



CHAPTER 3

Water and Its Treatment

3.0 INTRODUCTION

Water is a very essential part of nature but unluckily it is the most misused one.

Earth's $\frac{4}{5}$ part is covered by water, that is why, it is called blue planet. But most part of earth's water can't be used for drinking purposes because it is part of sea, oceans, glaciers and polar ice caps. It is only 0.3% of world's water resources that can be trapped for domestic, agricultural and industrial use.

3.1 SOURCES OF WATER

Main sources of water can be mainly categorised as :

- (i) Surface water
- (ii) Underground water

(i) **Surface Water.** Water which comes to the surface is called surface water. It is further of different types :

- (a) **Rain Water.** Rain water originates from surface water e.g. rivers, lakes, sea etc. Water from these water bodies gets evaporated upwards because of heat of atmosphere. These water vapours get condensed and come downwards in the form of rain. But on its way downwards, it gets mixed up with many atmospheric impurities e.g. gases, dust etc.
- (b) **River Water.** Rain and spring water flow over surface of land, dissolves minerals of soil and finally meet the rivers. So river water has many soluble and insoluble impurities.
- (c) **Lake Water.** Lake water is another source of surface water. It has quite less amount of dissolved minerals in it.
- (d) **Sea Water.** The rivers join in sea and their water has many impurities. So sea water is most impure water of surface water. Many soluble and insoluble salts are present in sea water.

(ii) **Underground Water.** A part of the rain water which reaches the surface of earth, penetrates into the earth and comes into contact with many soluble and insoluble minerals. Examples of underground water are well water and spring water. Underground water has high organic purity.

3.2 HARDNESS OF WATER

It is that character of water which prevents the lathering of soap. This is due to presence of many salts of calcium, magnesium and other heavy metals in water. Due to presence of these salts, boiling point of water is elevated (increased). Hence more fuel and time is required for cooking and for heating water.

While water which forms lather easily with soap solution is called Soft water. It has no dissolved salts of calcium and magnesium.

Hard water does not form lather with soap instead forms white scum or precipitate of insoluble salts of calcium and magnesium. Soap is actually sodium or potassium salt of higher fatty acids like stearic or palmitic acid. When these salts of soap react with calcium or magnesium salts present in water it forms insoluble salt of calcium or magnesium.

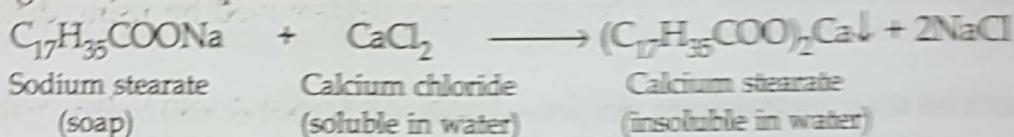


Table 3.1 Difference between hard and soft water

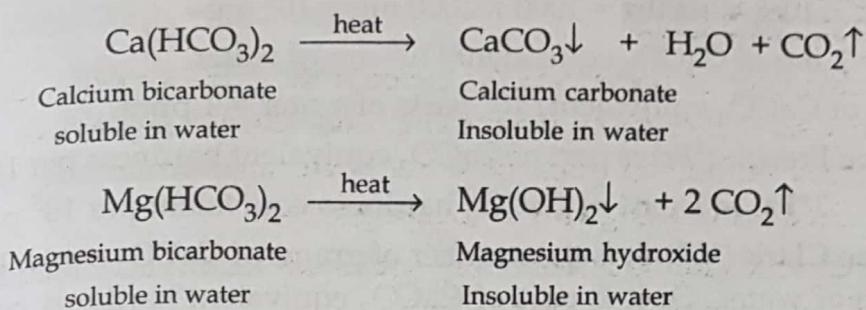
	Hard Water	Soft Water
1.	Water which does not form lather with soap is called hard water.	Water which forms lather easily with soap is called soft water.
2.	Hard water has dissolved salts of Ca and Mg.	Soft water does not have dissolved salts of Ca and Mg.
3.	Because of presence of impurities, boiling temperature of water is increased, because of which, lot of time and fuel go waste for heating water.	Less time and fuel is consumed for heating soft water.
4.	Because of presence of impurities, lot of soap is consumed by hard water.	Soft water consumes less soap for washing and bathing purposes.

3.2.1 Types of Hardness

Hardness of water is of two types :

- (A) Temporary Hardness
- (B) Permanent Hardness

(A) Temporary Hardness. Temporary hardness of water is due to presence of bicarbonate salts of Ca and Mg i.e. calcium bicarbonate and magnesium bicarbonate. These salts are soluble in water. Temporary hardness of water can be removed by process of boiling water. On boiling, these salts gets decomposed to give insoluble salts of Ca and Mg.



Temporary hardness is also called carbonate hardness.

(B) Permanent Hardness. Permanent hardness of water is due to chloride and sulphate of Ca and Mg i.e. Calcium chloride (CaCl_2), Magnesium chloride (MgCl_2), Calcium sulphate (CaSO_4) and Magnesium sulphate (MgSO_4). It cannot be removed by boiling water i.e. why it is called permanent hardness. It can be removed by using different chemical treatments.

Hardness of water is not only caused by Ca and Mg salts but some other salts are also responsible for hardness of water. But only Ca and Mg salts which are most often present in hard water.

3.2.2 Degree of Hardness in terms of Calcium Carbonate

The concentration of hardness as well as non-hardness causing ions are expressed in equivalent amount of calcium carbonate or equivalents of calcium carbonate (CaCO_3). The reason of selecting CaCO_3 as a reference standard is that it is most insoluble salt that can be precipitated in water treatment and molecular mass of CaCO_3 is 100, which makes the calculations easy as in this method multiplication and division of concentration is involved.

Whenever dissolved salts are present in water, these are converted into calcium carbonate equivalents e.g. If water has 20 ppm of $MgCl_2$, then $CaCO_3$ equivalent of this salt is $20 \times \frac{100}{95} = 21.06$ ppm, where 100 is molecular mass of $CaCO_3$ and 95 is molecular mass of $MgCl_2$.

3.2.3 Units of Hardness

Hardness of water can be expressed by using various units as :

- (i) Parts per million (ppm)
 (ii) Milligram per litre (mg/L)
 (iii) Degree french ($^{\circ}$ Fr)
 (iv) Degree clark ($^{\circ}$ Cl)

(i) **Parts per million** is the parts of calcium carbonate equivalent hardness present per 10^6 parts of water i.e. $1 \text{ ppm} = 1 \text{ part of CaCO}_3 \text{ equivalent hardness in } 10^6 \text{ parts of water.}$

(ii) **Milligram per litre** (mg/L) is the number of mg of CaCO_3 equivalent hardness present per litre of water. Thus $1 \text{ mg/L} = 1 \text{ mg of CaCO}_3 \text{ eq. hardness per litre of water weighs.}$

$$1 \text{ kg} = 1000 \text{ g} = 1000 \times 1000 \text{ mg} = 10^6 \text{ mg}$$

$1 \text{ mg/L} = 1 \text{ mg of CaCO}_3 \text{ equivalent}/10^6 \text{ mg of water}$

i.e. 1 part of CaCO_3 equivalent/ 10^6 parts of water = 1 ppm.

(iii) **Degree French (${}^\circ\text{Fr}$)** is part of CaCO_3 equivalent hardness per 10^5 parts of water.
 $1 {}^\circ\text{Fr} = 1 \text{ part of CaCO}_3 \text{ hardness equivalent per } 10^5 \text{ parts of water.}$

(iv) **Degree Clark (${}^\circ\text{Cl}$)**. It is the number of grams of CaCO_3 equivalent hardness per gallon of water. Or it is part of CaCO_3 equivalent hardness per 70,000 parts of water.

$1 {}^\circ\text{Clark} = 1 \text{ gram of CaCO}_3 \text{ eq. hardness per gallon of water}$

$1 {}^\circ\text{Cl} = 1 \text{ part of CaCO}_3 \text{ eq. hardness per 70,000 parts of water.}$

Relationship Among Various Units

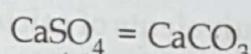
$$1 \text{ ppm} = 1 \text{ mg/L} = 0.1 {}^\circ\text{Fr} = 0.07 {}^\circ\text{Cl.}$$

Solved Numerical Problems

Based on Laws of Hardness

Example 1. Water has 204 mg of CaSO_4 /litre. Calculate the hardness in terms of CaCO_3 equivalents.

Solution.



$$136 \text{ gm} = 100 \text{ gm}$$

$$136 \text{ mg/L of CaSO}_4 = 100 \text{ mg/L of CaCO}_3 \text{ eq.}$$

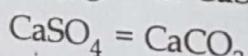
$$204 \text{ mg/L of CaSO}_4 = \frac{100 \text{ mg/L of CaCO}_3 \text{ eq.} \times 204}{136}$$

$$= 150 \text{ mg/L of CaCO}_3 \text{ eq.} = 150 \text{ mg/L or } 150 \text{ ppm.}$$

Hardness = 150 ppm Ans.

Example 2. How many gms of CaSO_4 dissolved/litre gives 210.5 ppm of hardness?

Solution.



$$136 \text{ g} = 100 \text{ g}$$

$$100 \text{ ppm of hardness} = 136 \text{ ppm of CaSO}_4$$

$$210.5 \text{ ppm of hardness} = \frac{136 \times 210.5}{100} = 286.3 \text{ ppm of CaSO}_4$$

$$= 286.3 \text{ mg/L or } 0.2863 \text{ g/L of CaSO}_4$$

Hence 0.2863 g of FeSO_4 dissolved/litre gives 210.5 ppm of hardness. Ans.

Example 3. Calculate temporary and permanent hardness of sample of water having following impurities :

$$\text{Mg}(\text{HCO}_3)_2 = 7.3 \text{ mg/L}$$

$$\text{Ca}(\text{HCO}_3)_2 = 16.2 \text{ mg/L}$$

$$\text{MgCl}_2 = 9.5 \text{ mg/L}$$

$$\text{CaSO}_4 = 13.6 \text{ mg/L}$$

Also calculate total hardness.

$$\text{Solution. Temporary hardness} = 7.3 \times \frac{100}{146} + 16.2 \times \frac{100}{162} \text{ mg/L} = 15 \text{ mg/L}$$

$$\text{Permanent hardness} = \left(9.5 \times \frac{100}{95} + 13.6 \times \frac{100}{136} \right) \text{ mg/L} = 20 \text{ mg/L}$$

$$\begin{aligned}\text{Total hardness} &= \text{Temporary hardness} + \text{Permanent hardness} \\ &= (15 + 20) \text{ mg/L} = 35 \text{ mg/L} = 35 \text{ ppm Ans.}\end{aligned}$$

Example 4. A sample of water has the following impurities in mg/lit. Find the temporary and permanent hardness in ppm.

$$\text{Ca}(\text{HCO}_3)_2 = 10.0 \text{ ppm}; \text{Mg}(\text{HCO}_3)_2 = 8.0 \text{ ppm}; \text{CaSO}_4 = 12.0 \text{ ppm}$$

$$\text{Solution. Hardness due to Ca}(\text{HCO}_3)_2 = 10 \times \frac{100}{162} = 6.2 \text{ ppm}$$

$$\text{Hardness due to Mg}(\text{HCO}_3)_2 = 8 \times \frac{100}{146} = 5.5 \text{ ppm}$$

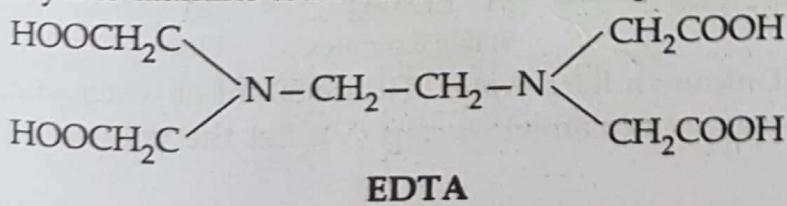
$$\text{Hardness due to CaSO}_4 = 12 \times \frac{100}{136} = 8.8 \text{ ppm}$$

$$\begin{aligned}\text{Temporary hardness} &= \text{Hardness due to Ca}(\text{HCO}_3)_2 + \text{Mg}(\text{HCO}_3)_2 \\ &= 6.2 + 5.5 = 11.7 \text{ ppm}\end{aligned}$$

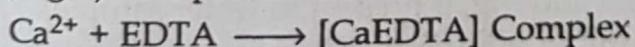
$$\text{Permanent hardness} = \text{Hardness due to CaSO}_4 = 8.8 \text{ ppm}$$

3.2.4 Estimation of hardness by EDTA Method

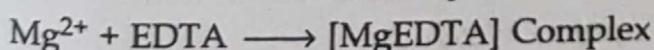
EDTA is ethylene diamine tetra-acetic acid. It is represented as :



When hard water is treated with EDTA, it forms stable complex ion with calcium (Ca^{2+}) or magnesium (Mg^{2+}) ions present in hard water.



stable complex

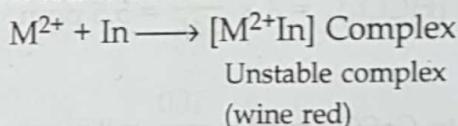


stable complex

EDTA is treated with hard water in presence of Eriochrome black-T. Different steps involved in the process of determination of hardness of water by using EDTA are :

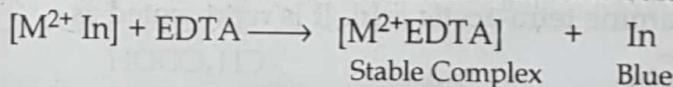
- (i) **Preparation of standard hard water.** Dissolve 1 g of pure dry CaCO_3 in minimum quantity of dilute HCl and evaporate the solution to dryness on a water bath. Dissolve the residue in distilled water to make 1 litre solution. Each ml of this solution has 1 mg of CaCO_3 equivalent hardness.
- (ii) **Preparation of EDTA solution.** Dissolve 4 g of pure EDTA crystal and 0.1 g MgCl_2 in 1 L of distilled water.
- (iii) **Preparation of Indicator.** Dissolve 0.5 g of Eriochrome black-T in 100 ml of alcohol.
- (iv) **Preparation of Buffer solution.** Add 67.5 g of NH_4Cl to 570 ml of concentrated ammonia solution and then dilute with distilled water to 1 litre.
- (v) **Standardization of EDTA solution.** Rinse and fill the burette with EDTA solution, pipette out 50 ml of standard hard water sample in a conical flask. Add 10-15 ml of buffer solution and 4 to 5 drops of indicator, wine red colour appears. Titrate with EDTA solution, till wine red colour changes to clear blue. Let the volume be used V_1 ml.

When indicator Eriochrome black-T is added to water sample, it reacts with metal ions M^{2+} (Ca^{2+} and Mg^{2+} ions) in the basic conditions to form an unstable complex, wine red in colour.



This is the reason that wine red colour appears. But this unstable complex is formed only in basic/alkaline conditions. To get these type of conditions, buffer is to be added to sample of water, before adding indicator.

When this is treated with EDTA, (i.e. when EDTA solution is added dropwise from burette to the sample having buffer solution and indicator), it forms a stable complex with metal ions and indicator is released. Hence the sample gives blue colour as indicator released is of blue colour.



- (vi) **Titration of Unknown hard water.** Titrate 50 ml of water sample with EDTA in the same way as explained in step (V). Let the volume be used of EDTA V_2 ml.
- (vii) **Titration of permanent hardness.** Take 250 ml of water sample in a beaker. Boil it, till volume is reduced to 50 ml (This heating is done to decompose bicarbonates of Ca and Mg, if present in water sample). Filter the sample. Make the volume 250 ml by adding distilled water. From this take 50 ml of sample and titrate it with EDTA in the same way as done in step (v). Let the volume of EDTA used be V_3 ml.

Calculations

50 ml of standard hard water = V_1 ml of EDTA

50×1 mg of CaCO_3 = V_1 ml of EDTA

1 ml of EDTA = $50/V_1$ mg of CaCO_3 eq.

50 ml of given hard water = V_2 ml of EDTA

$$= \frac{V_2 \times 50}{V_1} \text{ mg of } \text{CaCO}_3 \text{ eq.}$$

1 litre (1000 ml) of given hard water = $1000 V_2/V_1$ mg of CaCO_3 eq.

Total hardness = $1000 V_2/V_1$ mg/L

$$= 1000 V_2/V_1 \text{ ppm}$$

50 ml of boiled water = V_3 ml of EDTA

$$= V_3 \times \frac{50}{V_1} \text{ mg of } \text{CaCO}_3 \text{ eq.}$$

1000 ml of boiled water = $1000 V_3/V_1$ mg of CaCO_3 eq.

Permanent hardness = $1000 V_3/V_1$ ppm

Temporary hardness = Total hardness - Permanent hardness

$$= 1000 \frac{V_2}{V_1} - \frac{V_3}{V_1} \text{ ppm}$$

$$\boxed{\text{Temporary hardness} = \frac{1000(V_2 - V_3)}{V_1} \text{ ppm}}$$

EDTA method gives accurate results and is a rapid and convenient process to find hardness.

3.3 DISADVANTAGES OF HARD WATER IN DOMESTIC AND INDUSTRIAL USES

3.3 (a) Disadvantages of Hard water in Domestic use

As we know that hard water has dissolved salts of calcium and magnesium in it. These salt impurities in water creates problems when this water is used for domestic consumption as :

(i) **Bathing.** When hard water is used for bathing, lot of water goes waste. This is so because it does not form lather with soap instead it forms a sticky scum. So to remove this sticky scum, lot of water is used.

(ii) **Washing.** Hard water does not form lather with soap, instead forms a sticky scum i.e. precipitate of calcium and magnesium with soap. This scum sticks to

the clothes and hence spoils the clothes. Hard water keeps on forming sticky precipitates of Ca and Mg till whole of the Ca and Mg in water is consumed in the form of sticky ppts. Then after soap starts giving lather with water. In this way, a lot of soap/detergent goes waste.

- (iii) **Cooking.** Due to presence of dissolved salts of Ca and Mg in water, boiling point of water is elevated. Because of it more heat/fuel and time is consumed. Moreover the dissolved salts are deposited as carbonates on the inner walls of the water heating utensils.

3.3(b) Disadvantages of Hard water in Industries

Textile Industry, Sugar industry, Dyeing industry, Paper industry, Laundry, Pharmaceutical industry etc. are main consumers of water as far as industrial use of water is concerned. Use of hard water adversely affects these industries.

Boiler Feed Water

For steam generation boilers are used. If hard water is fed to the boilers, then many troubles are to be faced. These are :

3.3.1 Scale and sludge formation

3.3.2 Caustic Embrittlement

3.3.3 Boiler Corrosion

3.3.4 Priming and Foaming

3.3.1 Scale and Sludge Formation in Boilers

Boilers are used for the production of steam. When the hard water is directly fed into water, it leads to formation of scales and sludge.

How Sludge and Scales are Formed

In the boilers, water evaporates continuously and concentration of salts dissolved in water increases. It reaches a saturation point forming precipitates on the inner walls of the boiler.

If the precipitates are in the loose and slimy form, it is called **sludge** and if the precipitates are in the hard and **adhering coat** form, then it is called **scale**.

Sludge

Sludge is actually formed by substances which have greater solubility in the hot water than cold water e.g. $MgCO_3$, $MgCl_2$, $CaCl_2$, $MgSO_4$ etc.

Removal of Sludge. Sludge can be removed from the boiler by using wire brush. It is formed at that position of boiler, where flow of water is slow and relatively colder parts of the boiler.

Disadvantages of Sludge

1. It is a poor conductor of heat and hence lot of time and fuel is needed.
2. It disturbs the functioning of the boiler. It settles in the regions of poor water circulation (such as pipe connection, plug opening, gauze-glass connection) and may lead to even chocking of pipe.

Prevention of Sludge Formation

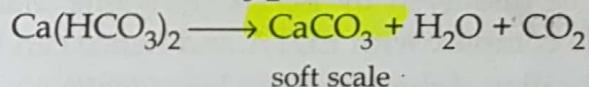
1. By using soft water.
2. By using blow down pipe operation i.e. partial removal of hard and concentrated water through a tap at the bottom of boiler. After blow down operation, soft water is added to the boiler from the top.

Scales

This is hard, adhered deposit on inner surface of boiler.

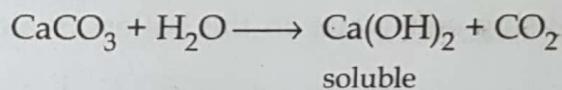
Formation of Scale is due to

Decomposition of different salts present in water as explained :

1. Decomposition of $\text{Ca}(\text{HCO}_3)_2$ present in water.

CaCO_3 is insoluble in water.

Soft scale is formed in low pressure boiler. But in high pressure boiler, CaCO_3 is soluble in water.

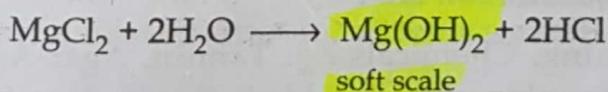


Soft scale can be easily removed by blow down process.

2. Deposition of Calcium sulphate (CaSO_4). This is **soluble in cold water**.

As temperature increases, solubility of CaSO_4 decreases in water. Hence CaSO_4 gets ppted. as **hard scale** on the heated-portion of boiler.

This is the main cause of scale formation in **high-pressure boilers**.

3. Hydrolysis of Magnesium Salts. Magnesium chloride (MgCl_2) undergoes hydrolysis in water as shown :

It leads to deposition of **soft scales**. Soft scale can be easily removed by blow down process.

4. Presence of Silica (SiO_2). Silica react with Ca and Mg present in hard water to form **Calcium silicate and Magnesium silicate**. These silicates stick to the inner wall of the boiler.*Advantages of Scale formation*

1. **Fuel Wastage.** Scales are bad conductors of heat so a lot of fuel and time is wasted to heat water.

2. **Lowering of Boiler Safety.** Due to deposition of scales in boiler, overheating of the boiler is to be done to get steam from water and hence boiler body become weak and it leads to **distortion of boiler body** and boiler tube.
3. **Decreased efficiency.** Scale may choke valve and condenser of boiler. This decreases efficiency of the boiler.
4. **Danger of explosion.** When thick scales crack due to uneven expansion, water comes in contact with over heated iron plate. This leads to **formation of large amount of steam and sudden pressure may develop, which may cause explosion.**

Removal of Scale

Scale can be removed by :

1. Using wire brush and scratching the scale.
2. Thermal shocks can be given i.e. by heating the boiler and then suddenly cooling it.
3. **Chemicals.** It can also be used to remove scales.
 CaCO_3 scales can be dissolved by using 5-10% HCl
 CaSO_4 scales can be dissolved by EDTA (Ethylene diamine tetra-acetic acid). Scale forms soluble complex with EDTA and hence can be removed.
4. By blow down operation if the scales are loose (soft).

Prevention of Scale formation

Prevention is always better than cure. Scale can be prevented by using :

(i) **External treatment.** By using soft water in the boilers, scale formation can be avoided.

(ii) **Internal treatment (sequestration).**

In this method, a ion is prohibited to show its original character by adding appropriate reagent, which :

(a) May convert scale to sludge which can be blown out.

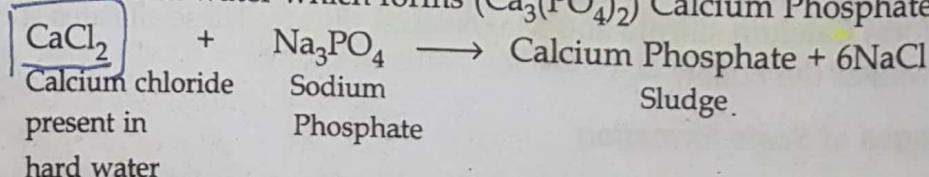
(b) May convert the scale to salt which are soluble in water.

These salts remain in water and cause no harm.

Different methods used for Sequestration are :

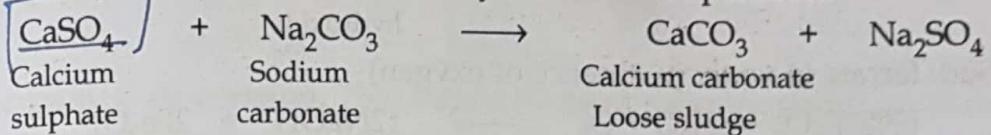
(a) **Colloidal Conditioning.** Chemicals e.g. Tannin, Agar-Agar which form a coating on the scale forming ppt. are added. This leads to formation of sticky and loose deposit which can be removed by blow down process.

(b) **Phosphate Conditioning.** In high pressure boilers, sodium phosphate (Na_3PO_4) is added to hard water which forms $(\text{Ca}_3(\text{PO}_4)_2)$ Calcium Phosphate as :



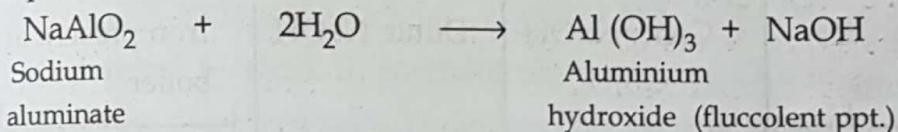
Calcium phosphate is sludge and removed by blow-down process.

- (c) **Carbonate Conditioning.** For scale forming CaSO_4 , Na_2CO_3 (sodium carbonate) is added to hard water. It converts calcium sulphate into calcium carbonate (loose scale) which can be removed by blow-down operation.

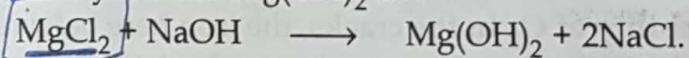


- (d) **Calgon Conditioning.** In this method, scale forming salts are converted into highly soluble complexes which are not easily ppted. on heating water. Calgon (sodium hexa metaphosphate) i.e. $\text{Na}_2[\text{Na}_4(\text{PO}_3)_6]$ is added to hard water e.g.
- $$\text{CaSO}_4 + \text{Calgon} \longrightarrow \text{Soluble complex of Ca ions}$$
- (hard water)

- (e) **Treatment with sodium aluminate.** Silica can be removed by using coagulant e.g., sodium aluminate, $\text{FeSO}_4 \cdot 2\text{H}_2\text{O}$ etc. These releases Al(OH)_3 and Fe(OH)_3 which can trap silica particles :



The NaOH , so formed precipitates some of Mg salts of hard water as magnesium hydroxide Mg(OH)_2 as :



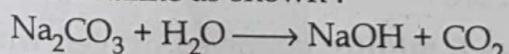
Later on Mg(OH)_2 are removed by blow-down process.

- (f) **Electrical Conditioning.** Electric discharge is passed through water, which prevent scale formation.
- (g) **Radioactive Conditioning.** Tablets having radioactive salts are added. These emit radiation of energy and prevent scale formation.
- (h) **Complexometric method.** Phosphate conditioning methods fail to prevent the deposition of iron oxide but this method checks it and prevents the boiler from wet corrosion. EDTA binds with scale forming cations and forms stable and soluble complexes which can be removed by **Blow-down** process.

3.3.2 Caustic Embrittlement

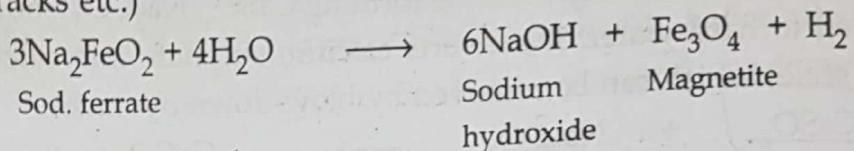
This is a type of boiler corrosion, which is caused by using **alkaline water** (water basic in nature i.e. water having $\text{pH} > 7$) in boiler.

Alkali in the water comes while doing **softening of water**. For softening of water Na_2CO_3 is added to react with dissolved Ca and Mg salts. Some unreacted Na_2CO_3 in water makes water alkaline as shown :

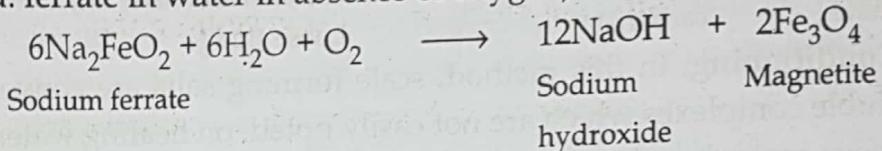


NaOH so formed in water makes water alkaline or **caustic**. In the **inner wall of boiler hair cracks are always present**. This NaOH moves through the **capillary action** from these hair cracks into the body of the boiler. As water evaporates concentration of NaOH increases and hence NaOH moves to the body of the boiler. It dissolves iron from the body of boiler as sodium ferrate.

This is called embrittlement of the boiler parts, particularly stressed parts (bends, joints, rivets, cracks etc.)



(Sod. ferrate in water in absence of oxygen)

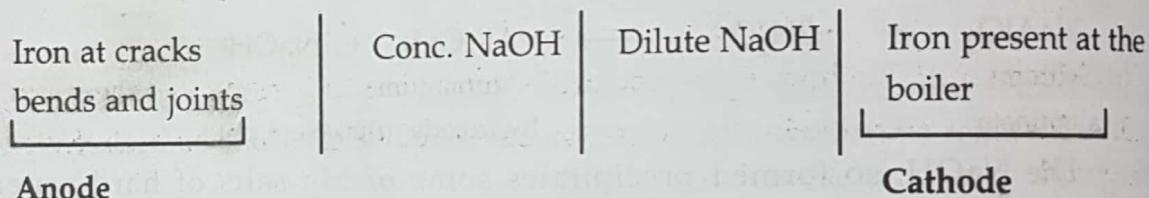


(Sod. ferrate in water in presence of oxygen)

NaOH is regenerated and magnetite is precipitated.

It can be seen that in both the processes, NaOH is regenerated and magnetite is precipitated out.

Caustic embrittlement can be explained as :



Due to non-availability of O_2 in the cracks, the iron here behaves as anode. Boiler walls behave as cathode. Therefore, Iron in the cracks undergo oxidation and gets corroded.

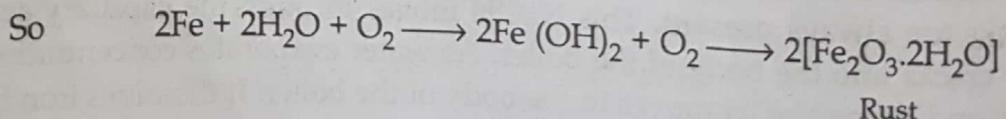
Prevention of Caustic Embrittlement

- (i) By not using Na_2CO_3 for softening of water. Instead sodium phosphate should be used.
 - (ii) By adding Tannin or Lignin to water because these **block the hair line cracks**.
 - (iii) By adding sod. sulphate (Na_2SO_4). It also **blocks the cracks**. The conc. of Na_2SO_4 should be so that the $\frac{\text{Na}_2\text{SO}_4 \text{ conc.}}{\text{NaOH conc.}} = 1 : 1, 2 : 1 \text{ or } 3 : 1$ at pressure upto 10, 20 and above 20 atmosphere respectively.

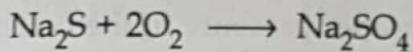
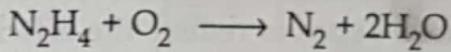
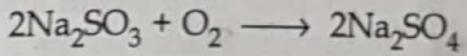
3.3.3 Boiler Corrosion

This leads to deterioration of the boiler body by **chemical or electrochemical attack by its environment**. Main reasons for it are :

1. Dissolved O₂ (D.O.). Water has 8 ml/litre dissolved oxygen which attack the boiler body as the boiler is made up of iron.



Removal of D.O. (a) By adding sodium sulphite (Na_2SO_3) or hydrazine (N_2H_4) or sod. sulphide (Na_2S) because all these consume O_2 by reacting, as :



(b) By mechanical de-aeration. That means by using vacuum-pump, air is removed from water mechanically.

2. **Dissolved CO_2 .** CO_2 in water, reacts with water to form carbonic acid as :

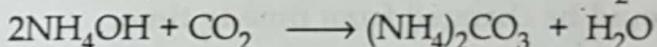


Carbonic acid

Carbonic acid has corrosive effect on the boiler body.

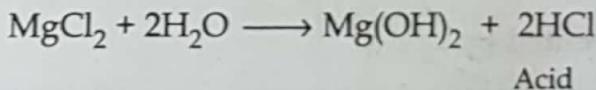
Removal of CO_2

(i) By adding ammonia, because ammonia absorbs CO_2 as shown :

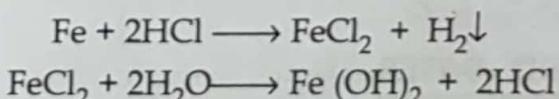


(ii) Mechanical Method. By mechanically removing CO_2 using vacuum pump.

3. **Acids from dissolved salts.** Water has dissolved salts, which on hydrolysis i.e. on reacting with water, release acid as :



This acid (HCl) reacts with the boiler body's iron in a chain reaction to produce HCl again.



So, the presence of a small amount of MgCl_2 may cause corrosion to a large extent.

Removal. Mineral salts can be removed by adding alkali. If pH of boiler water is 10.5, acid will not attack the boiler wall.

3.3.4 Priming and Foaming

When the boiler is steaming.

(a) Some particles of the liquid water are carried along with the steam, which makes wet steam, the process being called Priming.

- Cause.**
- (i) Presence of dissolved solids.
 - (ii) High steam velocity.
 - (iii) Sudden boiling.
 - (iv) Sudden increase in steam production.

(b) **Foaming.** Formation of bubbles or foam in the boiler continuously is called foaming.

Cause. If oil is present, it decreases surface tension of water.

Priming and foaming usually occur together.

Disadvantages of Priming and Foaming

1. Salts which are dissolved in water pass onto steam and then to the different parts where the steam goes i.e. to **turbine blades** where these salts get deposited as water evaporates. These deposits reduce the efficiency of the engine.
2. It is difficult to maintain proper pressure in the boiler.
3. The boiling point of water is increased which results in wastage of fuel.
4. Actual water level can't be accessed in the presence of foam.
5. Due to foaming, bubbles are carried along with steam to the engine. Hence it decreases the efficiency of the engine.

Prevention

Priming can be prevented by taking the following precautions :

- ✓ 1. Priming forming substances should be removed.
- ✓ 2. Scale/Sludge should be removed from time to time.
- ✓ 3. Boiler water should be changed from time to time.
- ✓ 4. Water level should be maintained at the lower level.
- ✓ 5. Fitting mechanical steam purifiers.
- ✓ 6. Avoid rapid change in the steaming rate.

Foaming can be prevented by :

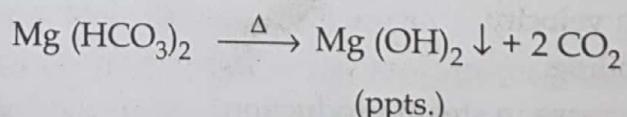
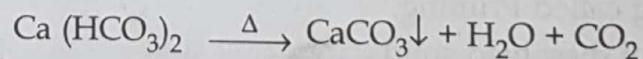
1. Using antifoaming agents e.g. castor oil.
2. Removing oil from boiler water by adding chemicals like **sodium aluminate**.

3.4 SOFTENING OF HARD WATER

Softening of hard water means removal of Ca and Mg soluble salts from water. It can be done by different methods. Important methods are discussed ahead.

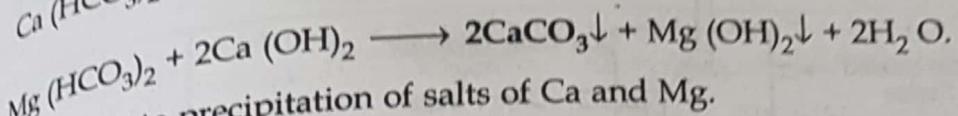
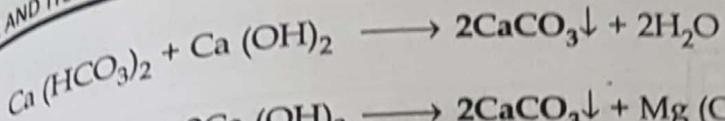
3.4.1 Removal of Temporary Hardness

(a) **By Boiling.** Temporary hardness is due to bicarbonates of Ca and Mg. It can be removed simply by boiling the hard water, as the **soluble bicarbonates** get decomposed to insoluble carbonates and hydroxides of Ca and Mg respectively.



The precipitates can be removed by filtration.

(b) **Clark's Method.** By treating water with **calculated amount of lime** $[\text{Ca}(\text{OH})_2]$.



It results into precipitation of salts of Ca and Mg.

3.4.2 Removal of Permanent Hardness

1. Lime soda Process

This method involves the treatment of water with lime $[\text{Ca}(\text{OH})_2]$ and soda (Na_2CO_3) , which results in the formation of **insoluble precipitates** of Ca and Mg, which can be removed by filtration.

(a) Cold lime soda process

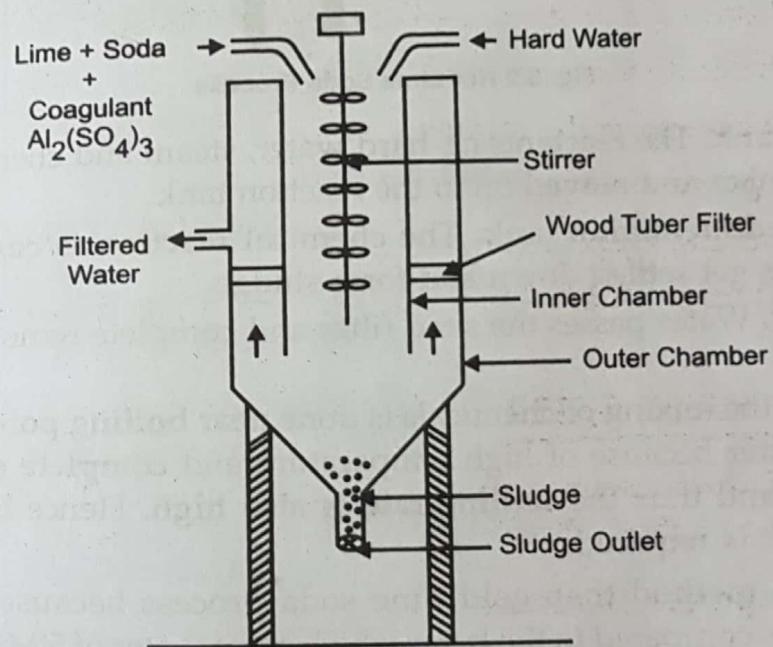


Fig. 3.1 Continuous cold lime soda process

Hard water is fed from top to inner vertical circular chamber fitted with stirrer. Calculated amount of lime and soda are added in this tank at room temperature. A small amount of coagulant $\text{Al}_2(\text{SO}_4)_3$ is added which entraps the fine impurities and thereby speeding up the process of sedimentation. Stirrers are there to cause proper mixing for upward and is passed through the outlet.

(b) Hot lime soda process

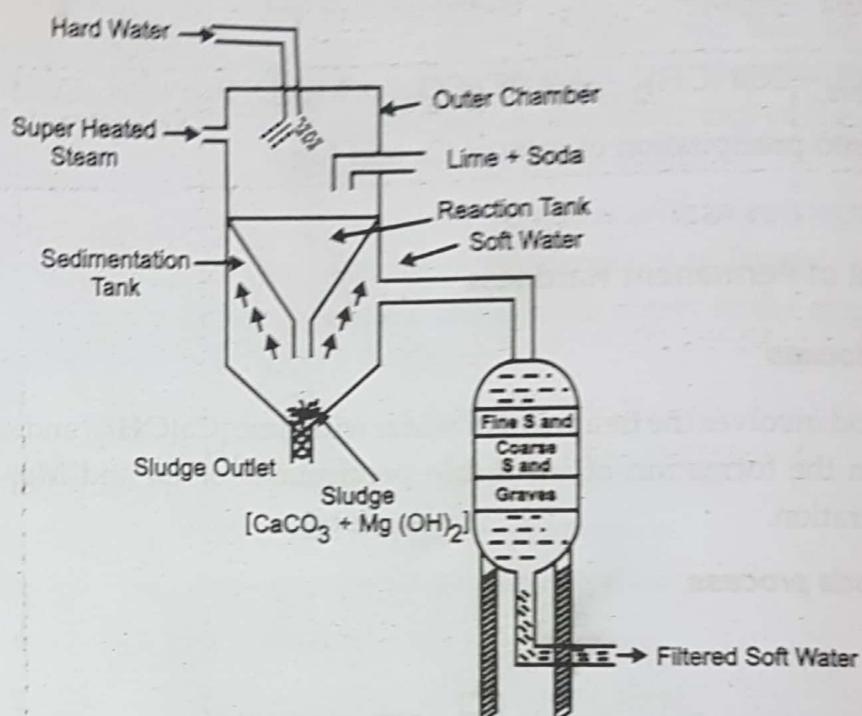


Fig. 3.2 Hot Lime Soda Process

- Reaction tank.** The reactants i.e. hard water, steam and chemicals are mixed in outer chamber and moved on to the reaction tank.
- Conical sedimentation tank.** The chemical reaction is completed here. The precipitates get settled down and form sludge.
- Sand filter.** Water passes the sand filter and complete removal of sludge takes place.

In this process, the mixing of chemicals is done near boiling point of water. Rate of reaction becomes faster because of high temperature and complete precipitation takes place more quickly and thus the settling rate is also high. Hence like cold lime soda process, no coagulant is required.

This is a better method than cold lime soda process because it gives water of 15-20 ppm hardness as compared to the latter which gives water of 50-60 ppm of hardness.

Difference between Cold and Hot lime Soda Method

Cold Lime-Soda Method	Hot Lime-Soda Method
1. It is carried out at room temperature	1. It is carried out at high temperature almost at b.pt. of water.
2. It is a slow process.	2. It is a fast process.
3. Coagulant $\text{Al}_2(\text{SO}_4)_3$ is added.	3. No need of coagulant.
4. Dissolved gases are not removed.	4. Dissolved gases are removed.
5. Water obtained is not very soft. The hardness content in water is around 60 ppm.	5. Water obtained is soft of hardness 15-20 ppm.

Table 3.2. Different impurities that can be removed from water by using lime soda process (Different chemical reactions involved are given below).

Impurity (Mole wt.) (Molecular Weight)	Reaction Involved	Requirement	Factor for CaCO_3 equivalent
$\text{Ca}(\text{HCO}_3)_2$ (162) Temp. impurity	$\text{Ca}(\text{HCO}_3)_2 + \text{Ca}(\text{OH})_2 \longrightarrow 2\text{CaCO}_3 \downarrow + 2\text{H}_2\text{O}$	L	$\frac{100}{162} \times 1$
$\text{Mg}(\text{HCO}_3)_2$ (146) Temp. impurity	$\text{Mg}(\text{HCO}_3)_2 + \text{Ca}(\text{OH})_2 \longrightarrow \text{Mg}(\text{OH})_2 \downarrow + \text{Ca}(\text{HCO}_3)_2$	2L	$\frac{100}{140} \times 2$
CaCl_2 (111) Perm. imp.	$\text{Ca}(\text{HCO}_3)_2 + \text{Ca}(\text{OH})_2 \longrightarrow 2\text{CaCO}_3 \downarrow + 2\text{H}_2\text{O}$		
CaSO_4 (136) Perm. Ca	$\text{CaCl}_2 + \text{Na}_2\text{CO}_3 \longrightarrow \text{CaCO}_3 \downarrow + 2\text{NaCl}$	S	$\frac{100}{111}$
MgCl_2 (95) Perm. imp.	$\text{CaSO}_4 + \text{Na}_2\text{CO}_3 \longrightarrow \text{CaCO}_3 + \text{Na}_2\text{SO}_4$	S	$\frac{100}{136}$
MgSO_4 (120) Perm. Imp.	$\text{MgCl}_2 + \text{Na}_2\text{CO}_3 \longrightarrow \text{MgCO}_3 + 2\text{NaCl} \quad \dots(1)$	L+S	$\frac{100}{95}$
$\text{Al}_2(\text{SO}_4)_3$ (342) Coagulant	$\text{MgCO}_3 + \text{Ca}(\text{OH})_2 \quad \dots(2)$ $1+2 = \text{Mg}(\text{OH})_2 \downarrow + \text{CaCO}_3 \downarrow$ $\text{MgCl}_2 + \text{Ca}(\text{OH})_2 + \text{Na}_2\text{CO}_3$ $\longrightarrow \text{Mg}(\text{OH})_2 + \text{CaCO}_3 + 2\text{NaCl}$ $\text{MgSO}_4 + \text{Na}_2\text{CO}_3 \quad \dots(1)$ $\longrightarrow \text{MgCO}_3 + \text{Na}_2\text{SO}_4 \quad \dots(1)$ $\text{MgCO}_3 + \text{Ca}(\text{OH})_2$ $\longrightarrow \text{Mg}(\text{OH})_2 + \text{CaCO}_3 \downarrow$ $1+2 = \text{MgSO}_4 + \text{Na}_2\text{CO}_3 + \text{Ca}(\text{OH})_2$ $\text{MgSO}_4 + \text{Na}_2\text{CO}_3 + \text{Ca}(\text{OH})_2$ $\longrightarrow \text{Mg}(\text{OH})_2 + \text{Na}_2\text{SO}_4 + \text{CaCO}_3$ $\text{Al}_2(\text{SO}_4)_3 + 3\text{Ca}(\text{OH})_2 \quad \dots(1)$ $\longrightarrow 2\text{Al}(\text{OH})_3 + 3\text{CaSO}_4$ $\text{CaSO}_4 + \text{Na}_2\text{CO}_3 \quad \dots(2)$ $1+2 = \text{CaCO}_3 + \text{Na}_2\text{SO}_4] \times 3$ $\text{Al}_2(\text{SO}_4)_3 + 3\text{Ca}(\text{OH})_2 + 3\text{Na}_2\text{CO}_3$ $\longrightarrow 2\text{Al}_2(\text{OH})_3 + 3\text{CaCO}_3 + 3\text{Na}_2\text{SO}_4$	L+S	$\frac{100}{120}$ $\frac{100}{342} \times 3$

Impurity (Mole wt.) (Molecular Weight)	Reaction Involved	Requirement	Factor for CaCO ₃ equivalent
H ⁺ (1) HCl or H ₂ SO ₄	2H ⁺ + Ca(OH) ₂ → Ca ²⁺ + 2H ₂ O ... (1) Ca ²⁺ + Na ₂ CO ₃ → CaCO ₃ + 2Na ⁺ ... (2) 1 + 2 = 2H ⁺ + Ca(OH) ₂ + Na ₂ CO ₃ → CaCO ₃ ↓ + 2H ₂ O + 2Na ⁺	$\frac{1L}{2} + \frac{1S}{2}$	$\frac{100}{1} \times \frac{1}{2}$
CO ₂ (44)	CO ₂ + Ca(OH) ₂ → CaCO ₃ ↓ + H ₂ O	L	$\frac{100}{44}$
H ₂ S (34)	H ₂ S + Ca(OH) ₂ → CaS↓ + 2H ₂ O	L	$\frac{100}{34}$
NaHCO ₃ (84) or HCO ⁻ ₃	2 NaHCO ₃ + Ca(OH) ₂ → CaCO ₃ + Na ₂ CO ₃ + 2H ₂ O	$\frac{1L}{2} - \frac{1S}{2}$	$\frac{100}{84} \times \frac{1}{2}$
NaAlO ₂ (182)	NaAlO ₂ + 2H ₂ O → Al(OH) ₃ ↓ + NaOH [as 1 NaOH = $\frac{1}{2}$ Ca(OH) ₂]	$-L \times \frac{1}{2}$	$\frac{100}{82} \times \frac{1}{2}$
FeSO ₄ · 7H ₂ O (278)	FeSO ₄ + Ca(OH) ₂ → Fe(OH) ₂ + CaSO ₄] × 2 ... (1) .Fe(OH) ₂ + H ₂ O + [0] → 2Fe(OH) ₃ ↓ ... (2) CaSO ₄ + Na ₂ CO ₃ → CaCO ₃ ↓ + Na ₂ SO ₄ ... (3) 1+2+3 = 2FeSO ₄ + 2Ca(OH) ₂ + 2Na ₂ CO ₃ + H ₂ O + [0] → 2Fe(OH) ₃ + 2CaCO ₃ + 2Na ₂ SO ₄	L + S	$\frac{100}{278}$

The table shows different impurities present in water which can be removed by using lime soda process. This process in addition to the removal of hardness-causing ions and salts also removes some other (non-hardness producing) impurities also, e.g. CO₂, H⁺, Al₂(SO₄)₃, NaAlO₂ etc. This table is used for calculating amount of lime and soda required for removal of certain impurities from the water sample. The first column is of the impurities present in water sample, the second column gives the chemical reaction of the impurity with either lime, soda or lime and soda both. It depends how a soluble salt of Ca or Mg is converted to its insoluble salt.

For other impurities e.g. NaAlO₂; which is actually a coagulant added in cold Lime Soda process. In water it undergoes hydrolysis to form insoluble ppt of aluminium hydroxide and simultaneously NaOH is also generated.

As Ca(OH)₂ i.e. lime provides OH ions for conversion of Mg salt into insoluble Mg(OH)₂ NaOH can also provide OH⁻ ions for the same purpose. This is so because NaOH is a strong base like Ca(OH)₂

In water softening a lime is added to water but if sodium aluminate is present in water then less equivalent of lime is needed as shown in the equation given in the table. So produced NaOH automatically do the softening. 1 molecule of $\text{Ca}(\text{OH})_2$ can release two OH^- ions but 1 molecule of NaOH releases only one OH^- ion so 1 mole of NaOH =

$$\frac{1}{2} \text{Ca}(\text{OH})_2$$

The next column gives the requirement i.e. for conversion into insoluble salt, what is required in the chemical reaction. L represents lime only, S represents soda only and L + S represents lime and soda both. Negative sign with L or S means that it is produced in the chemical reaction and not utilized. The fourth column is of CaCO_3 equivalent. Every impurity of water is reported as CaCO_3 eq. Hence here also given impurity is converted into its CaCO_3 equivalent factor.

Formula for Calculations

100 parts by mass of $\text{CaCO}_3 \equiv 74$ parts by mass of $\text{Ca}(\text{OH})_2$.

100 parts by mass of $\text{CaCO}_3 = 106$ parts by mass of Na_2CO_3 .

100 = Molecular mass of CaCO_3 .

74 = Molecular mass of $\text{Ca}(\text{OH})_2$.

106 = Molecular mass of Na_2CO_3 .

For solving a numerical, first the impurities are converted into their CaCO_3 equivalents and then their requirements are listed as :

Impurities mg/l	CaCO_3 equivalent	Requirement	Lime mg/l	Soda mg/l
Impurity I $= x_1 \text{ mg/l}$	$\frac{\text{Mol. wt. of } \text{CaCO}_3}{\text{Mol. wt. of impurity 1}} \times x_1$ $= y_1$	let (L + S)	y_1	y_1
Impurity II $= x_2 \text{ mg/l}$	$\frac{\text{Mol. wt. of } \text{CaCO}_3}{\text{Mol. wt. of impurity 2}} \times x_2$ $= y_2$	let $\frac{1}{2}\text{L} - \frac{1}{2}\text{S}$	$\frac{y_2}{2}$	$-\frac{y_2}{2}$
Total			$y_1 + \frac{y_2}{2}$	$y_1 + \left(-\frac{y_2}{2}\right)$

100 parts of $\text{CaCO}_3 = 74$ parts of lime

$$1 \text{ part of } \text{CaCO}_3 = \frac{74}{100} \text{ parts of lime}$$

$$y_1 + \frac{y_2}{2} \text{ parts of } \text{CaCO}_3 \text{ equivalent} = \frac{74}{100} \times y_1 + \frac{y_2}{2} \text{ parts of lime (mg/l)}$$

Likewise, for soda,

$$100 \text{ parts of } \text{CaCO}_3 = 106 \text{ parts of soda}$$

$$1 \text{ part of } \text{CaCO}_3 = \frac{106}{100} \text{ parts of soda}$$

$$y_1 - \frac{y_2}{2} \text{ parts of } \text{CaCO}_3 \text{ equivalent} = \frac{106}{100} \times y_1 - \frac{y_2}{2} \text{ parts of lime. So the formula}$$

for calculation of lime and soda :

Lime requirement

$$= \frac{74}{100} \times y_1 + \frac{y_2}{2} \times \text{vol. of water} \times 100\% \text{ purity of lime}$$

$$= \frac{74}{100} \times y_1 + \frac{y_2}{2} \times \text{vol. of water} \times \frac{100}{100} \text{ mg}$$

Soda requirement

$$= \frac{106}{100} \times y_1 - \frac{y_2}{2} \times \text{vol. of water} \times 100\% \text{ purity of soda}$$

$$= \frac{106}{100} \times y_1 - \frac{y_2}{2} \times \text{vol. of water} \times \frac{100}{100} \text{ mg}$$

Solved Numerical Problems

Numerical 1. Calculate the amount of lime and soda required for softening of 25,000 litres of water which was analysed as follows :

$\text{Ca}(\text{HCO}_3)_2 = 4.86 \text{ ppm}$, $\text{Mg}(\text{HCO}_3)_2 = 7.30 \text{ ppm}$, $\text{CaSO}_4 = 6.80 \text{ ppm}$,

$\text{MgCl}_2 = 5.70 \text{ ppm}$, $\text{MgSO}_4 = 9.00 \text{ ppm}$, $\text{SiO}_2 = 3.50 \text{ ppm}$, $\text{NaCl} = 5.85 \text{ ppm}$.

Sol. 70% lime

Impurity	CaCO_3 equivalent (ppm)	Requirements	
		Lime	Soda
$\text{Ca}(\text{HCO}_3)_2$	$\frac{100}{162} \times 4.86 = 3$	1 L = 3	-
$\text{Mg}(\text{HCO}_3)_2$	$\frac{100}{146} \times 7.30 = 5$	2 L = $2 \times 5 = 10$	-
CaSO_4	$\frac{100}{136} \times 6.80 = 5$	-	$1 S = 1 \times 5 = 5$
MgCl_2	$\frac{100}{95} \times 5.70 = 6$	1 L = $1 \times 6 = 6$	$1 S = 1 \times 6 = 6$
MgSO_4	$\frac{100}{120} \times 9 = 7.5$	1 L = $1 \times 7.5 = 7.5$	$1 S = 1 \times 7.5 = 7.5$

$$\text{Lime requirement} = \frac{74}{100} \times 26.5 \times 25,000 \times \frac{100}{100} = 4,90,250 \text{ mg}$$

$$\text{Soda requirement} = \frac{106}{100} \times 18.5 \times 25,000 \times \frac{100}{100} = 4,90,250 \text{ mg}$$

Numerical 2. Calculate the amount of lime and soda required for softening of 15,000 l of water, which is analysed as follows :

Temporary hardness = 20 ppm

Permanent hardness = 15 ppm

Permanent Mg hardness = 10 ppm.

$$\begin{aligned} \text{Sol. Lime requirement} &= \frac{74}{100} (\text{temp. hardness} + \text{permanent Mg hardness}) \\ &\quad \times \text{volume of water} \times 100\% \text{ purity} \\ &= \frac{74}{100} \times (20 + 10) \times 15,000 \times \frac{100}{100} = 330,000 \text{ mg} = 330 \text{ g} \end{aligned}$$

(because permanent Ca hardness can't be removed by using lime.)

$$\begin{aligned} \text{Soda requirement} &= \frac{106}{100} (\text{total permanent hardness}) \\ &\quad \times \text{volume of water} \times 100\% \text{ purity} \end{aligned}$$

$$= \frac{106}{100} \times 15 \times 15,000 \times \frac{100}{100} = 238,500 \text{ mg} = 238.5 \text{ g}$$

Numerical 3. A sample of water on analysis has been found to contain following in ppm.

$$\text{Ca}(\text{HCO}_3)_2 = 4.86$$

$$\text{CaSO}_4 = 6.80$$

$$\text{Mg SO}_4 = 8.40$$

Calculate the temporary and permanent hardness of the water.

Sol.

Impurities	CaCO_3 equivalent
$\text{Ca}(\text{HCO}_3)_2$	$\frac{100}{162} \times 4.86 = 3 \text{ ppm}$
CaSO_4	$\frac{100}{136} \times 6.80 = 5 \text{ ppm}$
MgSO_4	$\frac{100}{120} \times 8.4 = 7 \text{ ppm}$

$$\text{Temp. hardness} = 3 \text{ ppm}$$

$$\text{Perm. hardness} = 5 + 7 = 12 \text{ ppm.}$$

Numerical 4. Calculate the amount of lime and soda required per litre for the chemical treatment of water containing $\text{Ca}^{2+} = 80 \text{ ppm}$, $\text{Mg}^{2+} = 36 \text{ ppm}$. $\text{K}^+ = 39 \text{ ppm}$.

$\text{HCO}_3^- = 244 \text{ ppm}$. $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ added as coagulant = 69.5 ppm.

Sol. For solving this type of numerical (where impurities are given in the form of ions of Ca, Mg), CaCO_3 equivalent is calculated by using the M.wt. of ions but for the lime and soda requirement, always the permanent hardness is considered.

Impurity	CaCO_3 equivalent	Requirement	Lime	Soda
Ca^{2+}	$\frac{100}{40} \times 80 = 200$	S	-	200
Mg^{2+}	$\frac{100}{24} \times 36 = 150$	L + S	150	150
HCO_3^-	$\frac{100}{61} \times 244 = 400$	$\frac{1}{2}\text{L} - \frac{1}{2}\text{S}$	$\frac{1}{2} \times 400$	$-\frac{1}{2} \times 400$
$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	$\frac{100}{278} \times 69.5 = 25$		= 200	= -200
		L + S	25	25
			375	175

(As K^+ ions can't be removed by using lime and soda process, so no calculations for K^+)

$$\text{Lime requirement} = \frac{74}{100} \times 375 \times 1 \times \frac{100}{100} \\ = 277.5 \text{ mg Ans.}$$

Soda requirement

$$\frac{106}{100} \times 175 \times 1 \times \frac{100}{100} = 185.5 \text{ mg Ans.}$$

Numerical 5. A sample of water on analysis give the following results :
 $Ca^{2+} = 30 \text{ mg/l}$, $Mg^{2+} = 18 \text{ mg/l}$, $K^+ = 19.5 \text{ mg/l}$

$$CO_2 = 11 \text{ mg/l}, HCO_3^- = 122 \text{ mg/l}, Cl^- = 33.5 \text{ mg/l}$$

Calculate (i) Total hardness in Water.

(ii) Lime soda required for 1 litre of water sample.

Sol.

Impurity	Amount mg/l	$CaCO_3$ equivalent mg/l	Require- ment	Lime	Soda
Ca^{2+}	30	$\frac{100}{40} \times 30 = 75$	S	-	75
Mg^{2+}	18	$\frac{100}{24} \times 18 = 75$	L + S	75	75
CO_2	11	$\frac{100}{44} \times 11 = 25$	L	25	-
HCO_3^-	122	$\frac{100}{61} \times 122 = 200$	$\frac{1}{2}L - \frac{1}{2}S$	100	-100
				200	50

$$\text{Total hardness} = 75 + 75 = 150 \text{ mg/l.}$$

$$\text{Lime requirement} = \frac{74}{100} \times 200 \times 1 \times \frac{100}{100} = 148 \text{ mg/l Ans.}$$

$$\text{Soda requirement} = \frac{106}{100} \times 50 \times 1 \times \frac{100}{100} = 53 \text{ mg/l Ans.}$$

Numerical 6. Calculate the amount of Lime (91% pure) and soda (97.2% pure) required for softening one million litres of water containing

$\text{Ca}(\text{HCO}_3)_2 = 30.5 \text{ ppm}$; $\text{Mg}(\text{HCO}_3)_2 = 35.5 \text{ ppm}$; $\text{MgSO}_4 = 20.0 \text{ ppm}$; $\text{CaSO}_4 = 24.0 \text{ ppm}$; $\text{CaCl}_2 = 25.0 \text{ ppm}$ and $\text{NaCl} = 10.0 \text{ ppm}$.

Also calculate the temporary and permanent hardness of water sample.
(GNDEC May 2014)

Sol.

Impurities	CaCO_3 eq.	Requirement	L	S
✓ $\text{Ca}(\text{HCO}_3)_2$	$\frac{100}{162} \times 30.5 = 18.8$	L ✓	18.8	-
✓ $\text{Mg}(\text{HCO}_3)_2$	$\frac{100}{146} \times 35.5 = 24.3$	2L	48.6	-
✓ MgSO_4	$\frac{100}{120} \times 20 = 16.7$	L + S ✓	16.7	16.7
✓ CaSO_4	$\frac{100}{136} \times 24 = 17.6$	S ✓	-	17.6
✓ CaCl_2	$\frac{100}{111} \times 25 = 22.5$	S	-	22.5
			84.1	56.8

$$\text{Lime requirement} = \frac{74}{100} \times 84.1 \times \frac{100}{91} \times 10^6 = 68.38 \text{ Kg}$$

$$\text{Soda requirement} = \frac{106}{100} \times 56.8 \times \frac{100}{97.2} \times 10^6 = 61.96 \text{ Kg}$$

$$\text{Temporary hardness} = 18.8 + 24.3 = 43.1 \text{ ppm}$$

$$\text{Permanent hardness} = 22.5 + 17.6 + 16.7 = 56.8 \text{ ppm}$$

Numerical 7. Calculate the amount of lime (84% pure) and soda (92% pure) required for treatment of 20,000 L of water, whose analysis is as follows : $\text{Ca}(\text{HCO}_3)_2 = 40.5 \text{ ppm}$; $\text{Mg}(\text{HCO}_3)_2 = 36.5 \text{ ppm}$; $\text{MgSO}_4 = 30.00 \text{ ppm}$; $\text{CaSO}_4 = 34.0 \text{ ppm}$; $\text{CaCl}_2 = 27.75 \text{ ppm}$ and $\text{NaCl} = 10.00 \text{ ppm}$. Also calculate the temporary and permanent hardness of water.

Sol.

(GNDEC May 2013)

Impurities	CaCO_3 eq.	Requirement	Lime	Soda
$\text{Ca}(\text{HCO}_3)_2$	$\frac{100}{162} \times 40.5 = 25 \text{ ppm}$	L	25	-
$\text{Mg}(\text{HCO}_3)_2$	$\frac{100}{146} \times 36.5 = 25 \text{ ppm}$	2L	$2 \times 25 = 50$	-

Impurities	CaCO_3 eq.	Requirement	Lime	Soda
MgSO_4	$\frac{100}{120} \times 30 = 25 \text{ ppm}$	L + S	25	25
CaSO_4	$\frac{100}{136} \times 34 = 25 \text{ ppm}$	S	-	25
CaCl_2	$\frac{100}{111} \times 27.75 = 25 \text{ ppm}$	S	-	25
			100	75

$$\text{Lime required} = \frac{74}{100} \times 100 \times \frac{100}{84} \times 20,000 = 1.76 \text{ kg}$$

$$\text{Soda required} = \frac{106}{100} \times 75 \times \frac{100}{92} \times 20,000 = 1.12 \text{ kg}$$

$$\text{Temporary hardness} = 25 + 25 = 50 \text{ ppm}$$

$$\text{Permanent hardness} = 25 + 25 + 25 = 75 \text{ ppm}$$

Numerical 8. Calculate the amount of lime (91% pure) and soda (97.2 % pure) for softening one million litres of water containing :

H^+ (free acidity) = 1.5 ppm ; HCO_3^- = 396.5 ppm ; Mg^{+2} = 42 ppm ; Ca^{+2} = 90 ppm;

$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ = 14 ppm

[Given atomic masses of H = 1, Ca = 40, Mg = 24, O = 16, C = 12, S = 32, Fe = 56]

Ans.

Impurities	CaCO_3 eq.	Requirement	L	S
H^+	$1.5 \times \frac{100}{1} = 150$	$\frac{L}{2} + \frac{S}{2}$	75	75
HCO_3^-	$396.5 \times \frac{100}{61} = 650$	$\frac{L}{2} - \frac{S}{2}$	325	= - 325
Mg^{+2}	$42 \times \frac{100}{24} = 175$	L + S	175	175

Impurities	CaCO_3 eq.	Requirement	L	S
Ca^{2+}	$90 \times \frac{100}{40}$ $= 225$	S	-	225
$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	$14 \times \frac{100}{278}$ $= 5.03$	L + S	5.03	5.03
			580.03	155.03

$$\text{Line requirement} = \frac{74}{100} \times 580.03 \times \frac{100}{91} \times 10^6 \\ = 471.67 \text{ Kg}$$

$$\text{Soda requirement} = \frac{106}{100} \times 155.03 \times \frac{100}{97.2} \times 10^6 \\ = 169.0 \text{ Kg}$$

2. Zeolite or Permutit Process. This is a very effective method. Chemical formula of zeolite is :

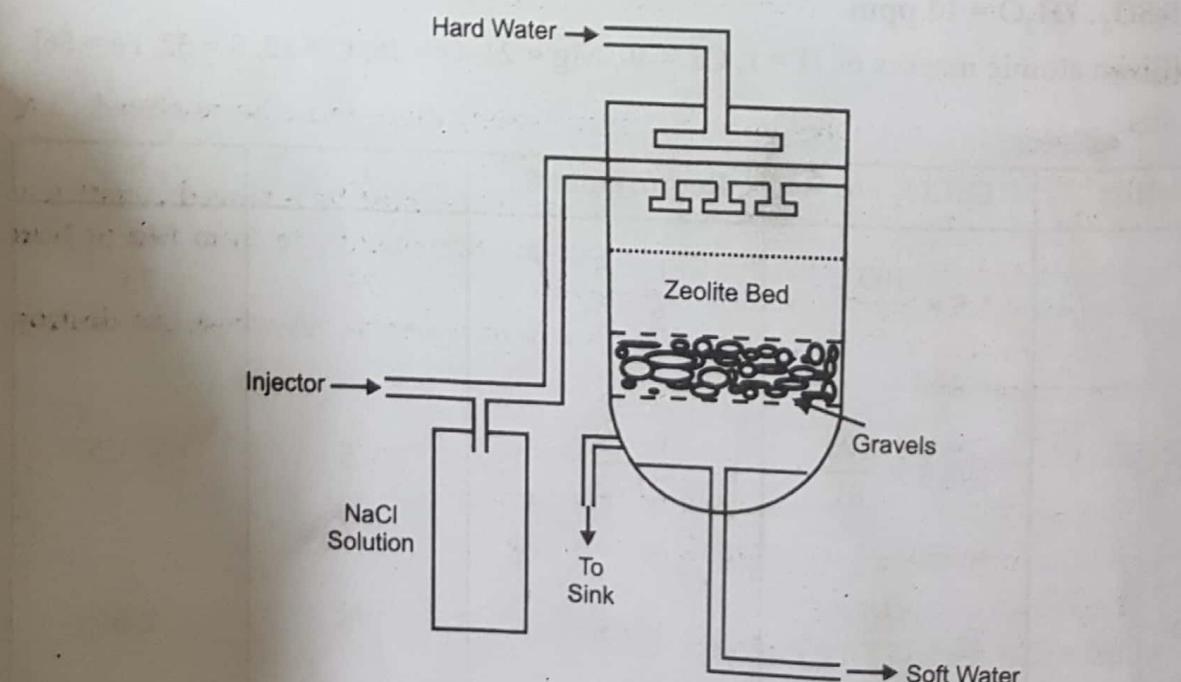
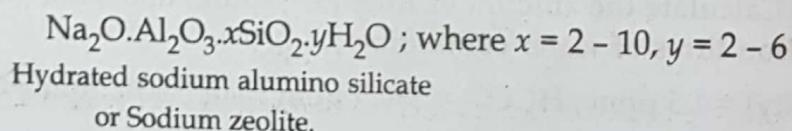


Fig. 3.3

This is capable of exchanging its Na^+ ions with hardness producing ions (Ca^{2+} and Mg^{2+}) present in hard water.

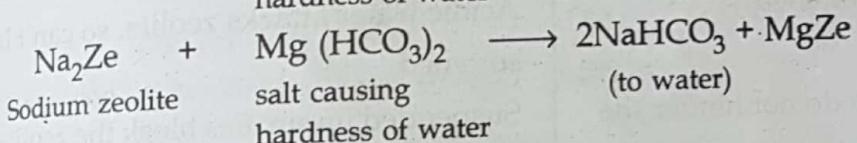
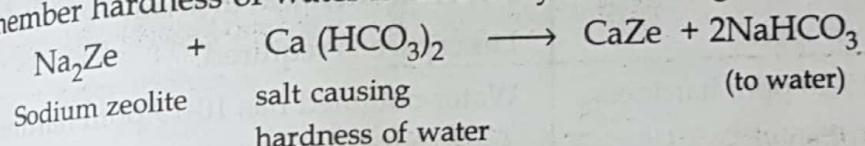
Zeolites are known as permuntit also.

Zeolites are of two types :

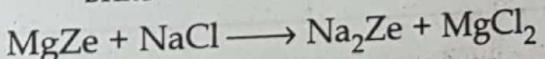
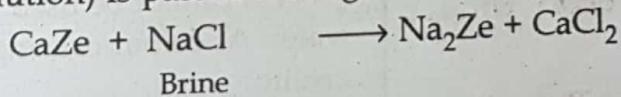
(i) **Natural Zeolites** are non-porous e.g. **natrolite** $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O}$.

(ii) **Synthetic Zeolites** are porous and possess gel-like structure.

Softening Process. Water is passed through zeolite beds. The Ca^{2+} and Mg^{2+} ions in the water are replaced by Na^+ ions of the zeolite bed i.e. Zeolite retains Ca^{2+} and Mg^{2+} ions of hard water and gives away its Na^+ to water. Although conc. of Na^+ ions of Na salts is increasing in the water, but these salts are not responsible for the hardness of water (Remember hardness of water is caused by Ca and Mg salts/ions).



Regeneration. After some time all the Na^+ ions of zeolite are replaced by Ca^{2+} / Mg^{2+} ions, and hence zeolite is no more effective. So, to remove this saturation 10% NaCl solution (brine solution) is passed through the used zeolite.



So, in this way used up zeolite is regenerated to sodium zeolite and CaCl_2 and MgCl_2 formed are removed from the zeolite softener to sink.

Limitations

1. If **suspended particles** are present in water, these must be removed first, otherwise these will clog the pores of zeolite.
2. If **Mn^{2+} or Fe^{2+}** ions are present in water, these must be removed completely otherwise these will replace Na^+ of zeolite permanently to form **Mn or Iron zeolite**, whose regeneration is not possible.
3. Mineral acids must be removed, if present in water because these can **destroy** the zeolite bed.

Advantages of Zeolite Process

1. The equipment used is **compact** so time saving.
2. No impurities are **precipitated**, so no sludge.
3. Less time for softening.
4. Less skill required for maintenance.

Disadvantages

1. Treated water has more of Na^+ ions.
2. This method leaves acidic ions (HCO_3^- and CO_3^{2-} ions) in soft water which if enters a boiler, generate CO_2 which leads to corrosion.
3. Turbid water can't be made soft by this process because it leads to clogging of the holes of zeolite bed.

Difference between Lime Soda and Zeolite Method

Lime-Soda Method	Zeolite Method
<ol style="list-style-type: none"> 1. It is not a cheap method. 2. Equipment needs more space. 3. Water obtained has 15-20 ppm hardness. 4. Acidic water can be softened. 5. Suspended impurities do not hinder the softening process. 6. Water obtained has lesser dissolved salts. 7. Process can be used for water having colour or turbidity. 	<p>It is an economical method. Less space is required. Water obtained has 10-15 ppm hardness. Acidic water attacks zeolite, so can't be softened.</p> <p>Suspended impurities block the zeolite so hinder the softening.</p> <p>Water obtained has more dissolved salts. Process cannot be used for coloured and water. As colour causing ions block the zeolite.</p>

Ion exchange or de-ionization or demineralization Process

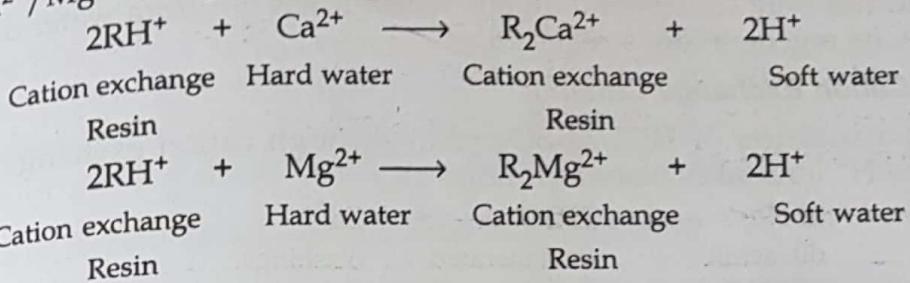
This is another method for softening of hard water.

Ion exchange resins are insoluble, cross-linked, long chain **organic polymers** with micropores (very small pores). The functional groups attached to the ion exchange resin are responsible for its ion exchange properties.

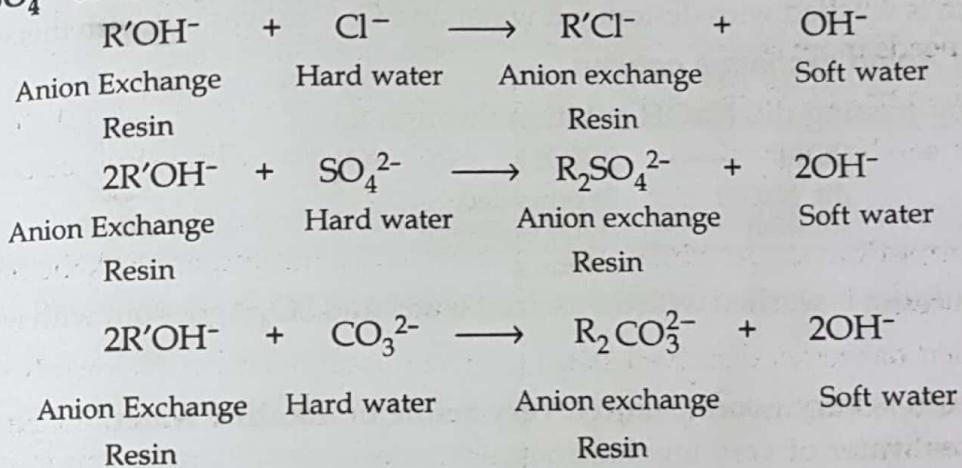
(i) **Cation Exchange Resin** is generally represented as RH^+ e.g. **styrene-divinyl benzene copolymer**. Resins containing acidic functional group $-\text{COOH}$, $-\text{SO}_3\text{H}$ (after treatment of sulphonation or carboxylation) are capable of exchanging their H^+ ions with cations of water (means cations of salts responsible for hardness of water) which come in their contact. (Ambertite IR - 120 and DOWEX - 50 are commercially available CER).

(ii) **Anion exchange polymer** is generally represented as $\text{R}'\text{OH}^-$, e.g. **styrene-divinyl benzene** or amine formaldehyde copolymer. These after treatment with dil. NaOH solution become capable of exchanging their OH^- with anion of H_2O . These are having basic functionalities e.g. $-\text{NH}_2$ or $-\text{OH}$ exchange their anion with anion of water (means anions of the salts responsible for hardness of water). (Ambertite - 400 and DOWEX 3 are examples of commercially available AER).

Process. The hard water is passed through cation exchange column which removes all the $\text{Ca}^{2+}/\text{Mg}^{2+}$ ions present in hard water as shown.



After this the same water is passed through anion exchange column, which removes all the SO_4^{2-} or Cl^- etc.



The H^+ and OH^- released respectively combine to form H_2O .

The water coming out of the ion exchanger is called de-ionized/de-mineralized water.

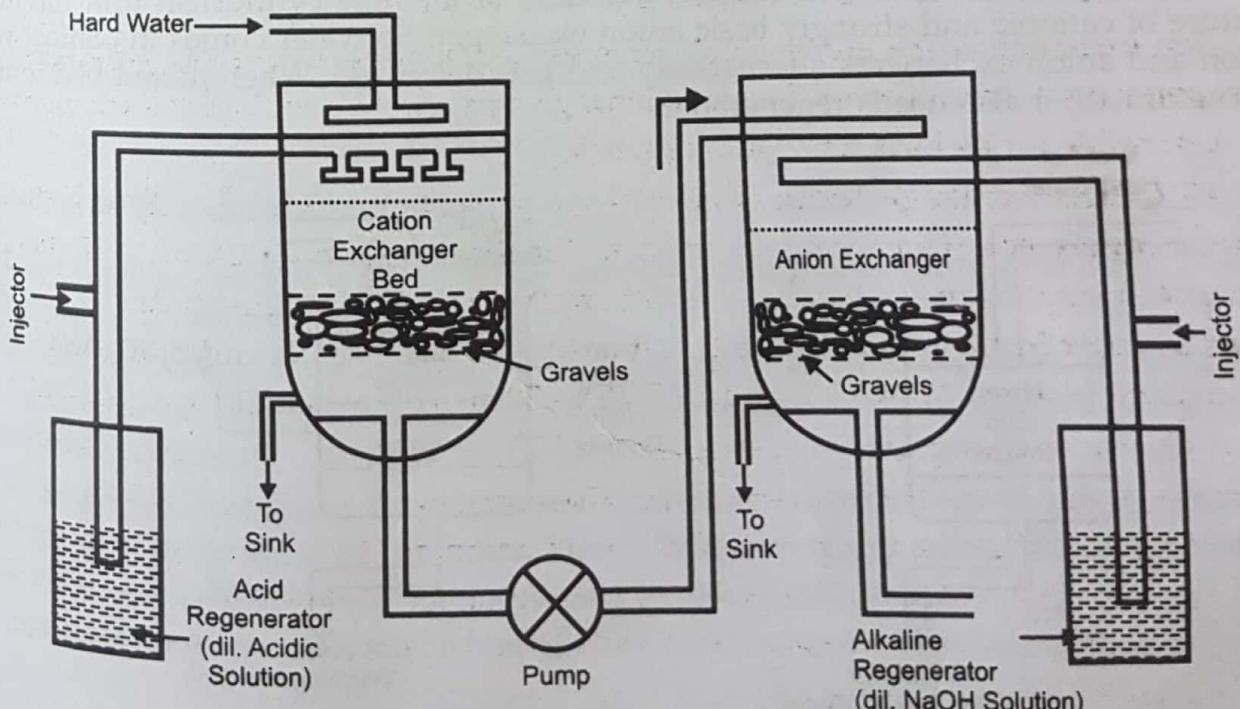
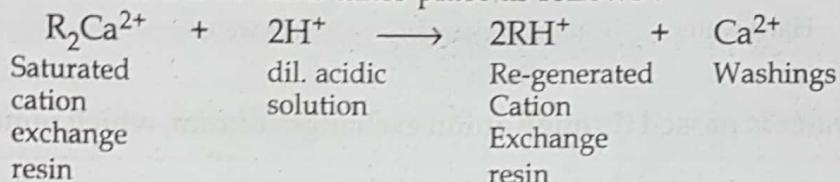


Fig. 3.4 Ion Exchange Process

When capacity of cation and anion exchanger to exchange H^+ and OH^- is lost, they are said to be exhausted. It is when ion exchange resin has given all its H^+ and OH^- ions to hard water and has only cations and anions which it has got from water during ion exchange process. Its regeneration is required.

Regeneration of Cation Exchange Column

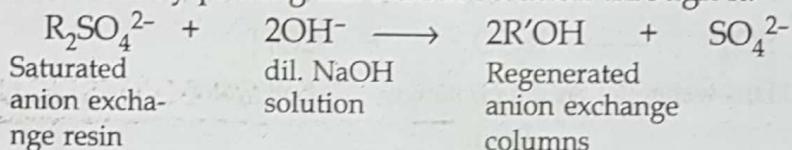
On passing a solution of HCl/H_2SO_4 (dil.) through cation exchange column, regeneration of the H^+ ions takes place as follows :



The column is washed with de-ionized water and Ca^{2+} moves out with this washing.

Regeneration of Anion exchange column

It is done by passing dil. $NaOH$ solution through it.



Again the column is washed with de-ionized water and SO_4^{2-} goes out with washings.

Advantages

1. This process is very good to soften very acidic or alkaline water.
2. It produces water of very low hardness.

Disadvantages

1. The Equipment is costly.
2. If water is turbid, output of de-ionization is low.

Mixed Bed Deionizer. It consists basically of a single cylindrical unit having a mixture of cationic and strongly basic anion exchanger. So water comes in contact with cation and anion exchangers alternatively and gets deionized. When mixed bed ionizer gets saturated, it also needs regeneration.

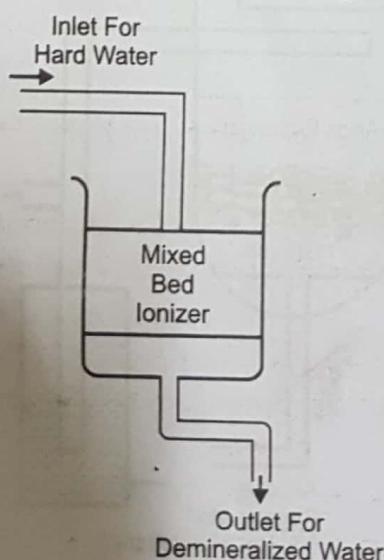


Fig. 3.5 Mixed Bed Ionizer

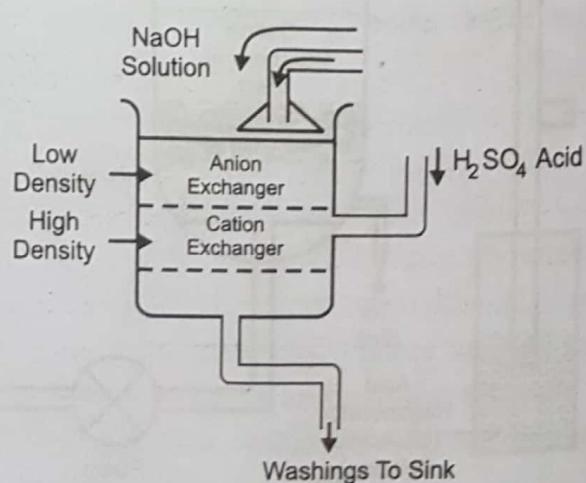


Fig. 3.6 Regeneration of Mixed Bed Ionizer

Regeneration

Mixed ion exchanger is **back washed**, which leads to formation of two layers.

Upper layer is of Anion exchanger because of its low density, which can be regenerated by passing caustic soda through it.

The **lower layer** is of cation exchanger because of its high density. It can be regenerated by passing **dilute sulphuric acid solution** through it.

Advantages of ion exchange method over zeolite method

1. Zeolite method replaces Ca^{2+} and Mg^{2+} ions by Na^+ ions but all the acidic impurities e.g. HCO_3^- and CO_3^{2-} are present as such. But in ion exchange resin even these impurities are also removed properly.
2. The soft water produced by zeolite method has 10-15 ppm hardness which can't be used in high pressure boiler, but by ion exchange method water of hardness as low as 2 ppm is obtained which can be used in high pressure boilers.

3.5 DRINKING WATER OR MUNICIPAL WATER OR WATER FOR DOMESTIC USE

Water for domestic use should have the following specifications :

1. It should be odourless.
2. It should be pleasant in taste.
3. Turbidity should not be more than 10 ppm.
4. It should be free from objectionable gases like H_2S .
5. It should be free from objectionable minerals such as Pb, As, Cr and Mn salts.
6. Its pH value should be around 8.0.
7. It should be reasonably soft.
8. It should be free from disease producing micro-organisms.

3.5.1 Purification of Water for Domestic Use**A. Removal of Suspended Impurities**

1. **Screening.** Water is passed through screens, having large number of holes. Hence floating matter is retained back.

2. **Sedimentation.** Water is allowed to stand undisturbed in big tanks of about 5 m deep for 2-6 hours. Suspended particles settle down. Supernatant water is withdrawn with the help of pumps.

Coagulation. Actually it is sedimentation with coagulation. Because colloidal impurities take large time to sediment. Hence coagulants are used. When water has colloidal impurities, these are simply removed by using coagulants.

Coagulants are chemicals which are added to water before sedimentation.

Coagulants react with bicarbonates present in water and form a bulky gelatinous precipitate called **Flock**. When these flocks move down, they catch the other suspended

particles, form bigger flocks, and thus settle down. The addition of coagulant removes odour, colour and improves taste of water.

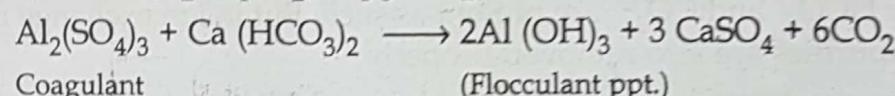
Coagulants like alum and ferrous sulphate provide Al^{3+} or Fe^{3+} ions, which neutralize the negative charge on clay particles. Now clay particles come near to each other and form bigger particles which settle down.

Thus, coagulants force the colloidal particles to settle down.

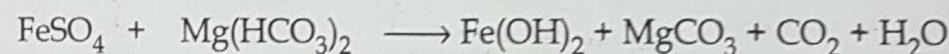
After adding coagulants, water is allowed to sediment.

Coagulants

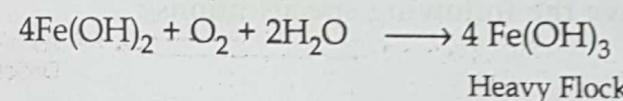
(i) Alum $[K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O]$ reacts in alkaline conditions.



(ii) Copper or Ferrous sulphate [$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$]. This is a good coagulant in alkaline conditions i.e. when pH is more than 8.5



Coagulant Present in
hard water



3. Filtration. Sedimented water is passed through sand and proper granular material for removal of colloidal particles, micro-organisms etc.

The arrangement is called gravity sand filter/sand filter

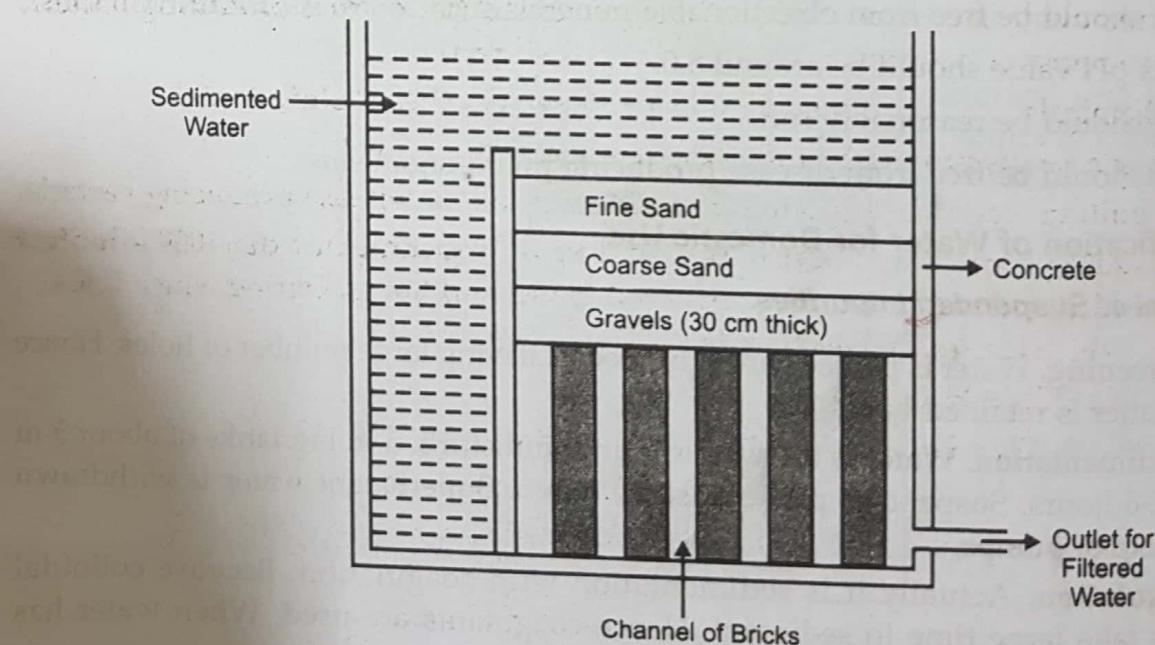


Fig. 3.7 Filtration Process

The suspended particles and germs are entrapped in the sand layer and water seeps downwards through sand bed and is drained out.

down. The addition of coagulant removes provide Al^{3+} or Fe^{3+} ions, which neutralize particles come near to each other and settle down.

to sediment.

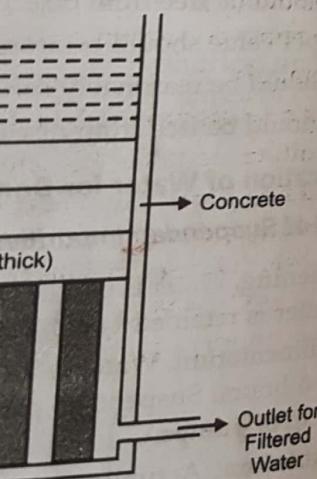
in alkaline conditions.
 $3 \text{CaSO}_4 + 6\text{CO}_2 \rightarrow \text{Ca}_3(\text{PO}_4)_2 + 3\text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O}$

O]. This is a good coagulant in alkaline

$\text{gCO}_3 + \text{CO}_2 + \text{H}_2\text{O}$

ough sand and proper granular material
s etc.

sand filter.



After 24 hrs, due to clogging of the pores of sand, the sand layer is scrapped off and is replaced by a new sand layer.

4. **Pressure Filter.** It is a cylindrical vertical steel tank having three layers of fine sand, coarse sand and pebbles. Impure sedimented water is mixed with alum solution and is added under pressure from the top. This added alum forms a slimy layer on the top. Deflector plate distributes the slimy layer uniformly over the top. Filtered water is collected from the outlet.

Pressure filter gets clogged after using it for some time. Its cleaning is must. This is done by backwashing. In backwashing water is forced under pressure to move upwards which removes all the particles responsible for clogging. This washing is removed from the top.

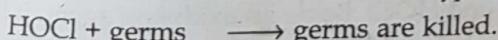
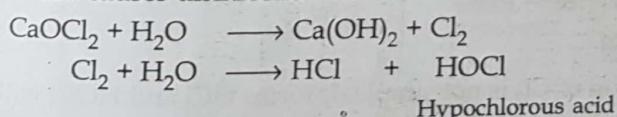
B. Removal of Microorganisms

After removing the suspended particles, water still has disease producing bacteria which can be removed and this process is called **disinfection**.

The chemicals which are used for this purpose are called **disinfectants**.

Water can be disinfected by following methods :

1. By boiling water for 10-15 minutes. This kills all the disease producing bacteria.
2. By adding bleaching power (CaOCl_2). 1 kg of bleaching powder/1000 kilolitres of water is added and water is allowed to stand for several hours. During which CaOCl_2 releases Cl_2 , which causes disinfection as :



Drawbacks

1. It introduces **Ca** in water and hence makes water hard.
2. On storage, bleaching powder gets deteriorated and hence its Cl_2 content is always checked beforehand.
3. Excess of bleaching powder leads to **bad taste and smell** to water. So its calculated amount should be used.

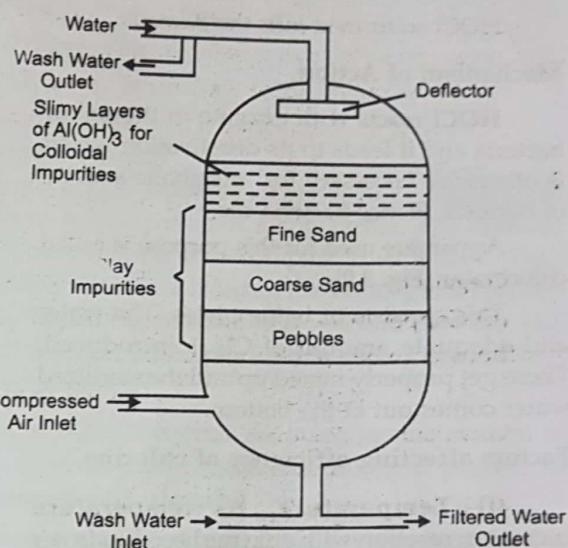
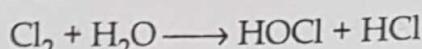


Fig. 3.8 Pressure Filter

3. By Chlorination. Chlorine either in gaseous or solution form is added to water and it forms HOCl.



HOCl so formed kills the Bacteria.

Mechanism of Action

HOCl reacts with enzyme in the cell of bacteria and it leads to its deactivation which is otherwise necessary for metabolic activity of bacteria. Hence bacteria die.

Apparatus used for this purpose is called chlorinator (Fig. 3.9).

This consists of baffle plates. The water and adequate amount of Cl_2 is introduced. These get properly mixed up and the sterilized water comes out at the bottom.

Factors affecting efficiency of chlorine

(i) **Temperature.** As temperature increases, reaction with enzyme becomes faster and hence more bacteria are killed.

(ii) **pH.** Smaller pH values are more favourable for disinfection by Cl_2 .

Advantages of Cl_2

- (i) Economical
- (ii) Little space for storage
- (iii) It is stable and does not deteriorate.
- (iv) It does not release any salt impurities in water.

Disadvantages

Excess of Cl_2 content in water may lead to **unpleasant taste and odour**. Its excess causes **irritation of mucous membrane**. Actual concentration of Cl_2 should be 0.1-0.2 ppm. It is less effective at higher pH.

Break Point Chlorination

The disinfection action of Cl_2 is not simple. It forms HCl and HOCl with water. The disinfection form of chlorine are Cl_2 and HOCl. Being an oxidizing agent, it first oxidises **organic matter** and other **reducing agents** e.g. NH_3 , H_2S etc. Ammonium ion exist in equilibrium with ammonia and H^+ . Ammonia reacts with HOCl and form mono, di and tri chloro amine depending on Cl_2 , which combine with a wide variety of materials, particularly reducing agents. These reactions complicate the use of Cl_2 for disinfection.

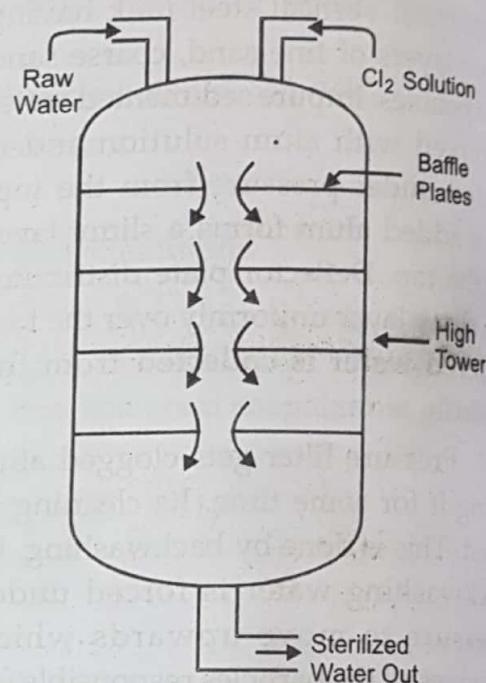
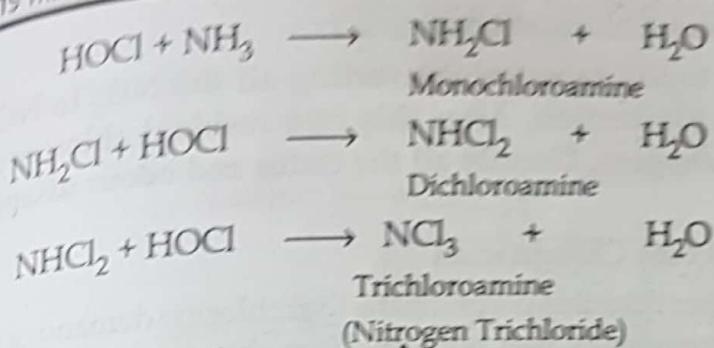


Fig. 3.9 Chlorinator



These chloroamines formed above act as chlorine reserve have significant disinfecting power and kill the organisms which were not killed earlier. The demand for Cl_2 must be satisfied before Cl_2 become available to accomplish disinfection. They result in production of numerous byproducts which are listed in the WHO guidelines for drinking water because of their potential health significance. The reaction between H_2S and Cl_2 will serve to illustrate the type of reaction that occur with reducing agents.



Fe^{2+} , Mn^{2+} and NO_2^- are examples of other inorganic reducing agents present in water supplies, that will react with Cl_2 . Organic compounds and halogens present in water react with HOCl and hence increases the Cl_2 demand.

The free Cl_2 for disinfection becomes available only after the requirement for Cl_2 by other reacting substances is met with. It is important to know the difference between free chlorine and combined chlorine residue.

(For efficient disinfection, a greater conc. of combined chlorine is required)

Free chlorine residue is Cl_2 and HOCl. Combined chlorine residue is chloramines.

The effect of passing Cl_2 into water can be represented as :

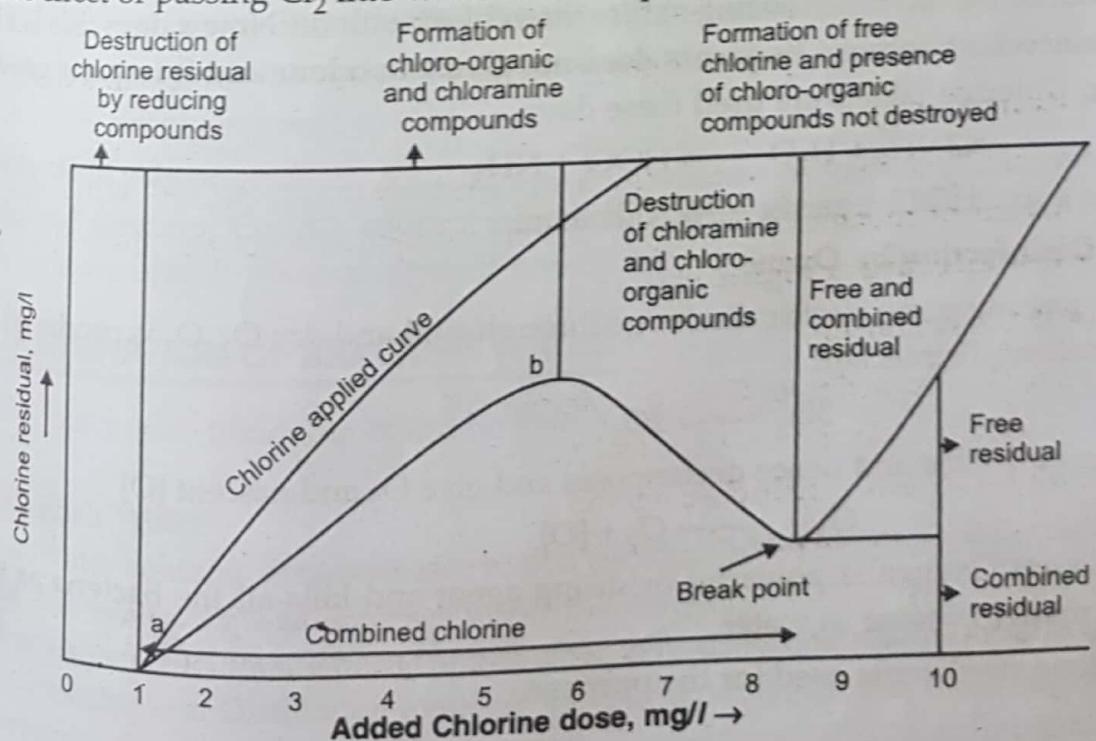


Fig. 3.10

Definition of Break Point Chlorination

Chlorination of water to the extent of converting all the NH_3 to NCl_3 or N_2 is referred to as break point chlorination. After this free residual chlorine appears in water which destroys the pathogens. Usually all the tastes and odour disappear at this stage.

Significance of Break Point Chlorination

The chlorine dosage higher than this point means that chlorine demand of the chlorine reactable material has been completely met with and free chlorine residual are available for bacterial action. It also signifies

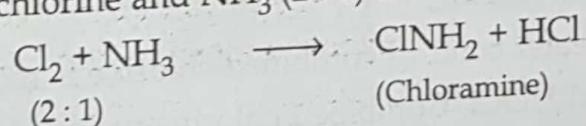
- complete decomposition of NH_3 .
- removal of colouring matter and odour of water.

An overdose of chlorine produces unpleasant taste and odour, and irritation of mucous membrane. So information regarding break point of water sample being chlorinated is useful in the following respects.

- (i) It indicates complete oxidation of organic matter responsible for imparting colour, bad smell and unpleasant taste of water.
- (ii) It ensures complete destruction of pathogens.
- (iii) It prevents the presence of excess chlorine which may impart bad taste or odour.

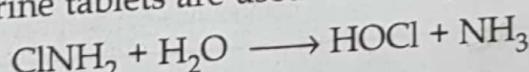
4. By using chloramine (ClNH_2)

When chlorine and NH_3 (2 : 1) are mixed, it leads to chloroamine formation.



[By volume]

Chloramine has much lasting nature than chlorine alone. Now a days this is a better used disinfectant because its excess does not give any odour and it imparts good taste to water. Chlorine tablets are used these days.



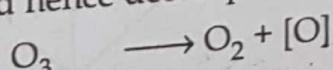
$\text{HOCl} + \text{germs} \longrightarrow \text{Kills them.}$

5. Disinfection by Ozone

By passing some electric discharge through cold and dry O_2 , O_3 is produced which is an excellent disinfectant.



O_3 is unstable and hence decomposes and give O_2 and nascent $[\text{O}]$



Nascent Oxygen is powerful oxidising agent and kills all the bacteria as well as organic matter present in water.

Ozone sterilizer is used for the purpose.

Ozone is released into water and the two are allowed to come in contact with each other in a tank. The disinfected water is removed from the top. The contact period is 10-15 minutes and usual dose is 2-3 ppm.

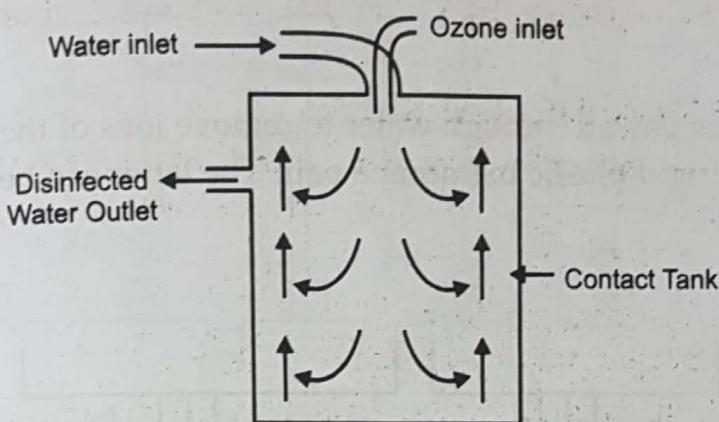


Fig. 3.11 Ozone Sterilizers

Disadvantage

This method is **very expensive**.

Advantage

The excess is not harmful because it **does not give any residue**.

C. Aeration

This is the most modern method for purification for town supply. Water is forced under pressure through a perforated pipe. As water sprays in air, it comes in contact with O_2 and U.V. rays. These kill bacteria and organic matter present in the water. If the exposure time is less, desirable results won't be there.

D. U.V.Rays

U.V. rays are very useful in killing bacteria. This method is very useful for swimming pools because it **does not require addition of any chemical to be added**.

Water is simply exposed to U.V. rays.

E. Removal of Algae

Salt of mercury, Cu, Ag, sodium penta-chlorophenate and quarternary ammonia compounds are used to remove algae, if present in water.

3.6 DESALINATION OF BRACKISH WATER

The process of removing common salts from the water is called **desalination** of water.

Brackish Water

e.g. Water contains dissolved salt with a peculiar salty (brackish) taste.

e.g. **Sea Water**. 3.5% salts comes under this category.

Brackish water is totally unfit for drinking, so desalination is must. For desalination process, Freezing and Distillation methods are used commonly. But these methods have their respective disadvantages. As freezing method used is useful in cold climate conditions

only and for distillation lot of fuel is consumed which is not environment friendly. Some more technically correct methods are given in the next section.

3.6.1 Different methods for Desalination of Water

1. Electrodialysis

Electric current is passed through water to remove ions of the dissolved salt, using electrodes and a thin rigid plastic membrane pair. The latter can be natural or synthetic.

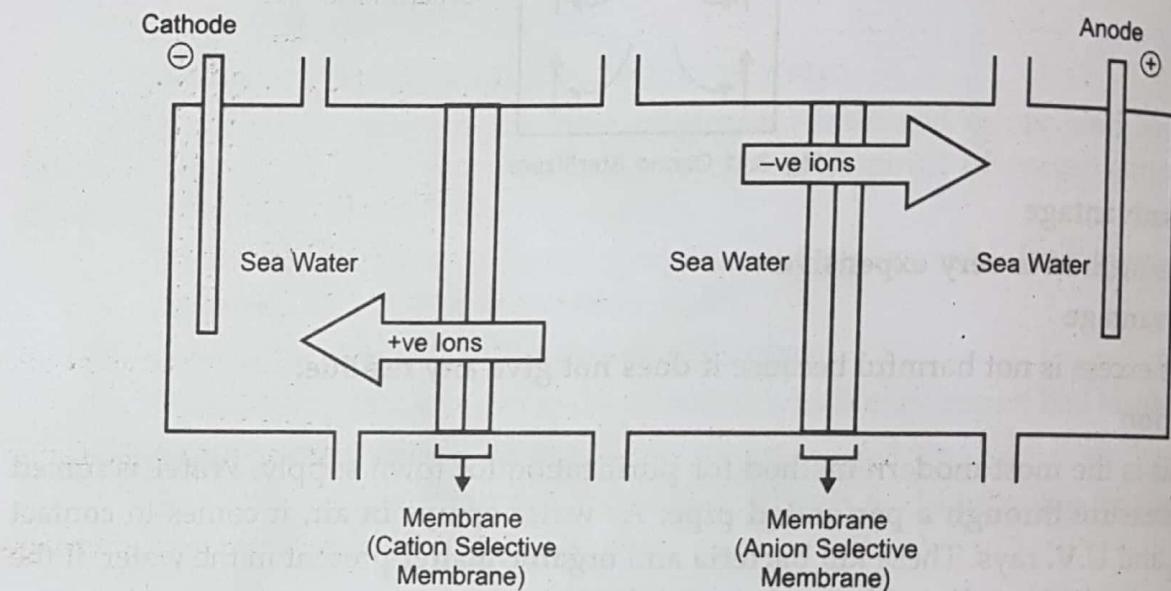


Fig. 3.12 Desalination of saline water by the concept of Electrodialysis

Electric current is passed through saline water

Na^+ start moving toward cathode (-)

Cl^- start moving toward Anode (+)

through membrane.

The membrane can be Ion selective membrane.

A Cation Selective Membrane will let only the cations to pass through it because it has fixed charge functional groups (e.g. RSO_3^- or RCOO^-) which repel the anions of the same size charge density as that of fixed functional group.

An Anion selective membrane has fixed charge functional group (as R_4N^+) and it allows only the passage of anions through it.

So conc. of NaCl in central compartment decreases. This desalined water is removed from time to time.

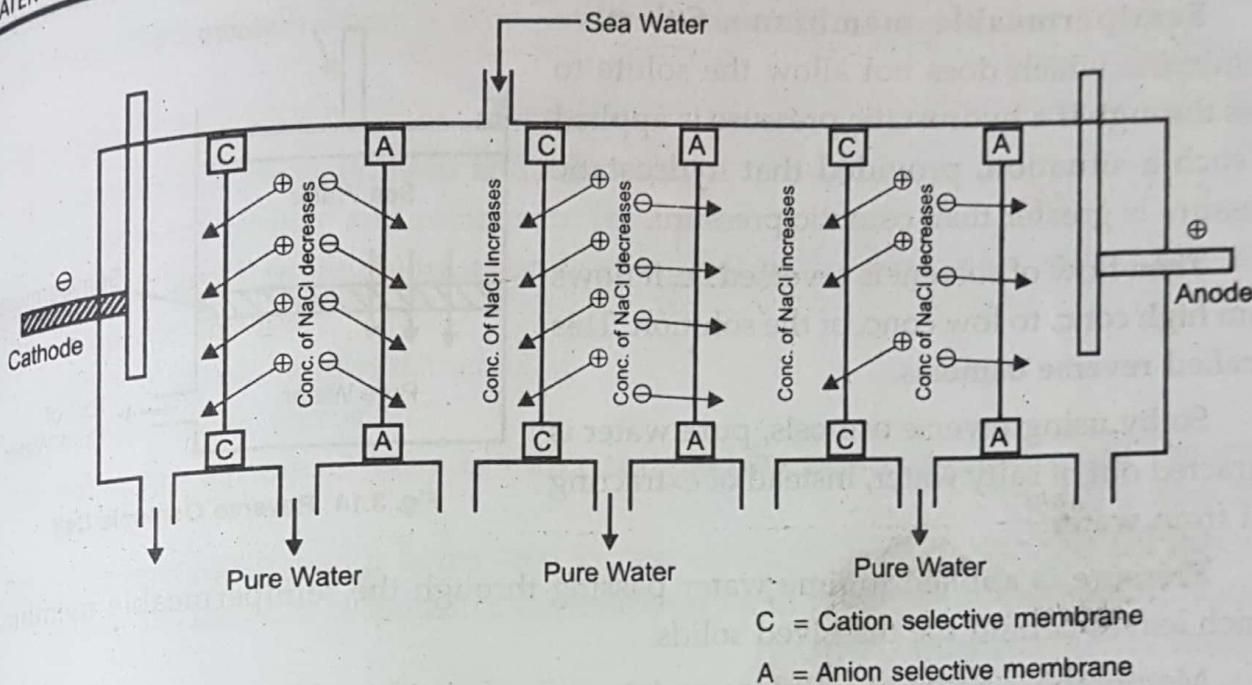


Fig. 3.13 Electrodialysis cell

An electrodialysis cell consists of a large number of pairs of rigid ion selective plastic membrane.

Water under pressure is passed through the cell. Electric charge perpendicular to flow of water is passed through it.

Cation selective membrane allows the passage of cations only because of **charge fixed functional groups**.

Anion selective membrane allows the passage of anions only because of charge fixed functional groups.

Ultimately one cell has greater conc. of salt while the alternate ones is deprived of NaCl.

Thus we get alternate stream of pure water and brine water.

Advantages

The following are a few advantages of electrodialytic process :

1. It is compact unit.
2. It is economical.
3. If electricity is available, this is the best suited device.

2. Reverse Osmosis

When two solutions of unequal concentration are separated from each other by semipermeable membrane, flow of the solvent from lower conc. of solution to higher conc. of solution take place Or flow of solvent from its high conc. to low conc. takes place. This is called osmosis.

Semipermeable membrane. Selective membrane which does not allow the solute to pass through if a hydrostatic pressure is applied to such a situation, provided that hydrostatic pressure is greater than osmotic pressure.

Then flow of solvent is reversed i.e. it flows from high conc. to low conc. of the solution. This is called **reverse osmosis**.

So by using reverse osmosis, pure water is extracted out of salty water, instead of extracting salt from water.

Pressure is applied to lime water passing through the semipermeable membrane which leaves behind the dissolved solids.

Membrane is a film of cellulose acetate, affixed to either side of the perforated tube.
Other option can be : Cellulose Membrane made of poly meth acrylate and polyamide polymers.

Advantages

The advantages of reverse osmosis are :

1. Useful not only to remove NaCl, but ionic, non-ionic, colloidal or high molecular weight organic matter.
2. It removes colloidal silica, which is not removed by demineralization.
3. Life time of membrane is 2 years. So it is an economical concept.
4. Replacement of water takes a few seconds only, so continuous supply of water can be maintained.



E

Exercise

Short Answer Type Questions

1. What is regeneration of ion exchangers ? How is it carried out ?
2. Why temporary hardness gets removed on heating ? Explain the chemical reaction. (PTU Dec. 2012, May 2014)
3. Differentiate between scale and sludge.
4. What is brackish water ? How can it be purified ?
5. Water softened by zeolites is unfit for use in boilers. Why ? (PTU May 2010)
6. Define ppm.

7. Why hardness of water is expressed in terms of CaCO_3 equivalent ?
 (GNDEC Dec. 2013)
8. What is degree of hardness of water ?
9. Differentiate between hard and soft water.
10. What is temporary and permanent hardness ?
11. What is break point chlorination ?
 (PTU May 2010)
12. What are zeolites ?
13. What is caustic embrittlement ?
14. What is boiler corrosion ?
15. What are zeolites ? Why is water softened by zeolite process unfit for use in boilers ?
 (PTU May 2005)
 (PTU Reappear)
16. Give specifications for boiler feed Water.
 (PTU May 2013)(PTU Reappear)
17. What are the salts responsible for temporary and permanent hardness of water ?
 (PTU May 2013)(PTU Reappear)
18. What is lime and soda ? What is its significance ?
 (PTU Dec. 2004)
19. Why buffer solution is used during titration of hard water against EDTA solution ?
 (PTU May 2005, Reappear)
20. What is the principle of lime soda process ? Explain by taking one example.
 (PTU 2009)
21. Give specifications of water for drinking purpose.
 (PTU 2009)
22. What is priming and foaming ?
 (PTU 2009)
23. What is cause of alkalinity of sea water ?
 (PTU 2009)
24. Give any two points of difference between cold and hot lime soda method.
 (PTU 2009)
25. Why should water be softened before use in boilers ?
 (PTU May 2009)
26. How water is softened by ion exchanger.
 (PTU May 2009)
27. Is Ca-EDTA complex soluble in water ?
 (PTU May 2009)
28. Give one method of prevention of caustic embrittlement.
 (PTU May 2009)
29. What are boiler problems caused by presence of silica in water ?
 (PTU Dec. 2013)
30. Give the names of three sludge forming and three scale forming compounds.
 (PTU Dec. 2012)
 (PTU Dec. 2012)
 (PTU May 2012)
31. Why natural water should not be used for boiler ?
 (PTU May 2013)
32. Milliequivalent per litre of hardness = ppm. Explain.
 (GNDEC Dec. 2013)
33. Define (i) Phosphate conditioning (ii) Caustic Embrittlement.
 (GNDEC, May 2016)
34. What is soft water ? Where is it required ?
 (GNDEC, May 2016)
35. Discuss caustic Embrittlement.
 (GNDEC, May 2016)
36. How water can be softened by Zeolite method ?
 (GNDEC, Dec. 2015)
37. A water sample has 19 mg of MgCl_2 per litre of water. Calculate the hardness of water in CaCO_3 equivalent.
 (GNDEC, Dec. 2015)
38. Name different types of hardness of water and different impurities (salts) responsible for each type.
 (GNDEC, Dec. 2015, Reappear)

39. What are disadvantages of scale and sludge formation in boiler.
 (GNDEC, Dec. 2014)
40. Why should the presence of CO_2 be avoided in boiler feed water ?
 (PTU May 2016, May 2015, Dec. 2014)
41. Distinguish between priming and Foaming.
 (PTU May 2016)
42. Why the water softened by zeolite process, unfit use in boiler ?
 (PTU Dec. 2015)
43. Differentiate between scale and sludge.
 (PTU May 2015)

Long Answer Type Questions

1. What are lime and soda ? Why does magnesium bicarbonate require double amount of lime for softening of hard water ?
 (PTU Dec. 2004, May 2007)
2. Name the salts causing temporary and permanent hardness. Describe two processes to remove hardness.
 (PTU Reappear)
3. Discuss the treatment of ground water to be used for domestic purposes.
 (PTU Dec. 2012, May 2013)(PTU Reappear)
4. What is break point chlorination ? Explain showing different zones. What are the advantages of break point chlorination ?
 (PTU May 2005)
5. (a) What are zeolites ? How do they function in softening of water ? What are their merits and demerits ? (GNDEC May 2014)(PTU May 2006, May 2009, May 2011)
 (b) Explain the method of desalination of water by Reverse Osmosis Method.
6. (a) Differentiate between hard and soft water.
 (b) Why hard water does not produce lather with soap ?
 (c) What are the units of hardness of water ?
7. What are the disadvantages of using hard water in boilers ?

Or

What happens when hard water is used in boilers.
 (PTU May 2009)

- 8. Give different methods for prevention of scale formation.
 — 9. Explain Caustic Embrittlement.
 10. What are ion exchange resins ? Describe in detail the ion exchange process for demineralization of water.
 (PTU May 2010, Dec. 2010)

Or

Describe method involved in treatment of water required for industries.

(PTU May 2009)

11. Write a short note on desalination of saline water by reverse osmosis.
 (PTU Dec. 2010)
12. What is sterilization of water ? Explain it.
 13. Compare hot and cold soda-lime process for softening of hard water.
 (PTU May 2007)

14. What happens when temporary hard water is boiled ? Write the chemical reactions.
 (PTU Dec. 2010)
15. (a) What disadvantages are expected if hard water is used for steam generation in boiler ? What process may be used to overcome these problems ?
 (b) How is water disinfected by chlorination ?
 (PTU Dec. 2013)
16. What is priming and Foaming ? Explain.
 (PTU May 2012, May 2013)
17. Discuss hot lime soda process of water softening.
 (PTU May 2012)
18. How and when microorganisms are killed by chlorination ?
 (GNDEC May 2013)
19. What is demineralized water ? How it is different from soft water ?
 (PTU Dec. 2013)
20. (a) What is specification of boiler feed water ?
 (b) Discuss hot lime - soda process for softening of water.
 (PTU May 2014)
21. Explain Purification of water for domestic use.
 (GNDEC, May 2016)
22. Explain the desalination of water by process of electrodialysis with a labelled diagram.
 (GNDEC, Dec. 2015)
23. What is scale and sludge ? Explain its disadvantages to boiler and different methods to prevent its formation.
 (GNDEC, Dec. 2015, Reappear)
24. Explain the zeolite process for softening of water. What are its advantages ?
 (GNDEC, Dec. 2014)
25. (a) What are major disadvantages of hard water when used for :
 (i) domestic purpose (ii) Industrial purpose (iii) Steam generation in boilers.
 (b) How is water disinfected by chlorination.
 (PTU May 2016)
26. Explain the Cold Lime-Soda process for removal of hardness of water and give the difference between cold and hot lime soda process.
 (PTU Dec. 2015)
27. Discuss the methods of disinfection of water.
 (PTU May 2016)
28. What do you understand by conditioning of boiler feed water ? Explain different types of conditioning.
 (PTU Dec. 2014)

Unsolved Numerical Problems

1. A sample of water was analysed and found to contain temporary magnesium hardness 25 mg/l. Permanent magnesium chloride hardness as 15 mg/l and permanent calcium sulphate hardness as 20 mg/l and SiO_2 as 300 mg/l. Calculate the lime and soda required for softening 30,000 l of hard water.
 (PTU May 2005)
2. Calculate the amount of lime (91% pure) and soda (91.2% pure) required for softening one million litres of water having ppm of $\text{Ca}(\text{HCO}_3)_2$ as 30.5, Mg (HCO_3)₂ as 35.5, MgSO_4 as 20, CaSO_4 as 24, CaCl_2 as 25 and NaCl as 10. Also calculate temporary and permanent hardness of water.
 (PTU Dec. 2004, Reappear)
3. A sample of water on analysis has been found to contain 10.05 mg/l $\text{Ca}(\text{HCO}_3)_2$, 12.5 mg/l $\text{Mg}(\text{HCO}_3)_2$, 7.5 mg/l CaSO_4 , 8.2 mg/l CaCl_2 , 2.6 mg/l MgSO_4 . Calculate the temporary and permanent hardness of water in ppm.
 (PTU May 2005 Reappear)

4. A sample of water has the following impurities in mg/l. Find the temporary and permanent hardness in ppm.
 $\text{Ca}(\text{HCO}_3)_2 = 10.00$, $\text{Mg}(\text{HCO}_3)_2 = 8.0$, $\text{CaSO}_4 = 12.0$ (PTU May 2006)
5. Calculate the amount of lime (85% pure) and soda (95% pure) required for softening 10,000 l of boiler feed water having the following impurities : $\text{Ca}(\text{HCO}_3)_2 = 16.2$ ppm, $\text{CaSO}_4 = 6.8$ ppm ; $\text{CaCl}_2 = 11.1$ ppm ; $\text{SiO}_2 = 8.0$ ppm ; $\text{MgSO}_4 = 6.0$ ppm ; $\text{NaCl} = 14.0$ ppm ; $\text{Mg}(\text{HCO}_3)_2 = 8.4$ ppm.
6. Calculate the amount of lime 90% pure and soda 98% pure for treatment of 1 million litres of water containing $\text{Ca}(\text{HCO}_3)_2 = 8.1$ ppm, $\text{CaCl}_2 = 33.3$ ppm ; $\text{HCO}_3^- = 91.5$ ppm ; $\text{MgCl}_2 = 38$ ppm and $\text{Mg}(\text{HCO}_3)_2 = 14.6$ ppm. The coagulant $\text{Al}_2(\text{SO}_4)_3$ was added at the rate of 17.1 mg/l of water.
7. A sample of water on analysis has been found to contain following in ppm :
 $\text{Ca}(\text{HCO}_3)_2 = 10.5$, $\text{Mg}(\text{HCO}_3)_2 = 12.5$, $\text{CaSO}_4 = 7.5$, $\text{CaCl}_2 = 8.2$, $\text{MgSO}_4 = 2.6$. Calculate the temporary and permanent hardness of water.
8. Calculate temporary hardness and total hardness of a sample of water containing ; $\text{Mg}(\text{HCO}_3)_2 = 7.3$ mg/l, $\text{Ca}(\text{HCO}_3)_2 = 16.2$ mg/l, $\text{MgCl}_2 = 9.5$ mg/l and $\text{CaSO}_4 = 13.6$ mg/l.
9. Calculate the amount of lime (84% pure) and soda (92% pure) required for treatment of 20,000 L of water analysed as :- $\text{Ca}(\text{HCO}_3)_2 = 40.5$ ppm, $\text{Mg}(\text{HCO}_3)_2 = 36.5$, $\text{MgSO}_4 = 30$ ppm, $\text{CaSO}_4 = 34$ ppm, $\text{CaCl}_2 = 27.75$ ppm, $\text{NaCl} = 10$ ppm. Also calculate temporary and permanent hardness. [Given atomic mass of H = 1, Na = 23, Ca = 40, Mg = 24, O = 16, S = 32, Cl = 35.5]. (PTU May 2007)
10. A water sample on analysis gave the following : $\text{Ca}^{2+} = 30$ mg/L, $\text{Mg}^{2+} = 24$ mg/L, $\text{CO}_2 = 24$ mg/L, $\text{HCl} = 50$ mg/L, $\text{K}^+ = 10$ mg/L. Calculate the quantities of lime (purity 90%) and soda (purity 94%) required to soften one million litres of water. (PTU May 2011)
11. Calculate the amount of lime and soda required per litre for chemical treatment of water containing $\text{Ca}^{2+} = 80$ ppm, $\text{Mg}^{2+} = 36$ ppm, $\text{HCO}_3^- = 244$ ppm and $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ added as coagulant = 69.5 ppm. What is total hardness of this water sample. (GNDEC, May 2016)
12. Calculate the amount of lime (91% pure) and soda (97.2% pure) required for softening of 100000 L of water containing $\text{Ca}(\text{HCO}_3)_2 = 30.5$ ppm, $\text{Mg}(\text{HCO}_3)_2 = 35.5$ ppm, $\text{MgSO}_4 = 20$ ppm, $\text{CaSO}_4 = 24$ ppm, $\text{CaCl}_2 = 25$ ppm and $\text{NaCl} = 10$ ppm. (GNDEC, Dec. 2014, Dec. 2015)
13. A water sample was found to have following impurities in mg/l: $\text{Ca}^{2+} = 30$, $\text{Mg}^{2+} = 24$, $\text{CO}_2 = 24$, $\text{HCl} = 50$, $\text{K}^+ = 10$. Calculate lime (90% pure) and soda (94% pure) required to soften one million litres of water sample. (GNDEC, Dec. 2015, Reappear)
14. Calculate the amount of lime and soda required to soften 50,000 L of water having following :
 $\text{Ca}(\text{HCO}_3)_2 = 8.1$ mg, $\text{Mg}(\text{HCO}_3)_2 = 5.0$ mg, $\text{CaSO}_4 = 13.6$ mg, $\text{NaCl} = 2.0$ mg; $\text{MgSO}_4 = 12.0$ mg and $\text{NaCl} = 4.7$ mg. ***** (PTU May 2015)