, algae or other biological contaminants grow on or in filtration membrane surfaces and pores.	Biological and microbial foulants tend to thrive in warm environments with low flow rates, where they are able to attach to the membrane and multiply while releasing a protective substance known as extracellular polymeric substance (EPS). Collectively, the microorganisms and EPS form a slimy gel layer known as a biofilm.	The chemical properties of biofilm make it resistant to normal cleaning strategies like backwashing or applications of biocides, such as chlorine. Membrane oxidation, although not a foulant, is most often caused by a free chlorine attack. It’s permanent and cannot be reversed.

Scaling or precipitation fouling Scaling, also known as inorganic or precipitation fouling, is caused by the presence of crystallized salts, oxides, and hydroxides in the feed solution. Membrane scaling occurs when dissolved constituents precipitate out of solution and collect on the membrane surface or lodge in its pores.	Precipitation fouling occurs when a solution grows more and more concentrated against the feed side of the membrane, and eventually surpasses the solution saturation point, causing ionic constituents to fall out of solution and crystallize and/or bind to the membrane surface.	Inorganic fouling can be prevented by treatment strategies that inhibit crystal growth, either though acid injection, softening, and application of other chemical scale inhibitors.
Organic fouling Organic fouling is defined as the collection of carbon-based material on a filtration membrane. Organic matter is often quite reactive, and the risk that it poses as a foulant depends upon a number of factors, including its affinity for the membrane material.	Natural organic matter consists of carbon-based compounds commonly found in soil, ground and surface water, resulting from decomposition of plant and animal material.	Facilities can minimize issues with organic fouling by implementing some form of raw water treatment and/or selecting a membrane material that resists adsorption of organic material to the membrane.

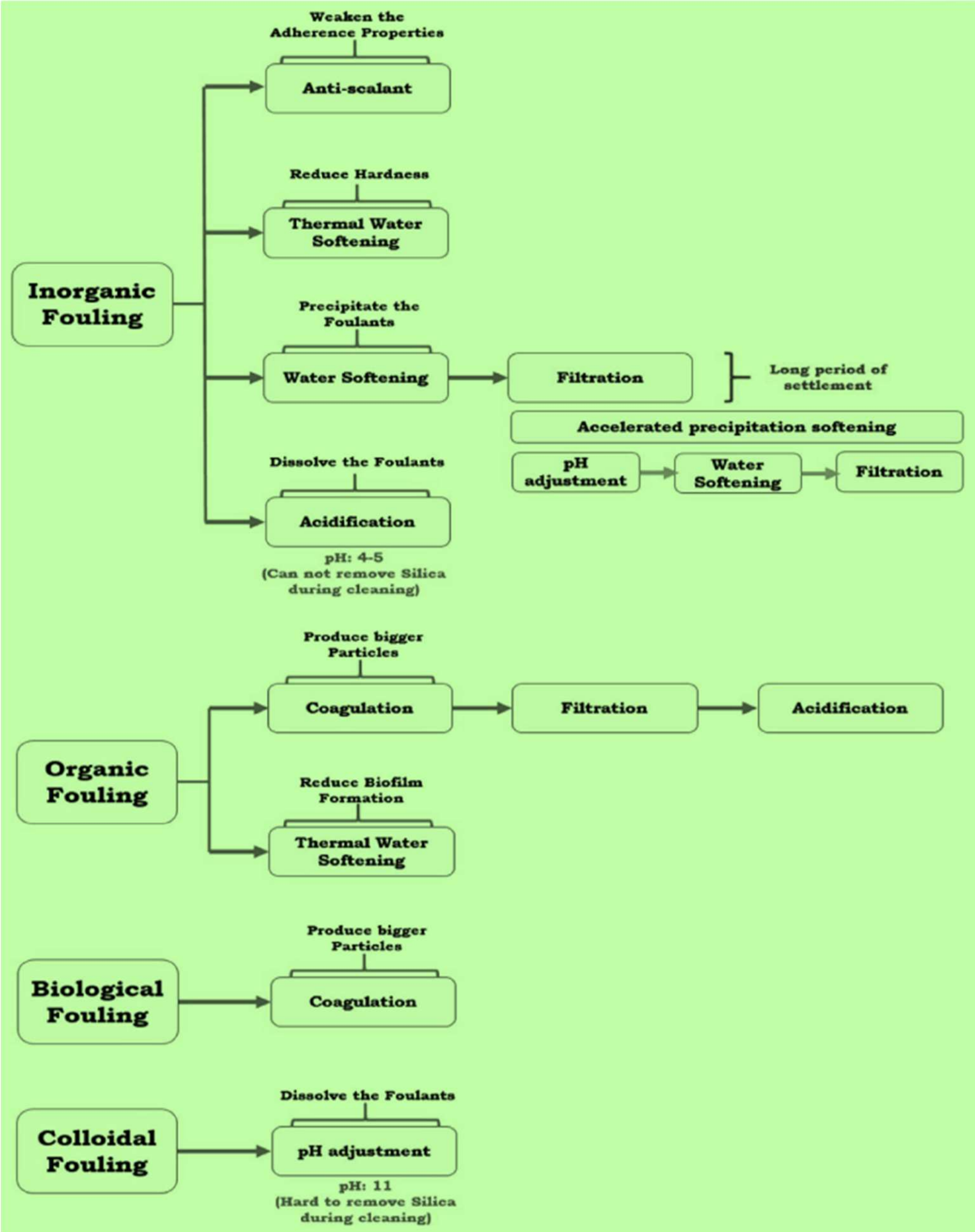
Inspection and Cleaning.

In addition to these preventive procedures, a program of regular inspection and cleaning of the ion exchange system helps to preserve the life of anion resin. Most cleaning procedures use one of the following:

- Warm (120°F) brine and caustic. Mild oxidants or solubilizing agents can be added to improve the cleaning.
- Hydrochloric acid. When resins are also fouled with significant amounts of iron, hydrochloric acids are used.
- Solutions of 0.25-0.5% sodium hypochlorite. This procedure destroys the organic material but also significantly degrades the resin. Hypochlorite cleaning is considered a last resort.

It is important to clean an organically fouled resin before excessive permanent degradation of the strong base sites occurs. Cleaning after permanent degradation has occurred removes significant amounts of organic material but does not improve unit performance. The condition of the resin should be closely monitored to identify the optimum schedule for cleaning.

Flow chart – Different types of Fouling and removal process



Practice quiz

https://forms.gle/xebvLEM6a95QexfKA

Assignment

Unit -1

S.No.	Questions	K level
1.	What is the hardness of a solution containing 0.585 g of NaCl and 0.6 g $MgSO_4$ per litre? (Ans: 500 ppm)	K3
2.	Calculate the hardness of water sample containing 2.4 mg of calcium chloride in 500 ml of water. (Ans: 4.8 ppm)	K3
3.	A sample of water is found to contain the following salts in mg/L. Mg $(HCO_3)_2$ = 14.6 ; Ca$(HCO3)_2$ =16.2 ; $MgCl_2$ = 9.5 ; $MgSO_4$ = 6.0. Calculate the temporary and permanent hardness of the sample of water. (Atomic weight of Ca = 40; Mg = 24; Cl= 35.5; C = 12; S = 32; O = 16 and H = 1) (Ans: Temporary hardness = 20 mg/L, Permanent hardness = 15 mg/L)	K3
4.	A sample of water is found to contain 19.71 mg/L Mg $(HCO_3)_2$; 12 mg/L $MgCl_2$; 24 mg/L $MgSO_4$ and 5.0 mg/L NaCl. Calculate the temporary and permanent hardness of water and express it in ppm. (Ans: Temporary hardness = 11.50 ppm, Permanent hardness = 22.63 ppm)	K3
5.	Calculate the carbonate and non-carbonate hardness of a sample of water containing the dissolved salts as given below in mg/L. Mg $(HCO_3)_2$ = 21.9; Ca $(HCO_3)_2$ =243; $MgCl_2$ = 190; $CaSO_4$ = 27.2; NaCl = 50. (Ans: Carbonate =165 ppm ; Non-Carbonate = 220 ppm)	K3

Part-A Questions and Answer

<table>
<tr><th>S.No.</th><th>PART-A
Q & A</th><th>K level</th><th>CO</th></tr>
<tr><td>1</td><td>Differentiate hard water and soft water.
<table>
<tr><th>Hard water</th><th>Soft water</th></tr>
<tr><td>Water which does not produce lather with soap solution, but produces white precipitate (scum) is called hard water.</td><td>Water which produces lather readily with soap solution is called soft water.</td></tr>
<tr><td>This is due to the presence of dissolved Ca and Mg salts.</td><td>Soft water contains salt of sodium ions and is free of calcium and magnesium ions.</td></tr>
</table></td><td>K2</td><td>CO1</td></tr>
<tr><td>2</td><td>Define Hardness of water.
It is the property of water which prevents lathering with soap due to the presence of calcium and magnesium salt impurities.
Based on the ease with which the hardness is removed, hardness is classified into two types:
i.Temporary Hardness or Carbonate Hardness
ii.Permanent or Non-carbonate Hardness</td><td>K1</td><td>CO1</td></tr>
</table>

<table>
<tr><th>S.No.</th><th>PART-A
Q & A</th><th>K level</th><th>CO</th></tr>
<tr><td>3</td><td>Differentiate temporary hardness and permanent hardness.
<table>
<tr><th>Temporary hardness</th><th>Permanent hardness</th></tr>
<tr><td>It is due to bicarbonates of calcium and magnisum</td><td>It is due to chlorides and sulphates of calcium and magnesium</td></tr>
<tr><td>It can be removed by boiling the water.</td><td>It canot be removed by boiling the water.</td></tr>
</table></td><td>K2</td><td>CO1</td></tr>
<tr><td>4</td><td>Why hardness is expressed in terms of $CaCO_3$ equivalents.
The choice of $CaCO_3$, in particular is due to:
i. Its molecular weight is 100 (equivalent wt. is 50) which makes the calculation easier.
ii. It is the most insoluble salt that can be precipitated in the water treatment easily.</td><td>K2</td><td>CO1</td></tr>
<tr><td>5</td><td>What happens when hard water is boiled?
When the water is boiled, the bicarbonates are decomposed yielding insoluble carbonates or hydroxides which are deposited as a crust or scales at the bottom of the vessel, while carbon dioxide escapes out.
$Ca(HCO_3)_2 \longrightarrow CaCO_3 \downarrow + H_2O + CO_2 \uparrow$
$Mg(HCO_3)2 \longrightarrow Mg(OH)_2 \downarrow + CO_2 \uparrow$</td><td>K1</td><td>CO1</td></tr>
</table>

S.No.	PART-A Q & A	K level	CO
6	**What are the different steps in water treatment?** • Coagulation • Flocculation • Sedimentation • Filtration • Disinfection.	K1	CO1
7	**What is sedimentation with coagulation?** The process of removing fine suspended and colloidal impurities by adding required amount of coagulant to water before sedimentation.	K1	CO1
8	**What is meant by break point chlorination?** • It involves addition of sufficient amount chlorine to oxidize Organic matter, reducing substances, free ammonia leaving behind free chlorine killing pathogenic bacteria. • The addition of sufficient amount of chlorine to satisfy chlorine demand is called break point chlorination	K2	CO1
9	**What are the advantages of break point chlorination?** i) oxidizes completely organic matter, NH3 and reducing agents, ii) removes colours in water iii) destroys completely all the disease producing bacteria iv) removes odour from water v) prevents if any growth of weeds in water.	K2	CO1

S.No.	PART-A Q & A	K level	CO
10	**Why water should be softened before using in boiler?** Water used for steam generation should be sufficiently pure. Otherwise it would cause boiler problems like scale and sludge formation, priming and forming, boiler corrosion, etc. Hence it should be properly softened before feeding into the boiler.	K1	CO1
11	**Why is calgon conditioning is better than phosphate conditioning?** In calgon conditioning, the added calgon forms highly soluble complex compound with CaSO4, thereby it prevents sludge and scale formation in boiler and also cause no harm to the boiler. On the other hand, in phosphate conditioning, hardness causing ions are converted into soft sludge. This sludge has to be removed by frequent blow down operation. Hence calgon conditioning is preferred over phosphate conditioning.	K2	CO1
12	**In the demineralization process, water is usually first passed through the cation exchanger and then through the anion exchanger. Give reason.** Cation exchangers are easily attacked by alkalis; while all types of ion exchangers are not attacked by acids. When water is first passed through the cation exchanger, cations are replaced by H+ ions making the out coming water acidic. This on passing through the anion exchanger does not harm it. If reverse sequence is used, the alkalis produced on passing water through the anion exchanger, harms the cation exchanger in the subsequent step. Hence such a sequence is avoided.	K2	CO1

S.No.	PART-A Q & A	K level	CO
13	**What is the main advantage of reverse osmosis process over ion exchange process?** Reverse osmosis removes all ionic, non ionic, colloidal and high molecular weight organic matter, while ion exchange process remove only ionic impurities.	K2	CO1
14	**Define fouling.** Resin can become fouled with contaminants that hinder the exchange process. The resin can also be attacked by chemicals that cause irreversible destruction. Some materials, such as natural organics foul resins at first and then degrade the resin as time passes. This is the most common cause of fouling and degradation in ion exchange systems.	K1	CO1
15	**Every demineralised water is soft water but every soft water is not demineralised water. Give reason.** Softening removes only hardness causing calcium and magnesium ions. But demineralization removes all types of ions irrespective of their nature. Hence the statement is true and justified..	K1	CO1

S.No.	PART-B QUESTIONS	K level	CO
1	Discuss drinking water quality parameter.	K2	CO1
2	What is called Municipal Water Treatment? Validate your answer.	K2	CO1
3	What is the need and importance of water treatment? Explain in detail.	K2	CO1
4	What is called breakpoint chlorination, Ozonation and Nano filtration? Substantiate with examples.	K2	CO1
5	What are sludges and scales? How are they formed? What are their disadvantages and how will you prevent them?	K2	CO1
6	Describe briefly the various methods of internal conditioning of boiler feed water.	K3	CO1
7	How will you prepare demineralized water using ion-exchange resins? Explain with neat diagram. Write its merits and demerits.	K2	CO1
8	What is desalination? With a neat diagram, describe the 'reverse osmosis' method for the desalination of brackish water.	K2	CO1
9	Explain briefly the principle, types and prevention of resin fouling and degradation.	K2	CO1
10	How is membrane fouling affect reverse osmosis?	K2	CO1

Supportive online certification courses

- https://www.edx.org/course/drinking-water-treatment
- Drinking water Treatment
- Edx 7-week course

- https://www.coursera.org/learn/water-treatment
- Introduction to Household water Treatment and Safe Storage
- Coursera 5-week course

- https://onlinecourses.nptel.ac.in/noc21_ce25/preview
- Water and waste water treatment
- NPTEL 12-week course

- As per FSSAI guidelines mineral water means all kinds of mineral water or natural mineral water by whatever name it is called or sold. All mineral waters shall conform to the following standards, namely:

S. No.	Characteristics	Requirements
1	Colour, Hazen unit/True	Not more than 2
2	Odour	Agreeable
3	Taste	Agreeable
4	Turbidity (Turbidity unit, NTU)	Not more than 2 nephelometric
5	Total Dissolved Solids (TDS)	150-170 mg/l
6	pH	6.5-8.5

- Besides these levels of mineral salts, heavy metals, toxic elements, environmental contaminants and microbial counts have also been specified.

Packaged Drinking Water (other than mineral water):

- It can be defined as water derived from nature processed to remove unwanted impurities and made fit for drinking is called packaged drinking water. The treatments, namely decantation, filtration, aerations, de-mineralization and reverse osmosis. Packed after disinfecting the water to a level that shall not lead any harmful contamination in the drinking water. The standards, packaging and labelling requirements have been specified under FSSA rules.

An overview of the main pre-treatment techniques and the substances, which are reduced during these processes.

Pre-treatment	$CaCO_3$	SO_4	SiO_2	MFI	Fe	Al	Bacteria	Organic matter
Acid dosage	X				O			
Anti-scalant	O	X						
Softening and ion exchange	X	X						
Preventive cleansing	O		O	O	O	O	O	X
Adjusting of process parametres		O	X					
Quick filtration			O	O	O	O		
Flocculation			O	X	O	O		
Micro and ultra filtration			X	X	O	O	O	X
Candle filtres			O	O	O	O	O	
X = highly effective O = effective pre-treatment								

Content beyond syllabus

Waste water (or) Sewage Treatment:

Untreated sewage poses a major risk to human health since it contains waterborne pathogens that can cause serious human illness. Untreated sewage also destroys aquatic ecosystems, threatening human livelihoods, when the associated biological oxygen demand and nutrient loading deplete oxygen in the water to levels too low to sustain life.

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Objectives:

The main objectives of waste water treatment are:

i) To convert harmful compounds into harmless compounds.

ii) To eliminate the offensive smell.

iii) To remove the solid content of the sewage.

iv) To destroy the disease producing microorganisms.

Treatment process:

The sewage (or) waste water treatment process involves the following steps:

I) Preliminary Treatment:

In this treatment, coarse solids and suspended impurities are removed by passing the waste water through bar and mesh screens.

II) Primary Treatment (or) settling process:

In this treatment, greater proportion of the suspended inorganic and organic solids is removed from the liquid sewage by settling. In order to facilitate quick settling coagulants like alum or ferrous sulphate is added. These produce large gelatinous precipitates, which entraps finely divided organic matter and settles rapidly.

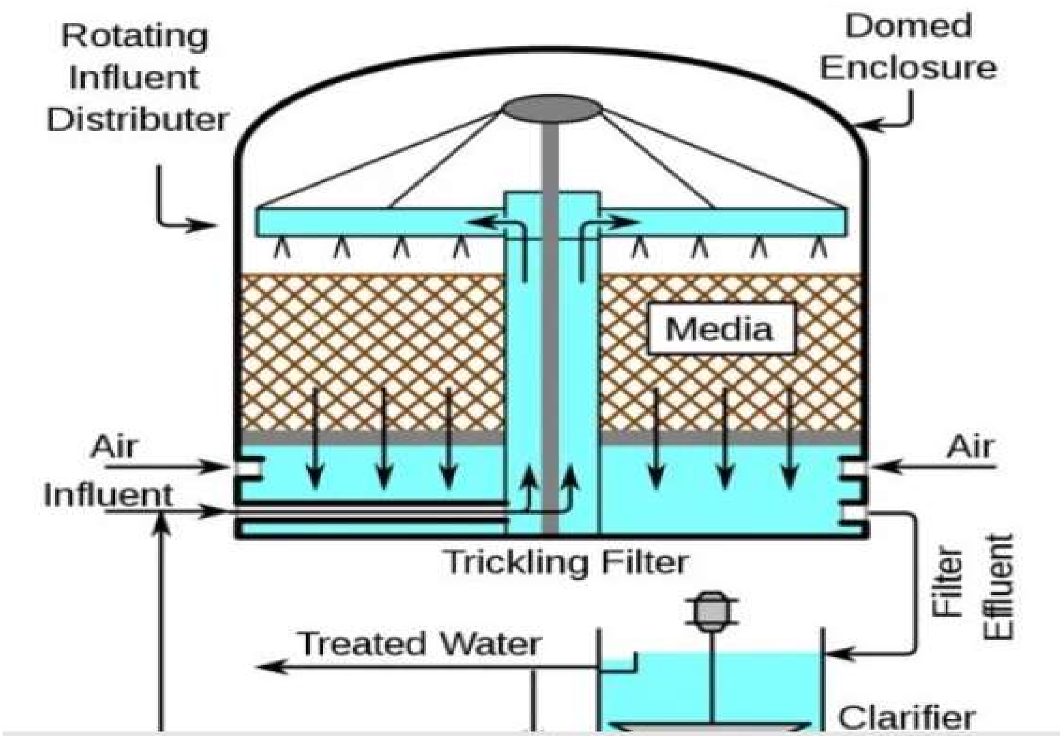
$$\mathbf{Al_2(SO_4)_3 + 6H_2O \rightarrow 2Al(OH)_3 \downarrow + 3H_2SO_4}$$

III) Secondary (or) Biological Treatment:

In this treatment, biodegradable organic impurities are removed by aerobic bacteria. It removes up to 90% of the oxygen demanding wastes. This is done by trickling filter or activated sludge process.

a) Trickling filter process:

The trickling filter is an aerobic treatment system that utilizes microorganisms attached to a medium to remove organic matter from wastewater. It consists of a circular tank which is filled with either coarse or crushed rock (media). Sewage is sprayed over this bed by means of slowly rotating arms. Air circulation in the void space, by blowers, provides oxygen for the microorganisms. When sewage starts percolating downwards, microorganisms present in the sewage grows on the surface of filtering media using organic material of the sewage as food. After completion of aerobic oxidation, the treated sewage taken out and the sludge is removed. This process removes about 80 – 85 % of BOD.



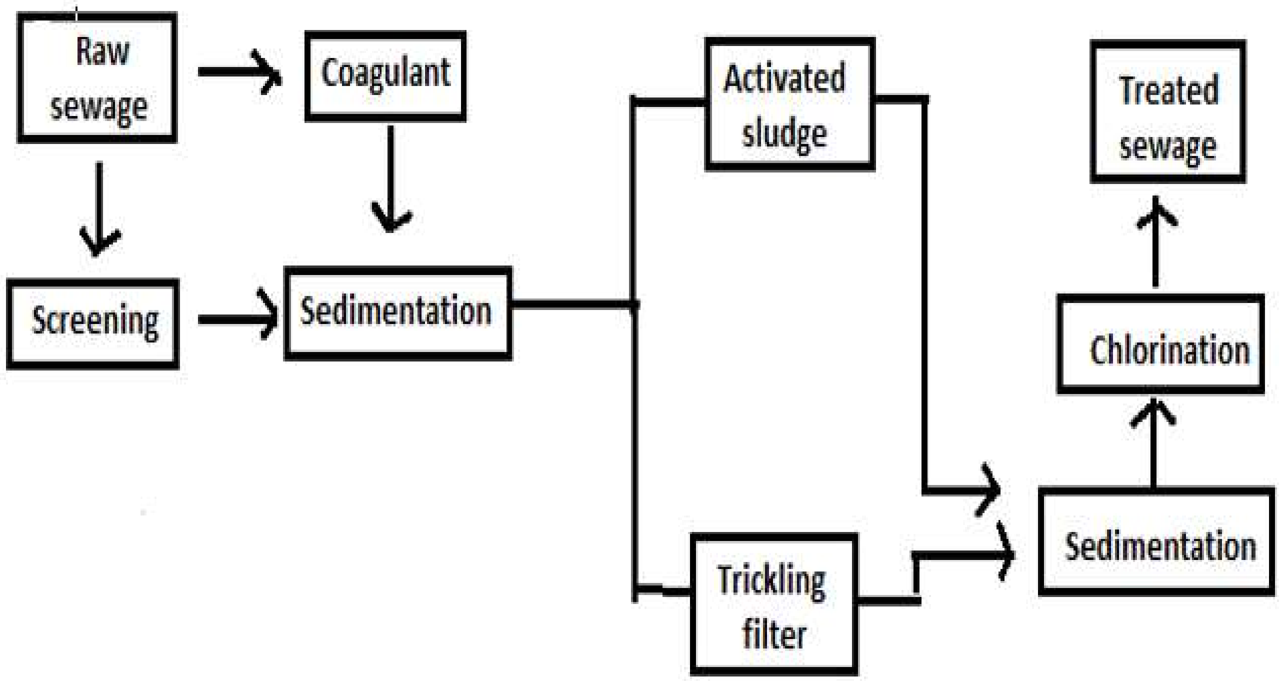
(b) Activated sludge process:

Activated sludge is biologically active sewage and it has a large number of aerobic bacteria, which can easily oxidize the organic impurities. The sewage effluents from primary treatment is mixed with the required amount of activated sludge and is aerated in the aeration tank. Under these conditions, organic impurities of the sewage get oxidized rapidly by the microorganisms.

After aeration, the sewage is taken to the sedimentation tank. Sludges settle down in this tank called activated sludge. A portion of which is used for seeding fresh batch of the sewage. This process removes about 90 – 95% of BOD.

IV. Tertiary treatment:

Tertiary treatment of wastewater is the third stage of the wastewater treatment and is also known as an advanced treatment. Tertiary treatment removes the load of nitrogen and phosphorus present in the water. It includes processes like filtration, chlorination, activated carbon adsorption, nitrification, and denitrification.



V. Disposal of sludge:

This is the last stage in the sewage treatment. Sludge formed from different steps can be disposed by:

i) Dumping into low lying areas.

ii) Burning of sludge (incineration).

iii) Dumping into the sea.

iv) Using it as low-grade fertilizers.

Prescribed Text Books & Reference Books

1. P. C. Jain and Monika Jain, "Engineering Chemistry", 17th Edition, Dhanpat Rai Publishing Company Pvt. Ltd., New Delhi, 2018.
2. S. S. Dara and S. S. Umare, "A Textbook of Engineering Chemistry", 12th Edition, S. Chand & Company, New Delhi, 2010.
3. O.G. Palanna, "Engineering Chemistry" McGraw Hill Education (India) Private Limited, 2nd Edition, 2017.
4. Shikha Agarwal, "Engineering Chemistry-Fundamentals and Applications", Cambridge University Press, Delhi, Second Edition, 2019.

Mini project suggestions

1.	Water testing – Students will bring water from home and check its quality
2.	Prototype for removal of hardness using zeolite
3.	Removal of hardness using lime –soda process
4.	Determination of BOD,COD and DO
5.	Estimation of hardness by collecting water samples from different areas and submitting the report by graphical representation

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Thank you