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# UNIT 4 WATER TECHNOLOGY

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## 4.1 INTRODUCTION

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Water representing the medium of life on earth is one of the most abundant compounds found in nature. Water cannot be produced or added as and when required by any technological means. The major constituent of water in any case is H<sub>2</sub>O which is the internal medium for almost all organisms, and principal external medium for several organisms. Although biological and physio-chemical properties of the pure chemical water are fascinating, its use or consumption determines its importance. Water is the substance which is present in all the three states of matter, i.e. gaseous, liquid and solid within the ranges of temperature and pressure common to the earth.

The availability of a water supply adequate in terms of both quantity and quality is essential for its use or consumption for different purposes like human use, crop production, industry etc. In this unit, we shall discuss some of the important aspects of use, water quality.

### Objectives

After studying this unit, you should be able to

- explain the important properties of water,
- classify the types of water,

- discuss the prevention methods for problems like scales, corrosion etc.,
- explain the industrial problems due to the use of hard water, and
- explain different water treatment methods.

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## 4.2 SOURCES OF WATER

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Water covers approximately three-fourths (75%) of the surface of the earth. Water present in surface, sub-surface, and atmosphere, in all its forms, is collectively called as *hydrosphere* in which surface water makes-up the major part of the earth's water supplies. Surface water refers to oceans (97%), ice caps and glaciers ( $\approx 2\%$ ), lakes, rivers, ponds, etc. (altogether comprises about 1% of the total surface water).

Sub-surface water consists of ground water including the soil moisture, while the atmospheric water presents water vapour and precipitation (rain and snowfall) in its all forms.

### (i) Oceans

Ocean water is the most impure form of natural water as all forms of running water (through rivers, springs etc.) pick up a large number of elements and compounds from the soil and air, and transports these substances in solution into the ocean. The continuous evaporation of water and no exit for these dissolved substances make the ocean water saline. The average total salt content of the oceans is 3.5% (35 g per kg of water) out of which sodium chloride contributes nearly 90% of the total dissolved salts.

Ocean water cannot be used a primary resource (direct use) for any purpose but can be used after desalination.

### (ii) Rivers

Rivers contain the surface running water which contributes about 85% of total water flow. Generally, rivers are exploited as primary resources for almost every use. Rivers contain many soluble minerals, organic matter and heavy metals. Direct discharge of untreated or partially treated domestic and industrial sewage into the river water makes it more unusable.

### (iii) Lakes and Reservoirs

Lakes, reservoirs and ponds represent the lentic waters (stagnant waters) which serve for many purposes like domestic water supplies, industrial processes, irrigation, and other commercial purposes. They contain constant chemical composition with high percentage of organic matter.

### (iv) Ground Water

It comes under sub-surface water which plays an important role in the overall water balance of the environment. Sub-surface has an enormous capacity to store the percolating water from the surface. This ground water is charged into surface flows (rivers, springs etc.) during the dry spell of the season. It is also used as a primary resource for many uses. The water table may go down in dry seasons due to evaporation and over-pumping but it is recharged by atmospheric precipitation.

### (v) Atmospheric Water

Atmospheric water is the ultimate source of all freshwater supplies on the earth received in the form of precipitation. It is not considered as a primary source of water supply. Atmospheric water also includes the water vapour in the environment which is to most nearly pure in nature. The atmospheric water is important in determining the conditions in the environment, particularly to keep the atmospheric temperature moderate within the hospitable range for most living organisms.

### 4.2.1 Hydrological Cycle

The total fresh and sea water content of earth is essentially fixed. The circulations of fresh water over the earth can be represented by a common process (hydrological cycle) under the influence of solar energy. Water is in a constant state of motion, i.e. through evaporation from surface waters and by evapotranspiration from plants, water molecules go to the atmosphere where they are transported by winds to various parts of the earth. In the transportation process, the water vapours come in contact with nuclei or surfaces and other atmosphere conditions where condensation takes place. Precipitation results when moisture in the clouds falls as rain, snow, sleet, hail, dew, or ice on the earth. As precipitation reaches the ground, the following three processes are occur :

(i) **Depression Storage and Interception**

In this first process, the precipitations are the filling of depressions (depression storage) and are intercepted by leaves and branches of trees and similar structure.

(ii) **Infiltration**

This is the second process in which precipitation enters underground through the surface. This process is carried out till to the saturation of infiltration capacity of the soil.

(iii) **Surface Runoff**

Surface runoff begins after the satisfaction of the depression storage and interception, and infiltration capacity. Water flows into streams, lakes and eventually to the oceans to complete the water cycle shown in Figure 4.1.

Figure 4.1 : Hydrological Cycle

### SAQ 1

- (a) What are the different sources of water?
- (b) What is the major function of atmospheric water?

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## 4.3 STRUCTURE OF WATER

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### Physical Structure

Water is the substance which is present in all the three states of matter, i.e. gaseous (water vapours), liquid, and solid (ice) within the ranges of temperature and pressure common to the earth.

### Chemical Structure

The chemical structure represented by the major constituent of water in all the states is  $\text{H}_2\text{O}$ , i.e. two hydrogen atoms and one oxygen atom. In the crystal structure of ice, the O-atom is surrounded by four H-atoms. Two H-atoms are linked to O-atom by covalent bonds (solid lines in Figure) and the remaining two H-atoms are linked to O-atom by two H-bonds shown by dotted lines (Figure 4.2). This type of bonding between O-atom and four H-atoms gives a tetrahedral structure to ice. In this structure, the covalent bond distance is  $1.0 \text{ \AA}$  whereas the H-bond distance is  $1.76 \text{ \AA}$ . Since H-bonds joining adjacent  $\text{H}_2\text{O}$  molecules are weaker and longer than normal covalent bonds, the structure of ice so obtained is cage like rigid structure as shown in Figure 4.2.

Figure 4.2 : Tetrahedral Structure of Ice (Cage-like Open Structure)

$\text{H}_2\text{O}$  molecules in the tetrahedral structure (cage-like open structure) of ice are not packed very closely together and hence there are vacant spaces in the structure. **The presence of four bonds per molecule in ice gives ice a three-dimensional figure** whereas in liquid state of water, there are average 2 to 3 bonds per molecule.

### 4.3.1 Properties of Water

Most of the anomalous properties of water can be explained on the basis of the presence of hydrogen bonds.

(i) **Ice has Lower Density than Water**

The cage-like open structure of ice has vacant spaces in it which gives a large volume to a given mass of ice. As density varies inversely to the volume, the density of ice is less. When ice is melted to liquid state, some of the H-bonds in the cage-like open structure of ice are broken to some extent and water molecules come closer to each other resulting in the decrease of volume. Hence, the density of water (liquid state) increases.

(ii) **Density of Water is Maximum at  $4^\circ\text{C}$**

As water is warmed from 0°C onwards, more and more H-bonds break down, resulting in contraction of volume. The effect of contraction predominates up to 4°C after which the effect of expansion (increase in volume) predominates due to increase in kinetic energy. Kinetic energy varies directly with the temperature. Thus, above 4°C the density of water starts decreasing again.

(iii) **Liquid State of Water**

The presence of lone pair of electrons on O-atoms in H<sub>2</sub>O molecules enables the water molecule to undergo association reaction with its own different molecules to form a cluster as (H<sub>2</sub>O)<sub>x</sub>. This process is known as polymerization. The formation of polymerized molecule (H<sub>2</sub>O)<sub>x</sub> by hydrogen bonding satisfies the explanation that water exists as a liquid state.

(iv) **Thermal Properties**

(a) ***Specific Heat***

The specific heat of a substance is the heat required to raise the temperature of one gram of the material by one degree celsius. Water has a specific heat of 1.0 calorie which is the highest among all substances except lithium and ammonia. The greater the specific heat, heating and cooling processes take place more slowly, i.e. here water heats or cools more slowly than other substances. Because of this property, the temperature and wind direction over shoreline and inland areas are well balanced.

(b) ***Latent Heat***

The latent heat of a substance is the heat required for a gram-mole of one state to convert it into another state. When the liquid state is converted into vapour state, it is called latent heat of vapourization which has quite a high value for water (539.55 cal/g). The latent heat of fusion (solid → liquid) of water is 79.71 cal/g. The high value of latent heat is due to the presence of hydrogen-bonds. These properties help in moderating the surface temperature of large bodies of water.

(v) **Cohesion and Adhesion**

Cohesion is the ability of water to stick to itself; therefore, water has a very high surface tension due to strong attraction of polar water molecules for each other by strong H-bonds on the surface of water. Adhesion is the ability of water to stick to some solid substance, hence, water shows the capillary action. Water in soil can rise several feet by capillary action which is used by plants.

## 4.4 SOLVENT ACTION OF WATER

Water is known as a universal solvent. It dissolves more substances than any other solvent. The solvent action of a solvent depends on its auto-ionisation. Water undergoes auto-ionisation as follows :



A polar molecule has positive and negative charge centers. Water is a polar molecule. Greater is the polarity of the bond, greater will be the charge separation and higher will be the dipole moment. Dipole moment is the product of charge

and distance between the two charges. The solvents (water) having higher values of dipole moment dissolve the polar substances (solutes) readily. Besides polar substances, several gases and organic molecules can also be dissolved in water. Water is chemically inert and does not change the properties of the solutes, nor does it get changed itself. The greater the polarity of a solvent molecule, greater is the solvation energy released on dissolution of a solute. The solvent action of water may be explained on the basis of Coulombic force of attraction ( $F$ ) between a cation and an anion in an ionic crystal. Thus,

$$F = \frac{q^+ q^-}{D r^2}$$

where  $q^+$  and  $q^-$  are charges on the cation and anion, respectively,  $D$  is dielectric constant, and  $r$  is the distance between the cation and anion. Water has the greater value of dielectric constant (78.5) than liquid  $\text{NH}_3$  (22.0), i.e. the force of attraction is lesser in water. Because of the force holding the ions of ionic crystal becomes weaker and hence ultimately water will dissolve the ionic crystal.

Greater the polarity of a solvent molecule, greater is the solvation energy released on dissolution of a solute. As a general rule, for a solid to be able to dissolve in a particular solvent (here water) its solvation energy must be greater than lattice energy of one solid. Because of this property, water is a better solvent for dissolving ionic compounds.

### SAQ 2

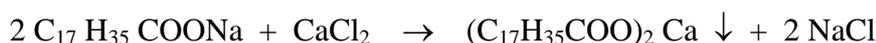
- Why does ice float on liquid water?
- Why is water a better solvent for ionic compounds than any other solvent?

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## 4.5 HARDNESS OF WATER

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Hardness of a water sample is a measure of its capacity to precipitate soap, i.e. to prevent the lathering of soap. Hardness is caused by multivalent metallic cations like  $\text{Ca}^{2+}$ , and  $\text{Mg}^{2+}$  ions. At supersaturated conditions, the hardness cations will react with anions in the water to form a solid precipitate. The principal hardness-causing cations are the divalent calcium, magnesium, strontium, ferrous ions, and manganous ions. These ions react with soap which is sodium salt of higher fatty acids and form insoluble scums (precipitates) of calcium or magnesium soaps. A typical divalent cation reaction is as follows :



Sodium stearate.

Lathering does not occur until all of the hardness ions are precipitated, at which point the water has been 'softened' by the soap. The polyvalent ions occur in water often in complex forms and not as free ions. As a result, they cannot precipitate soap. The most important anions with which multivalent metallic cations associated are bicarbonate (carbonate), sulphate, chloride, nitrate, and silicate.

### Sources

The multivalent metallic ions in water are derived largely from contact with the soil and rock formation. The ability to dissolve is gained in the soil where carbon dioxide is released by bacterial action. This carbon dioxide forms carbonic acid to reduce the pH value. Under the low pH conditions, basic materials are dissolved in it.

### 4.5.1 Types of Hardness

Hardness is classified in two ways :

- (i) With respect to the multivalent metallic ion, and
- (ii) With respect to the anions associated with multivalent metallic ions.

#### Hardness based on Metallic Ion

Calcium and magnesium are the most abundant ions in natural water which contribute the greatest portion of the hardness occurring in natural waters. Thus, it is assumed that the hardness due to these two metallic ions is considered as *total hardness*. Calcium hardness is caused by  $\text{Ca}^{2+}$  and is determined as the amount of  $\text{Ca}^{2+}$  required to softening the lime-soda ash. Similarly, magnesium hardness is due to  $\text{Mg}^{2+}$  ions and is determined as the amount of  $\text{Mg}^{2+}$  required for softening lime-soda ash. If magnesium hardness is determined, calcium hardness is obtained by subtracting magnesium hardness from total hardness, as follows :

$$\text{Total hardness} - \text{magnesium hardness} = \text{calcium hardness}$$

#### Hardness based on Anions

This hardness is classified as *carbonate hardness* and *non-carbonate hardness*, depending upon the anion with which it associates. When the hardness ions are associated with  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$  ions in water, the hardness is called carbonate hardness, otherwise, it is called non-carbonate hardness. The carbonate hardness is chemically equivalent to the carbonate plus bicarbonate alkalinity present in water. Thus,

When alkalinity < total hardness

$$\text{Carbonate hardness (in mg L}^{-1}\text{)} = \text{alkalinity (in mg L}^{-1}\text{)}.$$

When alkalinity  $\geq$  total hardness

$$\text{Carbonate hardness (in mg L}^{-1}\text{)} = \text{total hardness (in mg L}^{-1}\text{)}$$

The carbonate hardness is also known as *temporary hardness* which can be removed by boiling.

The non-carbonate hardness, known as *permanent hardness*, can be determined as :

Non-carbonate hardness = total hardness – carbonate hardness
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The permanent hardness cannot be removed by boiling. The non-carbonate hardness cations are associated with chloride, nitrate and sulphate anions.

### Pseudo Hardness

The metallic cation which is not a hardness-causing cation, but exhibits hardness when present in high concentration is known as *pseudo-hardness*. For example, sodium metal ion which is present in very high concentration in sea and brackish water, exhibits hardness.

## 4.5.2 Removal of Hardness

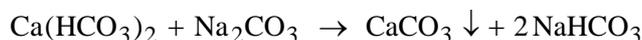
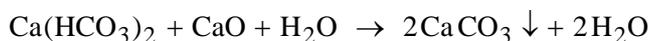
### (a) Removal of Carbonate or Temporary Hardness

Carbonate hardness is sensitive to heat and precipitate readily at high temperatures. Thus, it is removed as precipitates as :

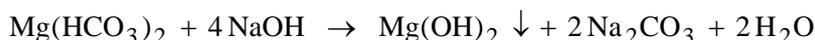
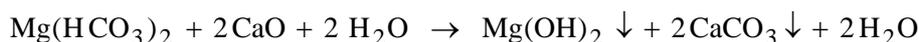


The other methods of removal are as follows :

The carbonate hardness of calcium may be removed chemically by using lime (CaO), caustic soda (NaOH) and soda ash (Na<sub>2</sub>CO<sub>3</sub>) as depicted below.



Carbonate hardness of magnesium may be removed chemically by using lime followed by caustic soda as follows :

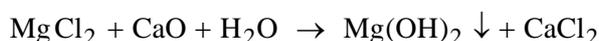
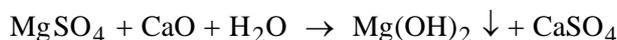


### (b) Removal of Non-carbonate or Permanent Hardness

Non-carbonate calcium hardness (calcium with non-carbonate anions) can be conveniently removed by using soda ash (Na<sub>2</sub>CO<sub>3</sub>). Thus,



The non-carbonate magnesium hardness (magnesium with non-carbonate anions) can be removed by using caustic soda or a combination of lime and soda ash. The representative chemical reactions are :



*Order of Removal*

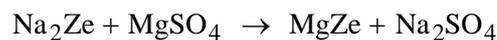
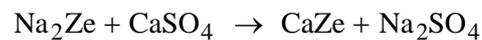
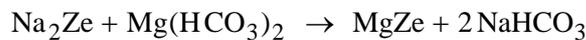
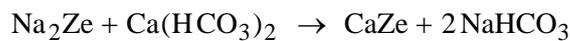
The order of removal depends on the solubility of the precipitates like  $\text{CaCO}_3$  and  $\text{Mg}(\text{OH})_2$ . Since  $\text{Mg}(\text{OH})_2$  is more insoluble than  $\text{CaCO}_3$ , the reaction producing  $\text{Mg}(\text{OH})_2$  should take precedence.

(c) **Split Treatment**

Water with a high concentration of magnesium is softened by split treatment. In this treatment, the raw water is split into two streams, the first stream is softened by using excess lime, and the second stream bypassed and remixed with the softened first stream. Thus, both streams are softened.

(d) **Zeolite Process (Permutit Process)**

The zeolites (natural and synthetic) are complex aluminosilicates whose chemical molecular form may be as  $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot x \text{SiO}_2 \cdot y \text{H}_2\text{O}$  where  $x$  varies from 2 to 10 and  $y$ , 2 to 6. These are capable of exchanging their sodium ions for  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  of the hard water reversibly. The chemical reaction may be as follows :



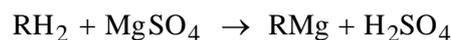
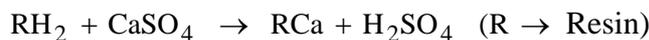
This process is suitable for removal of both carbonate and non-carbonate hardness of water.

(e) **Demineralization of Water**

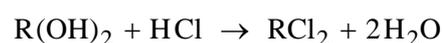
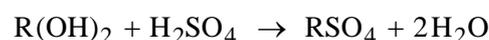
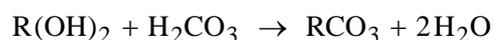
The process of complete removal of all ions present in a water is called *demineralization* which is carried out by using ion exchange resins. Ion exchange resins are insoluble, cross linked long chain organic polymers with a microporous structure. Based on the functional groups (acidic or basic) attached in resins, the resins may be classified as

- (i) Cation exchange resins, and
- (ii) Anion exchange resins, respectively.

*Cation exchange resins* are mainly styrene-divinyl benzene copolymers in which on sulphonation or carboxylation,  $-\text{SO}_3\text{H}$  or  $-\text{COOH}$  groups are introduced in the *para* position due to steric hindrance. These acidic functional groups are capable of exchanging their hydrogen ions with the cations in the water as per the following equation.

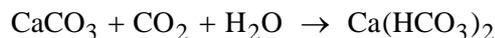


Similarly, the *anion exchange resins* are styrene divinyl benzene or amine formaldehyde copolymers, which contain quaternary ammonium groups as an integral part of the resin matrix. The  $-\text{OH}$  groups present in these resins can enter into the exchange reaction with anions in water.

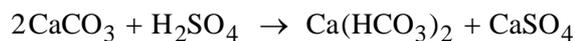


### 4.5.3 Excess Treatment and Stabilization

The optimum pH for precipitation of  $\text{CaCO}_3$  and  $\text{Mg(OH)}_2$  is 10.3 and 11, respectively. To achieve this pH value, excess lime or caustic is used which in turn causes scale forming. Scale forming can be stopped as long as the concentration of  $\text{CaCO}_3$  and  $\text{Mg(OH)}_2$  is less than their solubilities. Thus, to prevent scale formation, they must be stabilized. Stabilization may be obtained by a process known as *recarbonation*. The recarbonation is a process in which  $\text{CO}_2$  is used and the chemical reaction is



It can also be done by using one of the several acids.



#### Equivalents of Calcium Carbonate

The hardness of water is expressed as the equivalent amount of  $\text{CaCO}_3$ , i.e. the  $\text{MgCaCO}_3/\text{L}$  though calcium is not the only cation causing hardness. It is chosen as standard because of the following conveniences.

- (i)  $\text{CaCO}_3$  is chosen as the standard mainly because it is having great convenience in calculation as its molecular weight is 100 and equivalent weight is 50.
- (ii) It is sparingly soluble salt in water and can be easily precipitated out in the lime soda processes of softening water.

All the hardness causing impurities are first converted in terms of their respective weight equivalent to  $\text{CaCO}_3$  and is expressed in parts per million (ppm).

Equivalent of  $\text{CaCO}_3 =$

$$\frac{[\text{Mass of hardness producing substance}] \times [\text{Chemical equivalent of } \text{CaCO}_3 = 50]}{[\text{Chemical equivalent weight of the hardness producing substance}]}$$

The hardness can be calculated in alternative way as

$$\text{mg of } \text{CaCO}_3 \text{ L}^{-1} = \frac{100.09}{40.08} \times [\text{conc. of Ca, mg L}^{-1}] + \frac{100.09}{24.30} (\text{conc. of Mg, mg L}^{-1})$$

where 100.09, 40.08 and 24.30 are the molecular weight of  $\text{CaCO}_3$ , Ca, and Mg, respectively.

#### 4.5.4 Units of Hardness

The units used to represent hardness are as follows.

**(i) Parts per Million (ppm)**

Parts per million is the parts of calcium carbonate equivalent hardness per  $10^6$  parts of water.

1 ppm = 1 part of  $\text{CaCO}_3$  eq. hardness in  $10^6$  parts of water.

**(ii) Milligram per Litter ( $\text{mg L}^{-1}$ )**

It is the number of milligrams of  $\text{CaCO}_3$  equivalent hardness present per liter of water.

1  $\text{mg L}^{-1} = 1$  mg of  $\text{CaCO}_3$  eq. hardness per liter of water

1  $\text{mg L}^{-1} = 1$  part of  $\text{CaCO}_3$  eq. hardness per  $10^6$  parts of water.

Hence, 1  $\text{mg L}^{-1} = 1$  ppm.

**(iii) Degree of French ( $^{\circ}\text{Fr}$ )**

It is the parts of  $\text{CaCO}_3$  eq. hardness per  $10^5$  parts of water. Hence,

1  $^{\circ}\text{Fr} = 1$  part of  $\text{CaCO}_3$  eq. hardness per  $10^5$  parts of water.

**(iv) Clark's Degree ( $^{\circ}\text{Cl}$ )**

It is the number of grains of  $\text{CaCO}_3$  eq. hardness per gallon of water.

1 grain =  $\frac{1}{7000}$  lbs, and 1 gallon = 10 lbs.

1 $^{\circ}$  Clarke = 1 part of  $\text{CaCO}_3$  eq. hardness per 70000 parts of water.

***Relationship between various units of hardness***

1 ppm = 1 mg/L = 0.1 $^{\circ}\text{Fr}$ = 0.07 $^{\circ}\text{Cl}$ = 0.07 grain/gallon
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#### Impacts of Hardness

- (i) Hard water is not suitable for bathing, washing, cleaning and laundering. It is also not suitable for drinking and cooking purposes.

- (ii) Hard water produces heat retarding scales, so it is not suitable for use in boilers or condensers. It is not suitable for dyeing in the textile industry, beer industry, sugar industry, paper, pharmaceutical and food industries.
- (iii) Hard water creates some health problems like nervous system defects, pre-natal mortality and various types of cancer.

The general scale of hardness is given in Table 4.1.

**Table 4.1 : General Scale of Hardness**

Hardness of Water (mg/L CaCO <sub>3</sub> )	Description
0 – 17	Soft
17 – 60	Slightly hard
60 – 120	Moderately hard
120 – 180	Hard
More than 180	Very hard

Source : Lehr. et. al., (1980), “*Domestic Water Treatment*”, McGraw Hill Book Company, New Delhi

### SAQ 3

- (a) What are the types of hardness of water?
- (b) Mention the common units used for expressing hardness of water.
- (c) What is the principle applied to remove the hardness of water by the line-soda process?
- (d) What happens when temporary hard water is boiled? (Give equations)
- (e) Name three substances used for sterilization of water.

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## 4.6 SLUDGE AND SCALE FORMATION IN BOILERS

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### Sludge

In boilers, water evaporates continuously and the concentration of dissolved salts increases and the salts are thrown off in the form of slimy precipitates, thus, sludge is a soft, loose and slimy precipitate formed within the boiler. Sludges are formed by substances which have greater solubility in hot water than in cold water. For example :



### *Disadvantages of Sludge Formation*

- (i) Sludges are poor conductor of heat, so there is wastage of fuel.
- (ii) Sludge formation decreases the efficiency of the boiler.

- (iii) If sludges are formed along with scales, then both will be deposited on the inner walls of boiler and then it cannot be removed easily.

### ***Prevention of Sludge Formation***

- (i) By using soft water in boilers.  
 (ii) By frequent blow-down operation and replacing it by fresh water.  
 (iii) Sludge can be easily scrapped off with wire brush.

### **Scale**

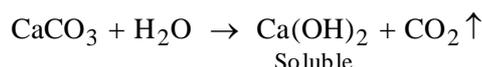
Scales are hard deposits, which stick very firmly to the inner walls of the boiler. Scales are difficult to remove as these are hard coating. The scale formation is due to

#### **(i) The Decomposition of Calcium Bicarbonate**



The soft scales are generally formed in low pressure boilers.

But in pressure boilers,  $\text{CaCO}_3$  is soluble, hence it is a soft scale.

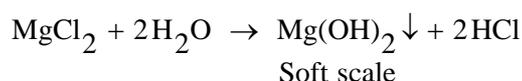


#### **(ii) Deposition of $\text{CaSO}_4$**

The solubility of Calcium Sulphate in water decreases with rise in temperature. Consequently,  $\text{CaSO}_4$  gets precipitated as hard scale on the heated portion of the boiler. Usually this type of scale is formed in high pressure boilers. The hard scale is difficult to remove.

#### **(iii) Hydrolysis of Magnesium Salts**

Dissolved magnesium salts undergo hydrolysis forming magnesium hydroxide precipitate.



#### **(iv) Presence of Silica ( $\text{SiO}_2$ )**

Silica present in water even in small quantity is deposited as Calcium Silicate ( $\text{CaSiO}_3$ ) or Magnesium Silicate ( $\text{MgSiO}_4$ ) or both. These deposits stick very firmly to the inner side of the boiler surface and are very difficult to remove.

### ***Disadvantages of Scale Formation***

#### **(i) Wastage of Fuel**

Scales have low thermal conductivity so heat transfer from boiler to inside water is not so efficient. This results in over heating and causes increase in fuel consumption. The wastage of fuel depends upon the thickness and nature of the scale which is shown in Table 4.2.

**Table 4.2 : Relationship between the Thickness of the Scale and the Wastage of Fuel**

<b>Thickness of Scale (mm)</b>	0.325	0.630	1.25	2.50	12.00
<b>Wastage of Fuel</b>	10%	15%	50%	80%	150%

**(ii) Lowering of Boiler Safety**

The boiler with scale deposits has to be excessively heated for a steady supply of steam. The over heating of the boiler tube makes the boiler material soft and weak. So the boiler could not withstand the pressure.

**(iii) Decrease in Efficiency**

Scales sometimes deposit in the valves and condensers of the boiler and choke them. This results in decrease in efficiency of the boiler.

**(iv) Danger of Explosion**

Sometimes due to over heating the thick scales may crack which causes the sudden contact of high heated boiler material with the water. This causes in formation of a large amount of steam and thereby high pressure develops which may lead to explosion.

***Removal of Scales***

- (i) At the initial stage, scales can be removed using scraper, wire brush etc.
- (ii) If scales are brittle, then by giving thermal shocks.
- (iii) By using suitable chemicals like dil. acids (for  $\text{CaCO}_3$  scale), EDTA (for  $\text{CaSO}_4$  scale) with which they form suitable complexes.
- (iv) By frequent blow down operation, if the scales are loosely adhering.

***Prevention of Scale Forming***

By giving certain chemical treatment to boiler water, the scale formation can be prevented. There are two treatment methods such as :

**(i) External Treatment**

Treatment of water before supplying it to the boiler is called external treatment. This includes the softening of water which has been discussed in detail in this unit.

**(ii) Internal Treatment**

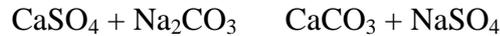
An internal treatment is accomplished by adding a proper chemical to the boiler water during the evaporation process itself. This process involves

- (a) Precipitation of scale forming impurities as sludges which can be removed by blow down operation, or

- (b) To convert them into soluble compounds thus do not cause any harm.

The important internal conditioning methods are discussed as :

- (i) **Carbonate Conditioning** : In low pressure boilers, scale formation can be avoided by adding sodium carbonate to boiler water, where  $\text{CaSO}_4$  is converted into calcium carbonate.



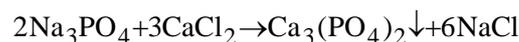
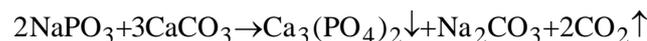
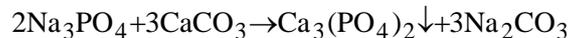
The deposition of  $\text{CaCO}_3$  is harmless and this can be removed. The carbonate conditioning can be used only for low pressure boilers. In high pressure boilers the excess of  $\text{Na}_2\text{CO}_2$  would be converted into  $\text{NaOH}$  due to hydrolysis.



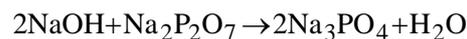
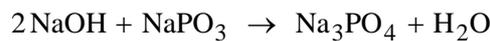
The  $\text{NaOH}$  formed causes caustic embrittlement in high pressure boilers.

- (ii) **Phosphate Conditioning** : The scale formation is prevented by adding adequate sodium phosphate to the boiler water. It is safer to precipitate  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$  as calcium phosphate and magnesium phosphate respectively which are non-adherent, soft scale and easily removable.

The main phosphate used for conditioning are  $\text{Na}_3\text{PO}_4$ ,  $\text{Na}_2\text{HPO}_4$ ,  $\text{NaH}_2\text{PO}_4$ ,  $\text{NaPO}_3$  and  $\text{Na}_4\text{P}_2\text{O}_7$  and the reactions involved are :



Similarly  $\text{Mg}^{+2}$  ions can be precipitated out. The formation of  $\text{Na}_2\text{CO}_3$  during the above reactions on hydrolysis in high pressure boilers produce  $\text{NaOH}$  which may cause caustic embrittlement. This can be prevented by adding sodium meta-phosphate and pyro-phosphate as

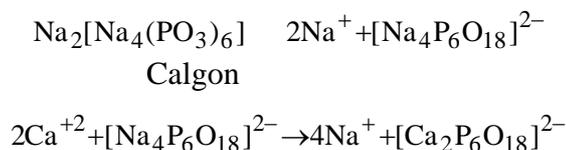


The choice of salt depends upon the alkalinity of the boiler feed water.

Sl. No.	Nature of the Boiler Feed Water	Chemicals to be added
1	Acidic water	Alkaline $\text{Na}_3\text{PO}_4$
2	Slightly alkaline water	Acidic $\text{Na}_2\text{HPO}_4$
3	Alkaline water	Acidic $\text{NaH}_2\text{PO}_4$

Phosphate conditioning is suitable to both low and high pressure boilers.

- (iii) **Colloidal Conditioning** : In low pressure boilers, the scale formation can be checked by adding some colloidal conditioning agents like tannin, agar-agar, glue, kerosene and starch which do not allow the scale forming impurities to precipitate. Thereby, resulting in formation of nonsticky colloidal solution which can be removed by blow down operation.
- (iv) **Calgon Conditioning** : The scale formation can be prevented by adding Calgon ( $\text{NaPO}_3$ )<sub>6</sub>, sodium hexameta phosphate to boiler water to form a highly soluble complex compounds with the  $\text{Ca}^{+2}$  ions.



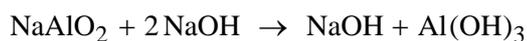
Calgon conditioning is suitable for low pressure boilers.

- (v) **EDTA Conditioning** : Some chelating agents like EDTA are added to boiler water to prevent scale formation by producing complex compound with  $\text{Ca}^{2+}$  ions.

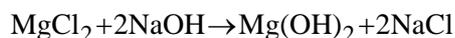


$[\text{Ca-EDTA}]^{2+}$  is a highly soluble complex and precipitation of  $\text{Ca}_2\text{SO}_4$  is prevented.

- (vi) **Treatment with Sodium Aluminate ( $\text{NaAlO}_2$ )** : Sodium aluminate gets hydrolysed inside the boiler giving  $\text{Al}(\text{OH})_3$  and  $\text{NaOH}$ .



The sodium hydroxide formed would react with  $\text{Mg}^{2+}$  ions forming  $\text{Mg}(\text{OH})_2$ .



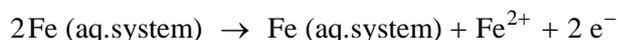
The flocculant precipitate of  $\text{Mg}(\text{OH})_2$  and  $\text{Al}(\text{OH})_3$  entrap suspended particles like oil, silica and other colloidal impurities. The loose precipitate can be removed by blow down operation.

- (vii) **Electrical Conditioning** : Glass bulbs containing mercury are set inside the boiler to prevent scale forming particles by emitting electric discharges when the water boils. Due to electrical discharges, the scale forming impurities cannot be aggregated together, thereby scale formation is prevented.
- (viii) **Radioactive Conditioning** : Tablets containing radioactive salts are placed inside the boiler water at a few points. The radioactive radiations emitted by these salts prevent scale formation.

## 4.7 BOILER CORROSION AND ITS PREVENTION

Corrosion is a process in which the metal atoms leave their location on the surface and stabilize in the form of ions in solution. Corrosion in an aqueous system occurs due to the interaction between the surface of the materials and water body under conditions of chemical stress, i.e. acidic or alkaline.

Water is a polar molecule and the polarisability of the water molecules on contact with the iron surface leads to the weakening of the O – H bond.



$[\text{Fe}(\text{H}_2\text{O})_5\text{OH}]^+$  is the primary corrosion product which gives secondary hydrolysis product, as  $\text{Fe}(\text{OH})_2$ . The other secondary products are  $\text{FeO.OH}$ ,  $\text{FeO}$ ,  $\text{Fe}_3\text{O}_4$ ,  $\text{Fe}_2\text{O}_3$  etc. All these secondary products are pH dependent.

### 4.7.1 Boiler Corrosion

Boiler corrosion is the deterioration of the boiler material by direct chemical or electrochemical attack of its (aqueous) environment. In high pressure boilers, the failure of boiler tubes made up of carbon steel is due to internal corrosion and external “hot corrosion”. The external corrosion is metallurgical in nature, therefore, we shall discuss about the internal corrosion.

#### Causes

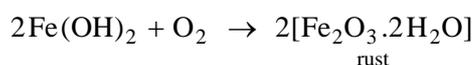
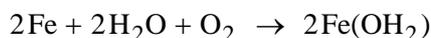
The internal boiler corrosion is caused due to the following important reasons :

- (i) Dissolved oxygen
- (ii) Dissolved  $\text{CO}_2$
- (iii) Presence of acids or acidic salts

These corrosion mechanisms and removal are discussed as :

#### *Dissolved Oxygen*

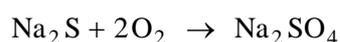
Normal water usually contains dissolved oxygen. When water is heated in the boiler, the free gas ( $\text{O}_2$ ) is evolved which corrodes the metal parts under high temperature.



Free gas ( $\text{O}_2$ ) reacts with iron in presence of water resulting in the formation of rust on the boiler.

#### Removal of Dissolved Oxygen

- (i) By adding a suitable proportion of sodium sulphite or hydrazine or sodium sulphide. Thus, the chemical reaction are as under :



- (ii) **By Mechanical Deaeration :** The deaeration is done by a vacuum pump to remove all the free gases ( $O_2$ ) as it provides high temperature, low pressure and large surface area which is shown in Figure 4.3.

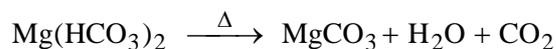
**Figure 4.3 : Mechanical Deaeration of Water**

***Dissolved CO<sub>2</sub>***

Dissolved  $CO_2$  with water forms carbonic acid which has the corrosive effect on the boiler material

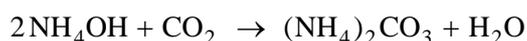


If water itself contains bicarbonate, then  $CO_2$  will be formed inside the boiler as well.



**Removal of  $CO_2$**

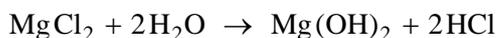
- (i) Dissolved  $CO_2$  can be removed by adding ammonia :



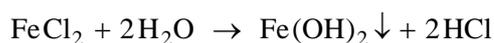
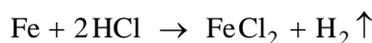
- (ii) **Mechanical Deaeration :** In the same way as it is for dissolved oxygen.

***Presence of Acids or Acidic Salts***

Dissolved salts present in water may undergo hydrolysis and produce acids.



The HCl produced reacts with iron as follows.



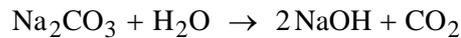
The presence of a small amount of  $MgCl_2$  will also cause corrosion of iron severely.

**Removal of Acids**

By adding acid neutralized alkali to the boiler water.

## 4.7.2 Caustic Embrittlement

It is a type of boiler corrosion caused by using highly alkaline water in the boiler. In high pressure boilers, when  $\text{Na}_2\text{CO}_3$  hydrolyses with water resulting in sodium hydroxide and carbon dioxide, the NaOH makes the boiler water caustic.



This NaOH containing water flows into the minute hair cracks, usually found on the inner walls of the boiler by capillary action. Due to high heat, water evaporates and dissolved caustic soda concentration increases. The caustic soda reacts with iron of boiler, producing sodium ferroate. Sodium ferroate causes embrittlement of the boiler parts when stress is more. This can be well expressed by the formation of concentration cell as follows :

### *Anodic area*

Iron as stressed area | concentrated NaOH | | dil. NaOH | Iron at plane surfaces

### *Cathodic area*

The iron in contact with concentrated NaOH becomes anodic part where the corrosion takes place, while the iron in contact with dilute NaOH becomes cathodic part which is not prone to corrosion.

## Removal of Caustic Embrittlement

- (i) By adding colloidal agents like tannins, agar-agar etc. to boiler water which help to block the hair cracks thereby preventing the infiltration of NaOH containing water to the inner side of the boilers.
- (ii) By using sodium phosphate in boiler water.
- (iii) Sometimes  $\text{Na}_2\text{SO}_4$  is used to block the hair cracks in the boilers. The proportion of  $\text{Na}_2\text{SO}_4$  in the boiler water depends on the boiler pressure as mentioned below :

$\frac{[\text{Na}_2\text{SO}_4]}{[\text{NaOH}]}$  Concentration ratio should be kept as given in the table.

$\frac{[\text{Na}_2\text{SO}_4]}{[\text{NaOH}]}$	1 : 1	2 : 1	3 : 1	4 : 1
Boiler Pressure (Atm)	10	20	30	40

## 4.7.3 Priming and Foaming

In the steam formation process, some drops of water carried along with steam is called priming. Priming is caused mainly due to the following factors

- (i) rapid boiling of water
- (ii) the presence of suspended solids
- (iii) high level of water in boiler
- (iv) the growth of algae
- (v) sudden change of steam production rate
- (vi) improper boiler design.

Priming can be minimized by the following factors :

- (i) by fitting mechanical steam purifier.
- (ii) minimizing the amount of dissolved and suspended impurities.

- (iii) avoiding rapid change in steaming rate.
- (iv) maintaining low water levels.

### Foaming

Foaming is the formation of continuous and permanent foam or bubbles in the boiler water which do not break easily and are carried over steam causing priming. Thus, priming and foaming occur together which is objectionable.

The main problems caused by foaming are :

- (i) If the bubbles do not break, they may be carried along the steam to super heater and turbine blades where the water evaporates and the dissolved salts get deposited.
- (ii) Actual water level inside the boiler cannot be judged properly.
- (iii) These decrease the life time and efficiency of the machinery.

Foaming can be minimized by the following ways :

- (i) Adding anti-foaming agents like castor oil, polyamides etc.
- (ii) Removing oil content from boiler-feed water by adding alum and soda ash.
- (iii) By blow down operation.

### SAQ 4

- (a) Name the gases dissolved in water that cause corrosion.
- (b) Why is water softened by zeolite process unfit for use in boilers?

## 4.8 pH VALUE AND WATER TREATMENT

### The Concept of pH

Sorenson (1909) proposed to express the hydrogen-ion activity in terms of negative logarithms of hydrogen-ion activity and designated these values as pH.

$$\text{pH} = -\log a_{\text{H}^+}$$

$$a_{\text{H}^+} = 10^{-\text{pH}}$$

When the solution is very dilute,  $a_{\text{H}^+} = C_{\text{H}^+}$

$$\therefore \text{pH} = -\log C_{\text{H}^+}$$

### Example 4.1

For a solution of  $\text{pH} = 3$ ,  $C_{\text{H}^+} = 10^{-3}$

Similarly, the activity of  $\text{OH}^-$  ions expressed in terms of pOH.

$$\begin{aligned}
 & \text{pOH} = -\log a_{\text{OH}^-} \\
 \text{or,} & \text{pOH} = -\log C_{\text{OH}^-} \\
 & C_{\text{H}^+} \cdot C_{\text{OH}^-} = K_w \\
 & -\log K_w = \text{p} K_w \\
 & \text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^- \\
 & \frac{C_{\text{H}^+} C_{\text{OH}^-}}{C_{\text{H}_2\text{O}}} = K \quad (C_{\text{H}_2\text{O}} = 1)
 \end{aligned}$$

$$\text{pH} + \text{pOH} = \text{p}K_w = \text{constant} = 10^{-14}$$

Thus, as pH increases, pOH must decrease and vice-versa. In pure water, which is neutral  $C_{\text{H}^+} C_{\text{OH}^-} = 10^{-7}$ , i.e. the pH of water is 7. Hence, the neutral solution has a pH = 7. Any solution having pH less than 7 will be acidic and a solution having pH more than 7 will be alkaline. The pH scale ranges from 0 to 14, with pH 7 at 25°C representing absolute neutrality.

The value of  $K_w$  changes with change in temperature, hence, the pH of neutrality changes with temperature. It is 7.5 at 0°C and 6.5 at 60°C.

pH does not measure total acidity or total alkalinity. The  $C_{\text{H}^+}$  and  $C_{\text{OH}^-}$  values can never be reduced to zero, no matter how alkaline or acidic, respectively a solution becomes. These are only the comparative values depending on the degree of ionization. For example, N/10 solutions of sulphuric acid and acetic acid which have same neutralizing value; the pH of N/10 sulphuric acid is approximately 1 because of its high degree of ionization, and the pH of acetic acid is about 3 because of its low degree of ionization. pH is an important factor which must be considered in control of the water quality.

#### 4.8.1 Water Treatment

Water treatment generally considers the purification of raw water for drinking purposes. The drinking water should be colourless, odourless, free from suspended impurities, germs, bacteria and other dissolved impurities which are injurious to health. It should be free from objectionable dissolved gases, turbidity, minerals. The pH value of the drinking water should be within the range of 6.5 to 8. Therefore, to make pure drinking water, some important stages of purification of raw water are :

- (a) Pretreatment
- (b) Sedimentation
- (c) Filtration
- (d) Disinfection

##### (a) Pretreatment

The important steps involved in the pretreatment of raw water are

- (i) Storage
- (ii) Prechlorination
- (iii) Aeration
- (iv) Coagulation and flocculation.

Let us now study them in detail.

(i) *Storage*

The raw water is stored for some period before the actual treatment starts in order to improve the quality of water by natural sedimentation of silt and inactivation of certain pathogenic organisms.

(ii) *Prechlorination*

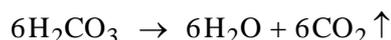
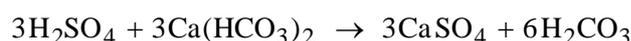
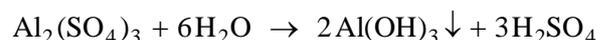
The storage water subjected to prechlorination to remove algal cells and bacteria. Prechlorination is suitable to low silt load water and it reduces the colour and slime formation. To some extent, it oxidises the iron and manganese which are precipitated out.

(iii) *Aeration*

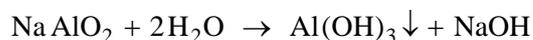
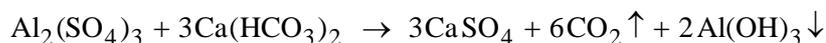
The raw water is first saturated with oxygen by bubbling compressed air. The free gases like CO<sub>2</sub>, H<sub>2</sub>S if present, will be removed. The process of aeration helps in removing tastes and odours caused by algal secretion in the form of volatile oils. Few Fe<sup>2+</sup> and Mn<sup>2+</sup> will also be oxidized and precipitated out.

(iv) *Coagulation and Flocculation*

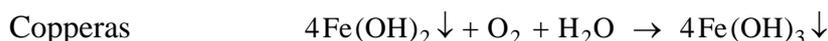
The aerated water which may contain small particles in the colloidal range, can be removed by promoting their agglomeration by flocculation in the presence of coagulants. The following are the most commonly used coagulants (a) alum, (b) sodium aluminate, copperas or ferrous sulphates. A coagulant is a chemical which reacts with water to form a bulky precipitate called *floc*. The agglomerated particles called *floccules* are latter separated from water by filtration. The reactions are



The overall reaction is



Sodium Aluminate



The floccules are separated by sedimentation and filtration.

(b) **Sedimentation**

The water with floccules are allowed to settle down for some period in a sedimentation basin in which floccule particles settled down at the bottom due to the force of gravity.

The clear supernatant water is then pumped out. The settling rate depends on the mass and density of the particles.

(c) **Filtration**

The partly clarified water from the sedimentation basin is then passed to the stand gravity filters to remove the small floc particles and microorganisms still remained in water after sedimentation.

#### Figure 4.4 : Sand Filter

All the suspended matter are filtered out in the sand bed. These filters are of two types :

- (i) Rapid sand filters (Filtering rate is more and is rapidly exhausted), and
- (ii) Slow sand filters (Rate is slow but durable).

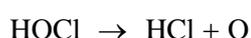
Generally, slow sand filters are used in the absence of coagulation and sedimentation.

#### (d) Disinfection

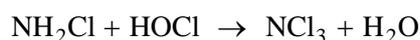
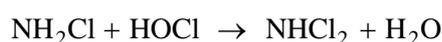
The final sand filtrate is very clean but may not be free from microorganisms. Therefore, disinfection of that filtered water is quite essential which is obtained by (i) chlorination, and (ii) ozonisation.

##### (i) Chlorination

Chlorine is a powerful disinfectant as it produces HOCl, OCl, Chloramines.



The hypochlorous acid is an unstable compound and quickly decomposes by releasing nascent oxygen. The presence of ammonia in water leads to the formation of chloramines as follows :



The chemical species HOCl, OCl are free chlorine residuals whereas chloramines are combined residuals and remain in water body for a longer period which help to kill the microorganisms even in a distribution system. The bacterial action of chlorine is mainly because of the toxic nature of the residuals and the oxidation of biomolecules by the nascent oxygen. The doses of chlorine are decided depending upon the pH, CO<sub>2</sub>, temperature and the time of contact with water.

Liquid chlorine is most effective and the apparatus used for this purpose is called *Chlorinator*.

**Figure 4.5 : Chlorinator**

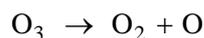
**Advantages**

- (i) It is effective.
- (ii) It is very much stable and does not deteriorate on keeping.
- (iii) It can be used at low as well as high temperatures.
- (iv) It introduces no salt impurities in the treated water.
- (v) It is a very powerful disinfectant.

**Disadvantages**

- (i) Excess of chlorine produces unpleasant taste and odour. It also produces irritation on mucus membrane. It should be used within the range of 0.1 to 0.2 ppm.
  - (ii) It is less effective in alkaline conditions.
- (ii) **Ozonisation**

Ozone behaves in a similar manner to chlorine by releasing nascent oxygen.



Thus, ozone is a very powerful disinfectant for bacteria, fungi and viruses. In general, the enteric viruses are much more resistant to ozone treatment than the bacteria of coliform group.

**Process**

Ozone is introduced into the water for a period of 10 to 15 minutes and its dose strength is about 2 to 3 ppm.

**Figure 4.6 : Ozone Sterilizer**

**Advantages**

- (i) Ozone does not leave any residuals in water.
- (ii) Small dose of chlorine is more effective after ozonisation.
- (iii) Ozonisation stops any development of tastes and odours.

### **Disadvantage**

It is very expensive.

### **Other Disinfection (U. V.) Process**

Germicidal U. V. radiation can be used for disinfection. It kills the microorganisms and develops no taste or odour to water.

The substances like  $\text{KMnO}_4$ , bromine and iodine have also been employed for purpose of disinfection. Electrolysis process in which with the addition of  $\text{NaCl}$  produces  $\text{Cl}_2$  can also be used for this purpose.

The complete flow diagram of drinking water treatment plant is shown in Figure 4.7.

**Figure 4.7 : Flow Diagram of Drinking Water Treatment Plant**

## **4.8.2 Desalination of Brackish Water**

The process carried out to remove the common salt ( $\text{NaCl}$ ) from the water body is known as desalination. The water containing dissolved salts with a peculiar salty or brackish taste, is called brackish water. Brackish water is totally unfit for human consumption and important methods employed for desalination are :

- (i) Distillation.
- (ii) Freezing.
- (iii) Reverse Osmosis.
- (iv) Electrodialysis.

### **Distillation**

The basic principle of distillation is to remove the non-volatile salts present in water. In the distillation process, the brackish water or sea water is boiled and the vapours are condensed and collected. This distilled water is free from volatile salts.

The distillation process will be more effective by using multistage evaporators so that more pure water vapour is condensed and collected. Since it is a multistage evaporators system less heat is required as the steam produced in one unit becomes the source of heat for the next unit.

### **Freezing**

When the brackish water is cooled to the freezing temperature, pure water separates out as ice leaving behind the salt in mother liquor. The ice crystals are washed properly with fresh water and then melted. But it is not effective process as there is possibility of entrapping the common salt solution as its presence reduces the freezing point of common water.

### Reverse Osmosis

Reverse osmosis involves manipulation of the osmotic pressure of a solution. Reverse osmosis process is employed to separate the pure water from its pollutant by using a membrane filter. This is also called as hyperfiltration or superfiltration. In this method, high pressure is applied to the waste to force out the liquid through a semi-permeable membrane leaving behind the dissolved solids. The concept of reverse osmosis is utilized in desalination water.

#### *Method*

In this process excess pressure greater than osmotic pressure is applied to the brackish water to force its pure water out through the semi-permeable membrane (Polymethacrylate, polysulphone or polyamide polymers).

- (i) It removes ionic, nonionic, colloidal and high molecular weight compounds.
- (ii) The life time of membrane is quite high.
- (iii) The membranes can be replaced very easily.

The principle of the reverse osmosis is shown in Figure 4.8.

**Figure 4.8 : Reverse Osmosis Cell**

### Electrodialysis

It is another membrane technology which is used for the concentration of ions. In this method the ions are pulled out of the brackish water, under an electric field.

#### Simple Electrodialysis

It consists of three chambers and electrodes (cathodic and anode) are used in the side chambers. The brackish water is fed in all the chambers. From the central compartment, the ions are pulled out from salt water by passing direct current through the plastic membrane pair. Since the cell membranes with fixed charge (negative or positive), whereby the membranes become impermeable to either cations or anions. Therefore, in brackish water  $\text{Na}^+$  starts moving towards cathode while the  $\text{Cl}^-$  ions towards the anode through the membrane.

The rate of pulling out of the ions from the salt water depends on the salinity of water.

**Figure 4.9 : Simple Electrodialysis**

### **Electrodialysis Cell using Ion Selective Membranes**

Ion selective membranes are generally employed for efficient separation. This type of electrodialysis cell consists of several pairs of plastic membranes. For satisfactory electrodialysis, fluorocarbon membrane materials such as “Nafion” are preferred. An ion selective membrane is permeable to one kind of ions only, i.e. permeable to either cation or anion. A cation selective membranes are polystyrene polymers with sulphonic acid groups ( $-SO_3^-$ ). Because of the presence of fixed negative charge on the membrane, it is permeable only to the cations. Similarly, quaternary ammonium group ( $NH_4^+$ ) is used as anion selective membrane.

#### *Method*

The cation and anion selective membranes are kept alternatively so that many chambers can be made through which brackish water passes as shown in Figure 4.10.

**Figure 4.10 : Ion Selective Membrane Dialysis**

By the passage of direct current to the electrodes, the cation selective membrane repels negative charged ions, but allows the +ve ions to enter, while the reverse is true for the anion selective membrane. Therefore, water in one chamber of the cell is desalinated water, while the salt water concentration increased in the next chamber. Thus, we get alternative streams of pure water and concentrated brine solution. Hence, this method enhances the efficient separation.

The important uses of the electro dialysis are in treatment of metal plating wastes, battery manufacturer, glass etching and desalination of effluents.

### SAQ 5

- (a) What is pH value?
- (b) What is brackish water?
- (c) What is electro dialysis?

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## 4.9 SUMMARY

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In this unit, you have learnt that :

- The main sources of water are surface, sub-surface and atmospheric water.
- Water exists in all the three states (solid, liquid and gaseous states).
- Ice crystal has tetrahedral (cage-like rigid or open) structure.
- Because of polarity and hydrogen bonding, water has some anomalous properties and is a better solvent than any other solvents for ionic compounds.
- The hardness of water is due to presence of multivalent metallic cations.
- Permanent hardness ( $\text{CaCl}_2$ ),  $\text{MgCl}_2$ , etc. cannot be removed, but temporary hardness  $\text{Ca}(\text{HCO}_3)_2$ ,  $\text{Mg}(\text{HCO}_3)_2$  can be removed by simply boiling.
- Softening is the removal of hardness producing salts from water.
- Sludge is a soft, loose, slimy deposit formed inside the boiler; while scale is hard, sticky adherant deposit formed on the inner surface of boiler.
- Desalination is a process to remove common salts from water.
- Dimineralized water is free from all ions.
- Reverse Osmosis is a process to separate pure solvent from contaminants by using a semi-permeable membrane and applying high pressure on concentrated side.
- pH is the negative logarithms of hydrogen ion activity.
- Dissolved oxygen, carbon dioxide and sulphur dioxide present in water causes boiler corrosion.

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## 4.10 ANSWERS TO SAQs

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**SAQ 1**

- (a) Oceans, rivers, lakes, ground water etc.
- (b) It maintains the atmospheric temperature moderate and suitable for living organisms.

**SAQ 2**

- (a) Because it has lower density.
- (b) Because it has high dielectric constant.

**SAQ 3**

- (a) Hardness due to metal ions and due to anions.
- (b) Parts per million (ppm) or milligram per liter ( $\text{mg L}^{-1}$ ).
- (c) Calcium and magnesium salts are removed by precipitating them at  $\text{CaCO}_3$  and  $\text{Mg(OH)}_2$  respectively.
- (d) 
$$\text{Ca(HCO}_3)_2 \xrightarrow{\Delta} \text{CaCO}_3 \downarrow + \text{H}_2\text{O} + \text{CO}_2 \uparrow$$
$$\text{Mg(HCO}_3)_2 \xrightarrow{\Delta} \text{Mg(OH)}_2 \downarrow + \text{CO}_2 \uparrow + \text{H}_2\text{O}$$
- (e) (i) Bleaching Powder, (ii) Liquid Chlorine, and (iii) Chloramine.

**SAQ 4**

- (a) Dissolved oxygen, carbon dioxide, and sulphur dioxide.
- (b) Water softened by zeolite process causes caustic embrittlement, since it contains large quantities of sodium salts, e.g.  $\text{NaCl}$  and  $\text{Na}_2\text{SO}_4$ .

**SAQ 5**

- (a) pH is the negative logarithm of hydrogen ion activity. In dilute condition,  $\text{pH} = -\log C_{\text{H}^+}$ .
- (b) Water containing dissolved salts with a peculiar salty (or brackish) taste.
- (c) A process in which the ions of the salts present in water are pulled out by passing direct current, using electrodes and thin rigid plastic membrane pair.