SECTION – B

MDU(ROHTAK)

B.TECH 1ST YEAR

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## (I) & (II) WATER AND ITS TREATMENT

SECTION –B:WATER AND ITS TREATMENT

<u>Sources of water</u>

Water resources are sources of water that are useful or potentially useful. Uses of water include agricultural, industrial,household, recreational and environmental activities. Virtually all of these human uses require fresh water.

97% of the water on the Earth is salt water. However, only three percent is fresh water; slightly over two thirds of this is frozen in glaciers and polar ice caps. The remaining unfrozen freshwater is found mainly as groundwater, with only a small fraction present above ground or in the air .Fresh water is a renewable resource, yet the world's supply of clean, fresh water is steadily decreasing.[ ]Water demand already exceeds supply in many parts of the world[ ] and as the world populationcontinues to rise, so too does the water demand. Awareness of the global importance of preserving water for ecosystem services has only recently emerged as, during the 20th century, more than half the world's wetlands have been lost along with their valuable environmental services for Water Education.[ ] The framework for allocating water resources to water users (where such a framework exists) is known as water rights.

Distribution of Earth's Water
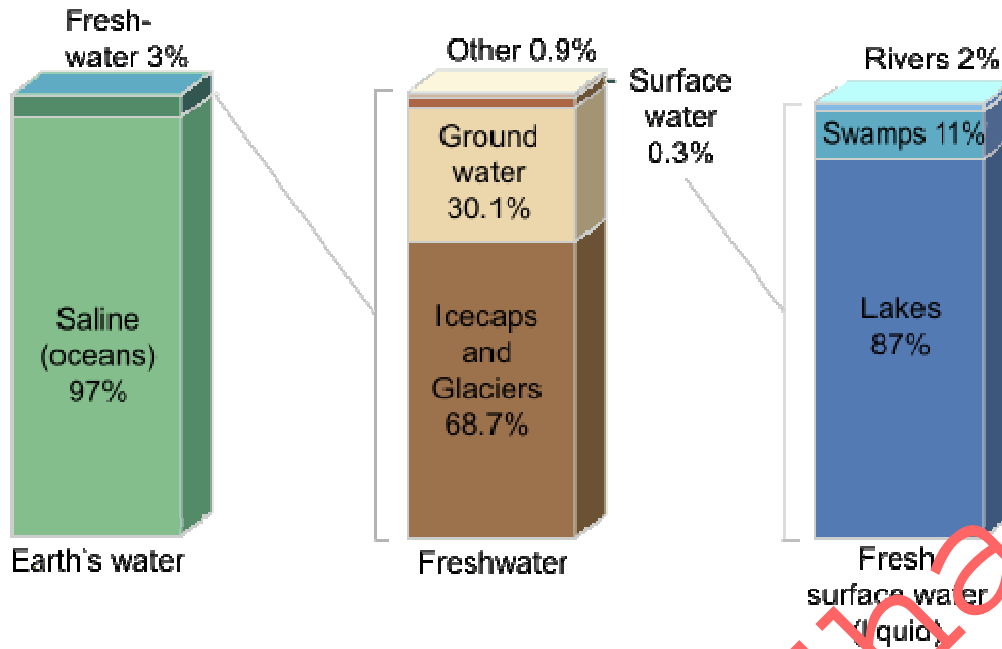
Water and Its Impurities

Water is the universal solvent. In nature, it is never totally pure. No matter how isolated it is from sources of contamination, it will always have some chemicals. Gases or minerals in the air, soil or rock are dissolved by the water. Some dissolved materials give water it's characteristic taste – "pure water" is generally considered to be flat and tasteless. On the other hand, minerals can cause hardness (calcium or magnesium), color (iron), contamination (arsenic), and radioactivity (radium, radon) in the water. Humans can cause contamination through the improper use of pesticides or fertilizers and through the disposal of waste. These impurities can dissolve in the water, causing it to be contaminated.

The minerals and impurities are normally present in very small concentrations. They are measured either as parts per million (ppm) (how many parts of impurities in a million parts of water) or milligrams per liter (mg/l). The terms are equivalent at low concentrations and are used interchangeably in the water and wastewater. Some parameters are measured in parts per billion (ppb) or micrograms per liter (µg/l). These terms are also essentially equivalent at low concentrations.

Groundwater dissolves much of the material that it percolates through. It is generally harder than surface water, and it usually contains more iron and manganese.

As stated earlier, water in nature is not pure. The table below shows typical concentration ranges for chemicals dissolved in ground or surface water.

	Range of concentrations typically found in groundwater	Range of concentrations typically found in surface water
Total Hardness	300 - 400 ppm	75 - 200 ppm
Alkalinity	250-350 ppm	45-250 ppm
Dissolved Oxygen	near 0	2 - 14 ppm
Carbon Dioxide	1 - 10 ppm	low
Calcium Hardness	high	sometimes high, usually low
Magnesium Hardness	tends to be high	sometimes high, usually low

Water that exists in nature, like any other material, undergoes changes. These changes are driven by both physical and chemical means.

The quality of groundwater is generally slower to change, especially when it comes from deeper aquifers. Groundwater is not directly exposed to air pollution, contamination from run-off (if the well is properly constructed), or wastewater discharge. The quality of groundwater is also protected by natural filtration, which can remove some contaminants, as water percolates through the soils and rock.

Sometimes, when contamination is found in groundwater, the use of a specific aquifer may have to be discontinued. Some organic chemicals that have contaminated some aquifers are very difficult and expensive to remove. It may be cheaper to drill a new well into a different aquifer. However, in many circumstances other aquifers do not exist, and contaminant cleanup or treatment is necessary.
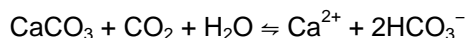
HARDNESS OF WATER

Hard water is water that has high mineral content (in contrast with "soft water"). Hard water is generally not harmful to one's health, but can pose serious problems in industrial settings, where water hardness is

monitored to avoid costly breakdowns in boilers, cooling towers, and other equipment that handles water. In domestic settings, hard water is often indicated by a lack of suds formation when soap is agitated in water. Wherever water hardness is a concern, water softening is commonly used to reduce hard water's adverse effects.

Sources of hardness

Water's hardness is determined by the concentration of multivalent cations in the water. Multivalent cations are cations (positively charged metal complexes) with a charge greater than 1+. Usually, the cations have the charge of 2+. Common cations found in hard water include Ca^{2+} and Mg^{2+}. These ions enter a water supply by leaching from minerals within an aquifer. Common calcium-containing minerals are calcite and gypsum. A common magnesium mineral is dolomite (which also contains calcium). Rainwater and distilled water are soft, because they also contain few ions.[1]

The following equilibrium reaction describes the dissolving/formation of calcium carbonate scales:

$$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{2+} + 2HCO_3^-$$

Calcium carbonate scales formed in water-heating systems are called limescale.

Calcium and magnesium ions can sometimes be removed by water softeners.[2]

Temporary hardness

Temporary hardness is a type of water hardness caused by the presence of dissolved carbonate minerals (calcium carbonate and magnesium carbonate). When dissolved, these minerals yield calcium and magnesium cations (Ca^{2+}, Mg^{2+}) and carbonate and bicarbonate anions (CO_3^{2-}, HCO_3^-). The presence of the metal cations makes the water hard. However, unlike the permanent hardness caused by sulfate and chloride compounds, this "temporary" hardness can be reduced either by boiling the water, or by the addition of lime (calcium hydroxide) through the process of lime softening.[3] Boiling promotes the formation of carbonate from the bicarbonate and precipitates calcium carbonate out of solution, leaving water that is softer upon cooling.

Permanent hardness

Permanent hardness is hardness (mineral content) that cannot be removed by boiling. When this is the case, it is usually caused by the presence of calcium and magnesium sulphates and/or chlorides in the water, which become more soluble as the temperature increases. Despite the name, the hardness of the water can be easily removed using a water softener, or ion exchange column.

Effects of hard water

With hard water, soap solutions form a white precipitate (soap scum) instead of producing lather. This effect arises because the 2+ ions destroy the surfactant properties of the soap by forming a solid precipitate (the soap scum). A major component of such scum is calcium stearate, which arises from sodium stearate, the main component of soap:

$$2\ C_{17}H_{35}COO^- + Ca^{2+} \rightarrow (C_{17}H_{35}COO)_2Ca$$
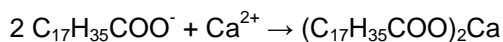
Hardness can thus be defined as the soap-consuming capacity of a water sample, or the capacity of precipitation of soap as a characteristic property of water that prevents the lathering of soap. Synthetic detergents do not form such scums.

Hard water also forms deposits that clog plumbing. These deposits, called "scale", are composed mainly of calcium carbonate ($CaCO_3$), magnesium hydroxide ($Mg(OH)_2$), and calcium sulfate($CaSO_4$).[1] Calcium and magnesium carbonates tend to be deposited as off-white solids on the surfaces of pipes and the surfaces of heat exchangers. This precipitation (formation of an insoluble solid) is principally caused by thermal decomposition of bi-carbonate ions but also happens to some extent even in the absence of such ions. The resulting build-up of scale restricts the flow of water in pipes. In boilers, the deposits impair the flow of heat into water, reducing the heating efficiency and allowing the metal boiler components to overheat. In a pressurized system, this overheating can lead to failure of the boiler.The damage caused by calcium carbonate deposits varies depending on the crystalline form, for example, calcite or aragonite.

The presence of ions in an electrolyte, in this case, hard water, can also lead to galvanic corrosion, in which one metal will preferentially corrode when in contact with another type of metal, when both are in contact with an electrolyte. The softening of hard water by ion exchange does not increase its corrosivity *per se*. Similarly, where lead plumbing is in use, softened water does not substantially increase plumbo-solvency.In swimming pools, hard water is manifested by a turbid, or cloudy (milky), appearance to the water. Calcium and magnesium hydroxides are both soluble in water. The solubility of the hydroxides of the alkaline-earth metals to which calcium and magnesium belong (group 2 of the periodic table) increases moving down the column. Aqueous solutions of these metal hydroxides absorb carbon dioxide from the air, forming the insoluble carbonates, giving rise to the turbidity. This often results from the alkalinity (the hydroxide concentration) being excesively high (pH > 7.6). Hence, a common solution to the problem is to, while maintaining the chlorine concentration at the proper level, raise the acidity (lower the pH) by the additoon of hydrochloric acid, the optimum value being in the range of 7.2 to 7.6.

Softening

For the reasons discussed above, it is often desirable to soften hard water. Most detergents contain ingredients that counteract the effects of hard water on the surfactants. For this reason, water softening is often unnecessary. Where softening is practiced, it is often recommended to soften only the water sent to domestic hot water systems so as to prevent or delay inefficiencies and damage due to scale formation in water heaters. A common method for water softening involves the use of ion exchange resins, which replace ions like Ca^{2+} by twice the number of monocations such as sodium or potassium ions.

DETERMINATION OF TOTAL, PERMANENT, TEMPORARY HARDNESS OF WATER SAMPLE (EDTA METHOD)

PRINCIPLE

Disodium salt of EDTA is used to estimate the various hardness of the given hard water.When EDTA is added to hard water, it reacts with calcium and magnesium ions present in hard water to form stable EDTA metal complexes. Eriochrome black-T is used as indicator. The

indicator forms a weak complex with the metal ions present in the hard water and gives wine red colour at a pH of 10 ± 0.1.
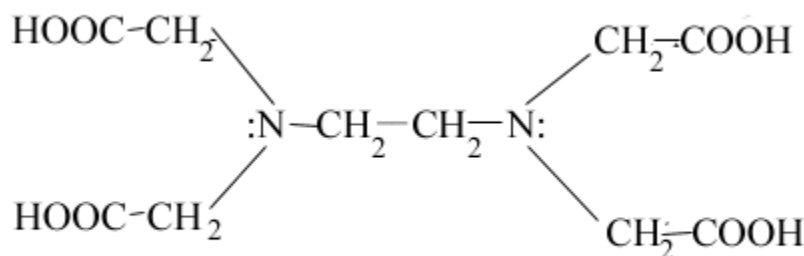
structure of EDTA

When EDTA is added into the hard water, the metal ions form a stable metal complex with EDTA leaving the indicator. When EDTA takes up all metal ions from the indicator- metal ion complex, the wine red colour changes into steel blue, which denotes the end point.

PROCEDURE

TITRATION – I

STANDARDISATION OF EDTA

1.   Burette solution   EDTA solution

2.   Pipette solution   Standard hard water (20 ml)

3.   Additional solution   5 ml of ammonia buffer   solution

4.   Indicator   Eriochrome black – T

5.   End point   Change of colour from wine red to

Steel blue

TITRATION – II

ESTIMATION OF TOTAL HARDNESS

1.   Burette solution   ⟶ EDTA solution

2.   Pipette solution   ⟶ given sample of hard water (20 ml)

3.   Additional solution   ⟶   5 ml of ammonia buffer solution

4.   Indicator   ⟶   Eriochrome black – T

5.   End point   ⟶   Change of colour from wine red to steel

blue

TITRATION – III

ESTIMATION OF PERMANENT HARDNESS

1.Burette solution   ⟶   EDTA solution

2.Pipette solution   ⟶   Boiled hard water sample (20 ml)

3.Additional solution   ⟶   5 ml of ammonia buffer solution

4. Indicator   ⟶   Eriochrome black – T

5.End point   ⟶   Change of colour from wine red

ALKALINITY IN WATER

Alkalinity measures the acid-neutralizing capacity of a water sample. It is an aggregate property of the water sample and can be interpreted in terms of specific substances only when a complete chemical composition of the sample is also performed. The alkalinity of surface waters is primarily
due to the carbonate, bicarbonate, and hydroxide content and is often interpreted in terms of the concentrations of these constituents. The higher the alkalinity, the greater the capacity of the water to neutralize acids; conversely, the lower the alkalinity, the less the neutralizing capacity. To detect the different types of alkalinity,
the water is tested for **phenolphthalein** and **total alkalinity**, using Equations:
Phenolphthalein alkalinity (mg/L) as CaCO3=**A x N x 50,000/mL of Sample**
Total alkalinity (mg/L) as CaCO3=**B x N x 50,000/mL of Sample**
where
A= titrant (mL) used to pH 8.3
B= titrant (mL) used to titrate to pH 4.5

N= normality of the acid (0.02N H2SO4 for this alkalinity test)

50,000 = a conversion factor to change the normality into units of CaCO3

PRINCIPLE

Alkalinity is caused by the presence of hydroxide, carbonate and bicarbonate. There are five alkalinity conditions possible in a given sample of water, hydroxide only, carbonate only, bicarbonate only, combination of carbonate and hydroxide or carbonate and bicarbonate. The various alkalinities can be estimated by titrating with a standard acid using Phenolphthalein and methyl orange indicators successively.
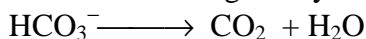
1) Phenolphthalein end point

Hydroxide alkalinity is completely neutralised and carbonate alkalinity is partially neutralised during Phenolphthalein end point.

$$OH^- + H^+ \longrightarrow H_2O$$
$$CO_3^{2-} + H^+ \longrightarrow HCO_3^-$$
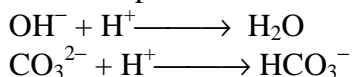
ii) Methyl Orange end point

Bicarbonate neutralisation occurs during methyl orange end point

$$HCO_3^- \longrightarrow CO_2 + H_2O$$

Alkalinity values are expressed in terms of milligram per litre as calcium carbonate.

PROCEDURE

TITRATION - I

(With Phenolphthalein indicator)

Burette Solution   :   HCl

Pipette Solution :   :   Water Sample

Indicator   :   Phenolphthalein

End Point   :   Disappearance of pink colour

TITRATION - II

(With Methyl orange indicator)

Few drops of methyl orange indicator are added to **the same solution** after the phenolphthalein end point.

Indicator   :   Methyl orange

End Point   :   yellow colour changes to red orange

Titer value and different alkalinities

S.No	Result of titration of [P] And [M]	Hardness causing ions		
		OH^-	CO_3^-	HCO_3^-
1	[P] = 0	0	0	[M]
2	[P] = [M]	[P] or [M]	0	0
3	[P] = 1/2[M]	0	2[P] or [M]	0
4	[P] >1/2 [M]	2[P] - [M]	2[M] -2[P]	0
5	[P] < ½ [M]	0	2[P]	[M- 2 [P]]

SCALE AND SLUDGE

when the concentration of salt in water reach to a saturation point, they thrown out of waterin the form of precipitate on the inner walls of the boiler. If this precipitate is loose and slimy, thisis known as **sludge** and if this is form a hard coating on inner walls of boiler this is known as **scale.**

Boiler Corrosion

Corrosion is the reversion of a metal to its ore form. Iron, for example, reverts to iron oxide as the result of corrosion. The process of corrosion, however is a complex electro chemical reaction and it takes many forms. Corrosion may produce general attach over a large metal surface or it may result in pinpoint penetration of metal. Corrosion is a relevant problem caused by water in boilers. Corrosion can be of widely varying origin and nature due to the action of dissolved oxygen, to corrosion currents set up as a result of heterogeneities on metal surfaces, or to the iron being directly attacked by the water.

While basic corrosion in boilers may be primarily due to reaction of the metal with oxygen, other factors such as stresses, acid conditions, and specific chemical corrodents may have an important influence and produce different forms of attack. It is necessary to consider the quantity of the various harmful substances that can be allowed in the boiler water without risk of damage to the boiler. Corrosion may occur in the feed-water system as a result of low pH water and the presence of dissolved oxygen and carbon dioxide.

Starting form these figures, and allowing the amount that can be blown down, the permitted concentration in the make-up water is thus defined.

Corrosion is caused principally by complex oxide-slag with low melting points. High temperature corrosion can proceed only if the corroding deposit is in the liquid phase and the liquid is in direct contact with the metal. Deposits also promote the transport of oxygen to the metal surface. Corrosion in the boiler proper generally occurs when the boiler water alkalinity is low or when the metal is exposed to oxygen bearing water either during operation or idle periods. High temperatures and stresses in the boiler metal tend to accelerate the corrosive mechanisms. In the steam and condensate system corrosion is generally the result of contamination with carbon dioxide and oxygen. Specific contaminants such as ammonia or sulphur bearing gases may increase attack on copper alloys in the system. Corrosion is caused by the combination of oxide layer fluxing and continuous oxidation by transported oxygen.

Caustic embrittlement

Caustic embrittlement" was first used to describe the cracking of riveted mild steel boiler plates due to local deposition of concentrated hydroxide at temperatures of 200 to 250°C (400 to 480°F). It was later known as "stress corrosion cracking" which is in turn replaced by "caustic cracking".

Caustic embrittlement is the phenomenon in which the material of a boiler becomes brittle due to the accumulation of caustic substances.
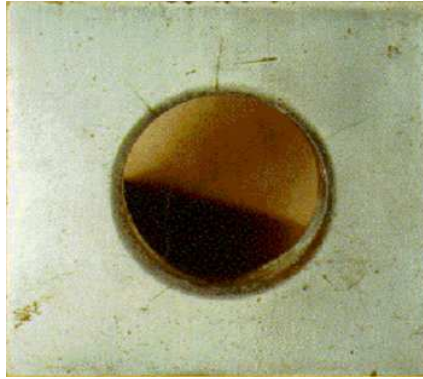
Cause

As water evaporates in the boiler, the concentration of <u>sodium carbonate</u> increases in the boiler. Sodium carbonate is used in <u>softening</u> of water by lime soda process, due to this some sodium carbonate maybe left behind in the water. As the concentration of sodium carbonate increases, it undergoes <u>hydrolysis</u> to form <u>sodium hydroxide</u>.

[[sodium carbonding material and the dissolves the <u>iron</u> of the boiler as <u>sodium ferroate</u>. the formed sodium ferroate will further undergo hydrolysis regenarating NaOH.Thus formed NaOH again attacks iron in stressed region and dissolve it.This causes embrittlement of boiler parts like <u>rivets</u>, bends and joints, which are under load owing to <u>stress concentration</u>.

Prevention

This can be prevented by using <u>sodium phosphate</u> instead of sodium carbonate as softening reagents. Adding <u>tannin</u> or <u>lignin</u> to boiler water blocks the hair-line cracks and prevents infiltration of NaOH into these areas. Adding Na_2SO_4 to boiler water also blocks hair-line cracks.

The domestic Water Treatments

The domestic Water Treatments involves treatment for potable or drinking purpose. Taste. Odor. Hardness. Contamination. These are four of the most common reasons why people install water treatment systems in their home.

An activated carbon filter removes many volatile organic chemicals, some pesticides, radon gas, hydrogen sulfide, and mercury. It also reduces odor, color, and taste problems (such as residual chlorine). Water is filtered through carbon granules that trap contaminants. But infrequently maintained filters can result in higher concentrations of contaminants and can serve as a breeding ground for bacteria.

WATER SOFTNING: LIME SODA TRETMENT

Soda lime is a process used in water treatment to remove **Hardness** from water. This process is now obsolete but was very useful for the treatment of large volumes of hard water. Addition of lime (CaO) and soda (Na_2CO_3) to the hard water precipitates calcium as the carbonate, and magnesium as its hydroxide. The amounts of the two chemicals required are easily calculated from the analysis of the water and stoichiometry of the reactions. The lime-soda uses lime, Ca $(OH)_2$ and soda ash, Na_2CO_3, to precipitate hardness from solution.
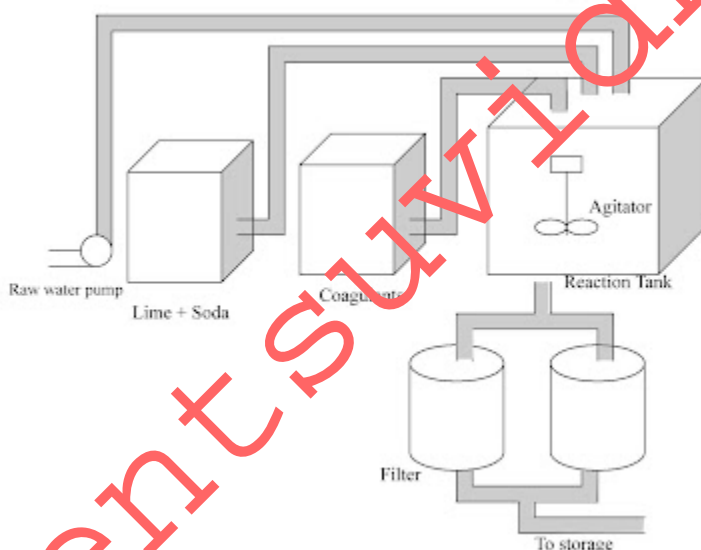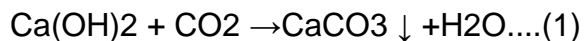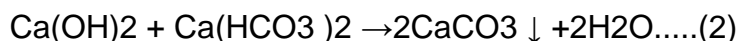

Soda lime water softening process

Carbon dioxide and carbonate hardness (calcium and Magnesium bicarbonate) are complexed by lime. In this process Calcium and Magnesium ions are precipitated by the addition of lime (Ca$(OH)_2$) and soda ash (Na_2CO_3).

Following are the reactions that takes place in this process:

As slacked lime is added to a water, it will react with any carbon dioxide present as follows:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 \downarrow + H_2O....(1)$$

The lime will react with carbonate hardness as follows:

$$Ca(OH)_2 + Ca(HCO_3)_2 \rightarrow 2CaCO_3 \downarrow +2H_2O.....(2)$$

$$Ca(OH)_2 + Mg(HCO_3)_2 \rightarrow MgCO_3 + CaCO_3 \downarrow +2H_2O.....(3)$$

The product magnesium carbonate in equation 3 is soluble. To remove it, more lime is added:

$$Ca(OH)_2 + MgCO_3 \rightarrow CaCO_3 \downarrow +Mg(OH)_2 \downarrow.....(4)$$

Also, magnesium non-carbonate hardness, such as magnesium sulfate, is removed:

$$Ca(OH)_2 + MgSO_4 \rightarrow CaSO_4 + Mg(OH)_2 \downarrow.....(5)$$

Lime addition removes only magnesium hardness and calcium carbonate hardness. In equation 5 magnesium is precipitated, however, an equivalent amount of calcium is added. The water now contains the original calcium non-carbonate hardness and the calcium non-carbonate hardness produced in equation 5. Soda ash is added to remove calcium non-carbonate hardness:

$$Na_2CO_3 + CaSO_4 \rightarrow Na_2SO_4 + CaCO_3 \downarrow .....(6)$$

To precipitate $CaCO_3$ requires a pH of about 9.5; and to precipitate $Mg(OH)_2$ requires a pH of about 10.8, therefore, an excess lime of about 1.25 meq/l is required to raise the pH.

The amount of lime required: lime (meq/l) = carbon dioxide (meq/l) + carbonate hardness (meq/l) + magnesium ion (meq/l) + 1.25 (meq/l)

The amount of soda ash required: soda ash (meq/l) = non-carbonate hardness (meq/l)

After softening, the water will have high pH and contain the excess lime and the magnesium hydroxide and the calcium carbonate that did not precipitate. Recarbonation (adding carbon dioxide) is used to stabilize the water. The excess lime and magnesium hydroxide are stabilized by adding carbon dioxide, which also reduces pH from 10.8 to 9.5 as the following:

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

$$CO_2 + Mg(OH)_2 \rightarrow MgCO_3 + H_2O$$
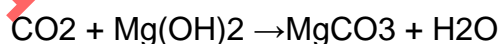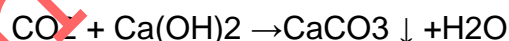
Further recarbonation, will bring the pH to about 8.5 and stablize the calcium carbonate as the following:

$$CO_2 + CaCO_3 + H_2O \rightarrow Ca(HCO_3)_2$$
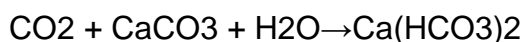
It is not possible to remove all of the hardness from water. In actual practice, about 50 to 80 mg/l will remain as a residual hardness.

Limitation of Soda Lime Process:

Lime soda softening cannot produce a water at completely free of hardness because of the solubility (little) of CaCO3 and Mg(OH)2. Thus the minimum calcium hardness can be achieved is about 30 mg/L as CaCO3, and the magnesium hardness is about 10 mg/L as CaCO3. We normally tolerate a final total hardness on the order of 75 to 120 mg/L as CaCO3, but the magnesium content should not exceed 40 mg/L as CaCO3 (because a greater hardness of magnesium forms scales on heat exchange elements)ss

Hydrated lime $Ca(OH)_2$ and sodium Carbonate are used in this method to precipitate Calcium and Magnesium ions. Particularly, $Ca(OH)_2$ is used for Carbonate ions and $NaCO_3$ is used for non Carbonate ions.

For temporary hardness,

$$Ca(HCO_3) + Ca(OH)_2 \longrightarrow 2CaCO_3\downarrow + 2H_2O$$
$$Mg(HCO_3) + Ca(OH)_2 \longrightarrow 2MgCO_3\downarrow + 2H_2O$$
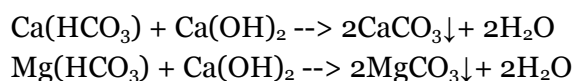
Here, the solubility of $Ca(HCO_3)$ is lower than that of $Mg(HCO_3)$. $CaCO_3$ precipitate first while water is treated with $Ca(OH)_2$ and at 100^oC temperature the solubility of CO_3 is 12-75 ppm.

For permanent hardness.

$$CaSO_4 + NaCO_3 \longrightarrow CaCO_3 + Na_2SO_4$$
$$MgCl_2 + Ca(OH)_2 \longrightarrow CaCl_2 + Mg(OH)_2$$
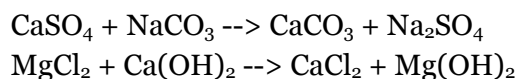
In 2nd reaction from above $CaCl_2$ is produced which is replaced by $CaCO_3$ by using Na_2CO_3.

$$CaCl_2 + Na_2CO_3 = CaCO_3 + NaCl$$
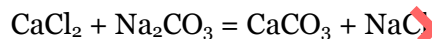
The main parts of the process are:

1. Reagent tanks (Soda lime + Coagulants)
2. Reaction tank
3. Filter
4. Soft water storage tank.

Process:

The lime and soda are entered into the reagent tank. At the same time, predetermined amount of raw hard water is pumped into the Reaction tank. A large propeller acts as an agitator into the Reaction tank. The agitation is increased to get more amount of ppm, steam is passed through the sideway pipe to increase the temperature of the mixer. The water is filtered to remove $CaCO_3$ after precipitation is completed and finally passed to the soft water storage tank.
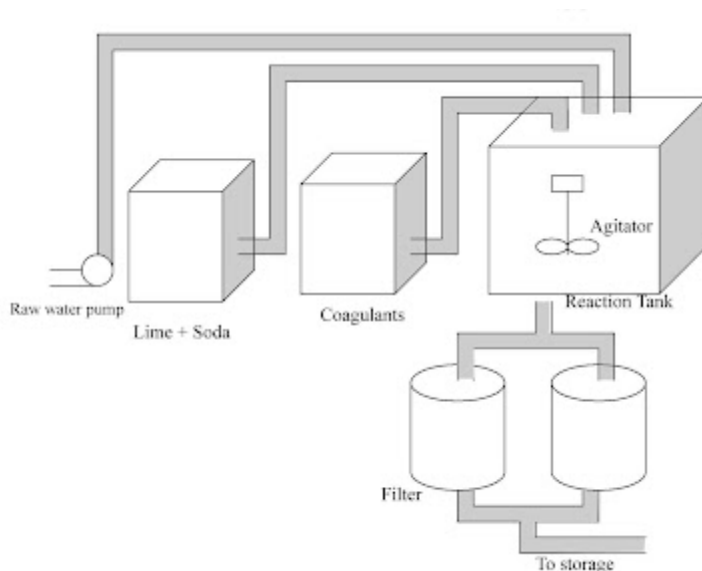
Precipitation rate can be increased by:

1. By increasing Temperature.
2. By using excess reagent and stirring.
3. By using sand grain.

The residual hardness that presents in water as $CaCO_3$ can be decreased by either hot or cold method. For cold method it can be reduced to 5-20 ppm and for hot process it is 5-15 ppm.
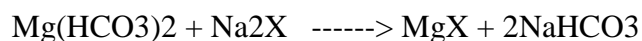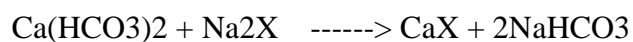
After processing with lime soda method if the water contains somehardness, then it can be removed by adding phosphate. In this process, some NaOH are also used.

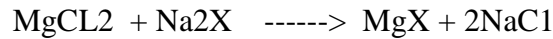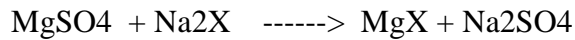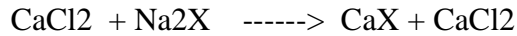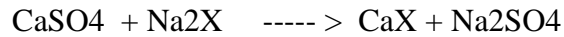$$10CaCO_3 + 6Na_3(PO_4) + 2NaOH \rightarrow \{Ca(PO_4)_2\}Ca(OH)_2 + NaCO_3$$
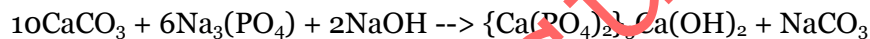
ZEOLITE:ION EXCHANGE PROCESS

Ion-exchange is used extensively in small water systems and individual homes. Ionexchange

resin, (zeolite) exchanges one ion from the water being treated for another ion that is in the resin

(sodium is one component of softening salt, with chlorine being the other). Zeolite resin

exchanges sodium for calcium and magnesium. The following chemical reactions show the

exchange process, where X represents zeolite, the exchange material.

Removal of carbonate hardness:

$$Ca(HCO3)2 + Na2X \longrightarrow CaX + 2NaHCO3$$

$$Mg(HCO3)2 + Na2X \longrightarrow MgX + 2NaHCO3$$

<div align="center">Removal of non-carbonate hardness:</div>

$$CaSO_4 + Na_2X \longrightarrow CaX + Na_2SO_4$$

$$CaCl_2 + Na_2X \longrightarrow CaX + CaCl_2$$

$$MgSO_4 + Na_2X \longrightarrow MgX + Na_2SO_4$$

$$MgCL_2 + Na_2X \longrightarrow MgX + 2NaC1$$

These reactions represent cation exchange, the exchange of positive ions. To replenish the

sodium ions used, units need to be regenerated with material containing high amounts of sodium

normally salt brine. This allows the resin to be reused many times.

Ion-exchange does not alter the water's pH or alkalinity. However, the stability of the water is

altered due to the removal of calcium and magnesium and an increase in dissolved solids. For

each ppm of calcium removed and replaced by sodium, total dissolved solids increase by 0.15

ppm. For each ppm of magnesium removed and replaced by sodium, total dissolved solids

increase by 0.88 ppm.

Measurements used to express water hardness in ion-exchange differ from units used in limesoda softening. Hardness is expressed as grains per gallon rather than mg/l of calcium carbonate.

 1 grain/gallon 17.12 mg/l

If water contains 10 grains of hardness, would hardness be expressed 171.2 mg/l?

10 grains x 17.12 mg/l / grain

  = 171.2 mg/l of hardness

EQUIPMENT AND OPERATION

Ion-Exchange Resins

Natural green sand called glauconite has very good exchange capabilities and was once widely used. Synthetic zeolites, known as polystyrene resins, are most commonly used now. Cost is reasonable, and it is easy to control the quality of the resin. They also have much higher ion exchange capacities than the natural material.
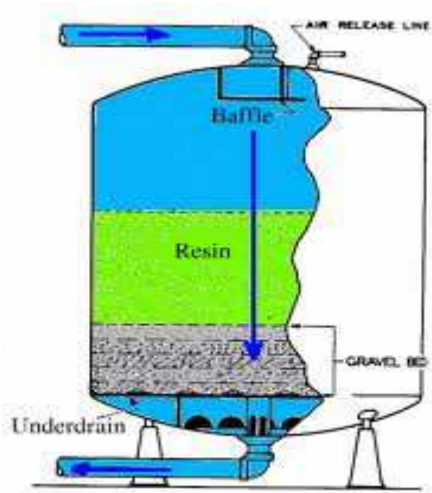
The ability of the resin to remove hardness from the water is related to the volume of resin in the tank.

Softeners should remove about 50,000 grains of hardness per cubic foot of resin. Resins

hold hardness ions until they are regenerated with a salt brine solution. The hardness ions are

exchanged for sodium ions in the salt brine.

Example:

If water contains 10 grains per gallon of hardness, how many gallons of water would the resin

remove? The tank holds 500 cubic feet of resin with capability of removing 45,000 grains per

gallon per cubic foot.

Gallons = cubic feet x grains per cubic foot

    grains per gallon

= 500 cubic feet x 45,000 grains/cubic foot

          10 grains per gallon

= 22,500,000 grains

          10 grains/gallon

= 2,250,000 gallons before requiring regeneration Ion Exchange Softening

Mixed-Bed Demineralization

Resin-based demineralization systems are typically designed in two-bed or mixed-bed configurations. Two-bed deionizers have separate tanks of cation and anion resins. In mixed-bed deionizers, the anion and cation resins are blended into a single tank or vessel. Generally, mixed-bed systems will produce higher quality water with a lower total capacity than two-bed systems. They are often used as post treatment for a reverse osmosis (RO) or electro Deionization (EDI) system as a final polishing step. Many industrial high purity water systems that do not incorporate membrane treatment use a three-step process consisting of acation exchange step, an anion exchange step, and a mixed bed step for polishing the water to high purity.Usually a mixed bed-polishing unit contains strong acid Cation (SAC) resin and strong base Anion (SBA) resins

combined to a ratio of approximately 40% Cation resin to 60% Anion resin. (All resin volumes are dependant upon the incoming water analysis and the required quantity of treated water).

Please note: The Cation resin must be a strong acid Cation type (SAC) and the Anion resin must be a strong base Anion resin (SBA)
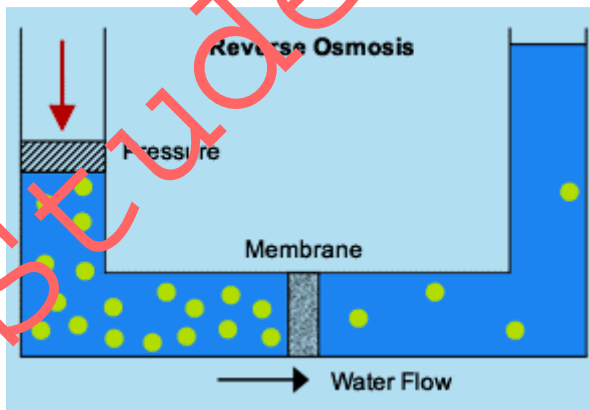
Reverse Osmosis

Osmosis is a physical force. It is the natural tendency of water with a low concentration of dissolved particles to move across a semi-permeable membrane to an area of water with a high concentration of dissolved particles. The water will try to reach equilibrium on both sides. I.e. both sides of the semi-permeable membrane will have the same concentration of dissolved particles. This is how plants absorb nutrients from the soil. The osmosis effect can be found in many places such as blood cells or plant leaves.

Osmosis:
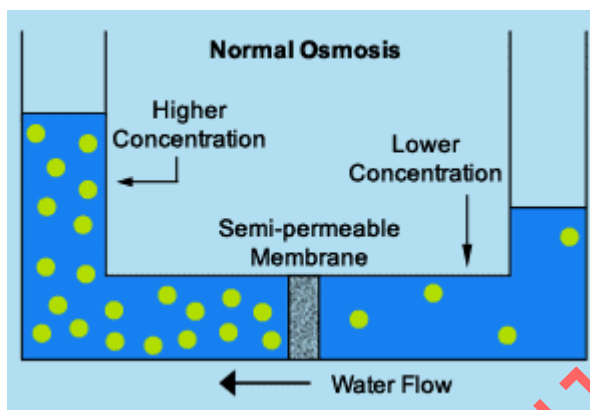
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Reverse Osmosis:

As mentioned before Osmosis is the passage of water through a semi permeable membrane from a dilute solution to a concentrated solution is known as Osmosis. Reverse Osmosis is the reverse of the above, but for water to travel in the opposite direction pressure is applied.

Reverse Osmosis equipment will typically remove everything out of the water except the water itself. Most Reverse Osmosis units now use spiral wound membranes, due to the manufacturing technology moving onward have now become the cheapest membranes on the market.

Electrodialysis:
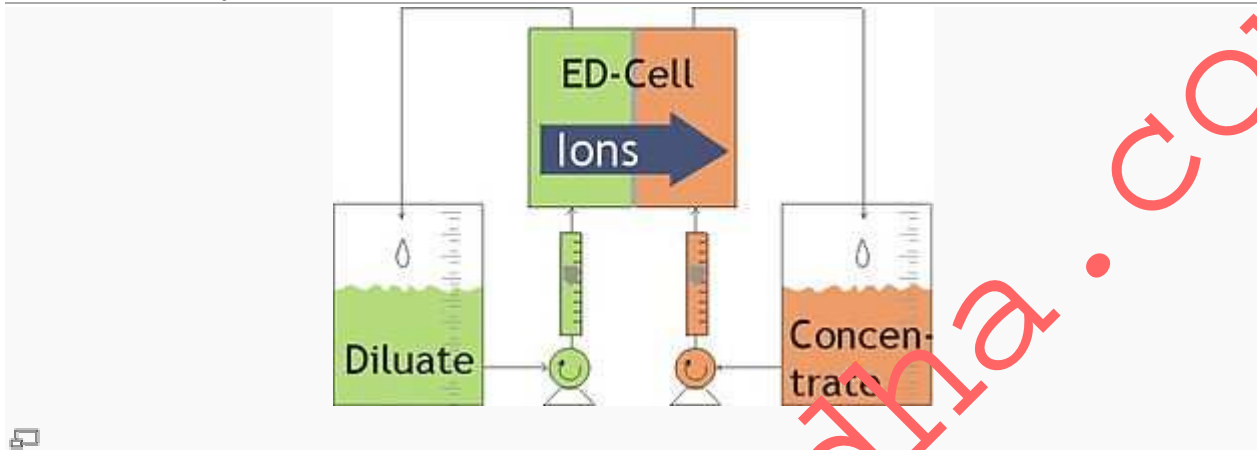
Electrodialysis (**ED**) is used to transport salt ions from one solution through ion-exchange membranes to another solution under the influence of an applied electric potential difference. This is done in a configuration called an electrodialysis cell. The cell consists of a feed (diluate) compartment and a concentrate (brine) compartment formed by an anion exchange membrane and a cation exchange membrane placed between two electrodes. In almost all practical electrodialysis processes, multiple electrodialysis cells are arranged into a configuration called an electrodialysis stack, with alternating anion and cation exchange membranes forming the multiple electrodialysis cells. Electrodialysis processes are different compared to distillation techniques and other membrane based processes (such as reverse osmosis) in that dissolved species are moved away from the feed stream rather than the reverse. Because the quantity of dissolved species in the feed stream is far less than that of the fluid, electrodialysis offers the practical advantage of much higher feed recovery in many applications.

Method
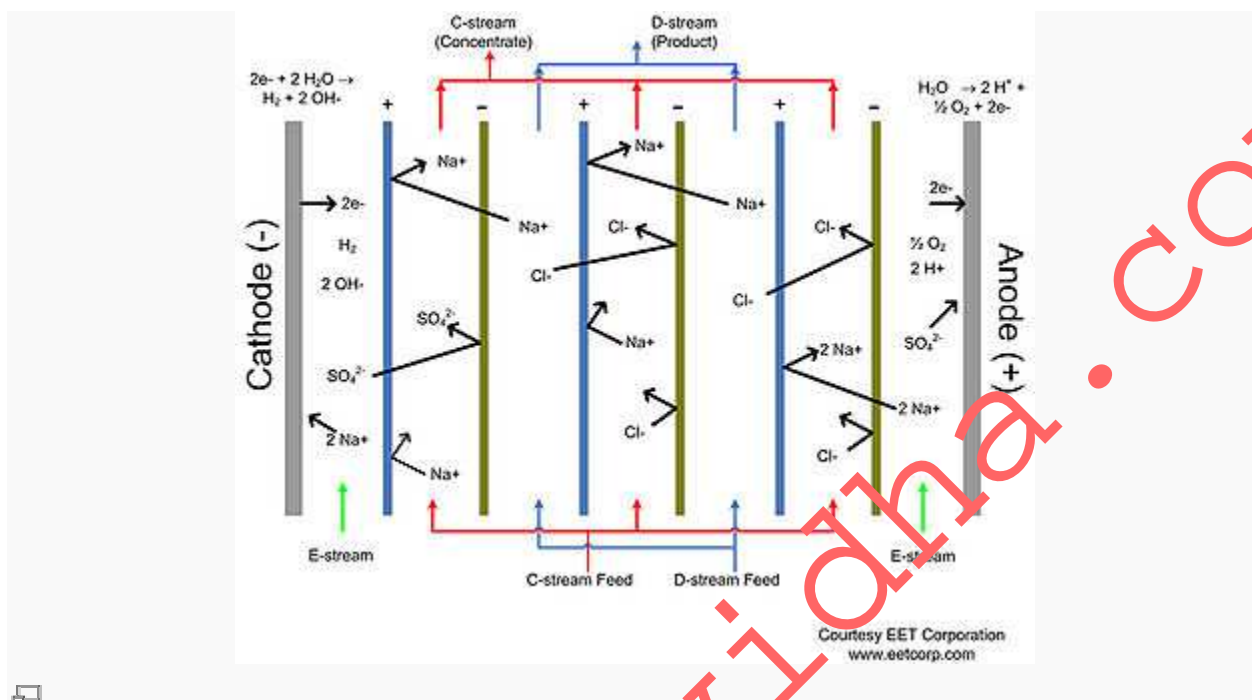
In an electrodialysis stack, the diluate (D) feed stream, brine or concentrate (C) stream, and electrode (E) stream are allowed to flow through the appropriate cell compartments formed by the ion exchange membranes. Under the influence of an electrical potential difference, the negatively charged ions (e.g., chloride) in the diluate stream migrate toward the positively charged anode. These ions pass through the positively charged anion exchange membrane, but are prevented from further migration toward the anode by the negatively charged cation exchange membrane and therefore stay in the C stream, which becomes concentrated with the anions. The positively charged species (e.g., sodium) in the D stream migrate toward the negatively charged cathode and pass through the negatively charged cation exchange membrane. These cations also stay in the C stream, prevented from further migration toward the cathode by the positively charged anion exchange membrane.[As a result of the anion and cation migration, electric current flows between the cathode and anode. Only an equal number of anion and cation charge equivalents are transferred from the D stream into the C stream and so the charge balance is maintained in each stream. The overall result of the electrodialysis process is an ion concentration increase in the concentrate stream with a depletion of ions in the diluate solution feed stream . The E stream is the electrode stream that flows past each electrode in the stack. This stream may consist of the same composition as the feed stream (e.g., sodium chloride) or may be a separate solution containing a different species (e.g.,sodium sulfate).[5] Depending on the stack configuration, anions and cations from the electrode stream may be transported into the C stream, or anions and cations from
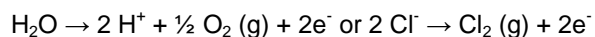
the D stream may be transported into the E stream. In each case, this transport is necessary to carry current across the stack and maintain electrically neutral stack solutions.

Anode and cathode reactions

Reactions take place at each electrode. At the cathode,

$2e^- + 2\ H_2O \rightarrow H_2\ (g) + 2\ OH^-$

while at the anode,
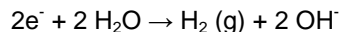
$H_2O \rightarrow 2\ H^+ + \frac{1}{2}\ O_2\ (g) + 2e^-$ or $2\ Cl^- \rightarrow Cl_2\ (g) + 2e^-$

Small amounts of hydrogen gas are generated at the cathode and small amounts of either oxygen or chlorine gas (depending on composition of the E stream and end ion exchange membrane arrangement) at the anode. These gases are typically subsequently dissipated as the E stream effluent from each electrode compartment is combined to maintain a neutral pH and discharged or re-circulated to a separate E tank. However, some (e.g.,) have proposed collection of hydrogen gas for use in energy production.