

## UNIT-I WATER TECHNOLOGY

### ***Lecture session 2: Topics : Sources of water ,Impurities of water, Hardness- its types and estimation***

Water plays an important role in our daily life. 70% of the earth is covered by water, out of which 97% is in oceans and hence saline (not usable) 2% is locked as polar ice caps (not available for use) only 1% is available as surface and ground water (Usable) Though the ground water is clear, it contains dissolved salts, hence not pure. Surface water contains dissolved salts, dissolved gases and suspended impurities. Water is an essential commodity for any engineering industry. The sources for water are of stationary or of flowing type. Depending on the source, water may consist of impurities in soluble or dispersed or suspended form. The impurities in water impart some undesirable properties to water and hence render water ineffective for the particular engineering application.

#### **Sources of water**

##### **1. Surface water**

Rain water is the most pure form of water because it is obtained due to precipitation of surface water. When it flows it dissolves considerable amount of gases and suspended solid particles which are both organic and inorganic.  
Eg. River water ,lake water etc.

##### **2. Sea water**

It is the most impure form of water. The continuous evaporation of water from the surface of sea makes it richer in dissolved impurities.

##### **3. Underground water**

A part of the rain water which percolates into the earth and comes in contact with a number of minerals and dissolves some of them.  
Eg. Shallow and deep springs and wells

#### **Impurities of water**

##### **1. Physical Impurities**

These impurities impart the color, odour, taste of water and also makes it turbid.  
Eg. Clay, sand oil globules, vegetable and animal matter

##### **2. Chemical Impurities**

These impurities pollute the water and produces harmful effects on human beings.

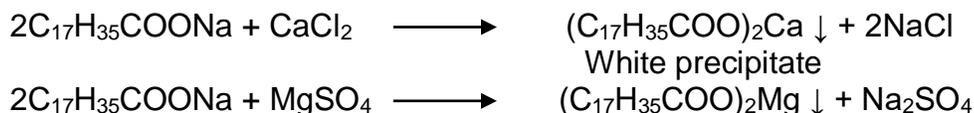
- Dissolved Inorganic salts:  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$  etc.
- Dissolved Gases:  $\text{CO}_2$ ,  $\text{O}_2$ ,  $\text{N}_2$ , Oxides of nitrogen.

##### **3. Biological impurities**

These impurities are due to the discharge of domestic and sewage waste into water which causes diseases.  
Eg. Microorganisms like bacteria, fungi etc.

## Hardness

The property of water which prevents it from lathering. Water which does not produce lather with soap solution but produces white precipitate is called hard water and which produces lather readily with soap solution are called soft water.



## Types of Hardness

- Temporary Hardness or Carbonate Hardness (CH) or Alkaline Hardness (AH)  
This is due to the presence of bicarbonates of calcium and magnesium. It can be removed by mere boiling. The bicarbonates are converted into insoluble carbonates and hydroxides, which can be removed by filtering.



- Permanent Hardness or Non-carbonate Hardness (NCH) or Non-alkaline Hardness (NAH)

This is caused by the presence of chlorides and sulphates of calcium and magnesium. It cannot be removed by boiling. It can be removed only by Chemical or special treatment.

## Units of Hardness

The concentration of hardness is expressed in terms of equivalent amount of  $\text{CaCO}_3$  because it is the most insoluble salt obtained in water treatment and its molecular weight is 100 (Eq.Wt 50). The different units are

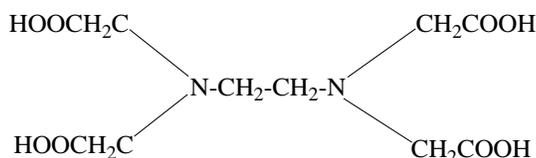
- ppm : 1 part of  $\text{CaCO}_3$  equivalent hardness in  $10^6$  parts of water
- mg/L : 1 mg of  $\text{CaCO}_3$  equivalent hardness in 1 L of water

Weight of 1 L of water = 1 Kg. = 1000 g = 1000000 mg =  $10^6$  mg

**Hence 1ppm = 1mg / L**

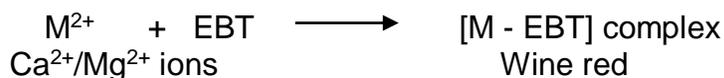
## Determination of hardness of water by EDTA method

This is a complexometric method where ethylene diaminetetraacetic acid (EDTA) is used to determine the temporary and permanent hardness of water.

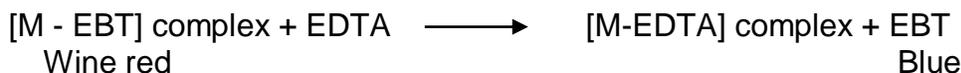


## Principle

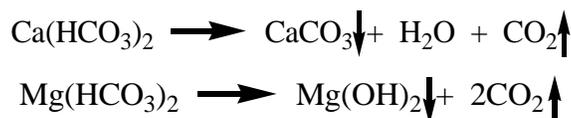
In order to obtain the equivalence point, EBT or eriochrome black – T (an alcoholic solution of blue dye) is employed as indicator which initially forms a stable complex with  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions and forms a wine-red color complex. This indicator is effective at a pH of about 10 and hence buffer ( $\text{NH}_4\text{OH-NH}_4\text{Cl}$ ) is added in each titration.



During the course of the titration against EDTA solution, it forms a stable complex and releases free EBT, which instantaneously combines with  $\text{M}^{2+}$  ions still present in the solution, thereby wine red color is retained. When all metal ions have formed  $[\text{M-EDTA}]$  complex, then the next drop of EDTA added replaces the EBT indicator from the complex and makes it completely free. Then the color changes from wine red to steel blue. The change of color marks the end point of the titration.



Temporary hardness of water is caused by the presence of bicarbonates of Ca and Mg and permanent hardness is caused by chlorides and sulphates of Ca and Mg. Total hardness is estimated by titrating the sample water against disodium salt of EDTA using Eriochrome Black-T indicator. Temporary hardness is removed on boiling the water sample and hence temporary hardness is calculated as a difference of permanent hardness from the total hardness.



## Procedure:

### Titration I: Standardization of EDTA

Pipette out 20 mL of standard hard water (1 g  $\text{CaCO}_3$  dissolved in HCl and evaporated to dryness, then diluted to 1 lit where 1ml of this solution contains hardness equivalent to 1 mg of  $\text{CaCO}_3$ ) into a clean conical flask. Add 10 mL of ammonical buffer solution, 2 drops/ a pinch of Eriochrome Black-T indicator and titrate against EDTA solution taken in the burette. The end point is the change of color from wine red to steel blue. Repeat the titration for concordancy. Note the concordant value as  $V_1$  ml.

Volume of standard hard water = 20 mL

**1 mL of std. hard water contains 1 mg of  $\text{CaCO}_3$**

20 mL of std. hard water contains 20 mg of  $\text{CaCO}_3$

20 mL of std. hard water consumes  $V_1$  mL of EDTA

$V_1$  mL of EDTA = 20 mg of  $\text{CaCO}_3$

1 mL of EDTA = 20 / V<sub>1</sub> mg of CaCO<sub>3</sub>

### Titration II: Estimation of total hardness

Pipette out 50 mL of given sample of hard water into a clean conical flask. Add 10 mL of ammonical buffer solution and 2 drops/a pinch of EBT indicator and titrate against EDTA solution taken in the burette. The end point is the change of color from wine red to steel blue. Repeat the titration for concordancy. Note the concordant value as V<sub>2</sub> mL.

50 ml of water sample consumes V<sub>2</sub> mL EDTA

$$\text{Total Hardness in 1000 mL} \equiv \frac{20}{V_1} \times V_2 \times \frac{1000}{50} \text{ mg of CaCO}_3$$

### Titration III: Estimation of permanent hardness

Pipette out 100 mL of water sample in a 250 mL beaker. Boil for 30-45 minutes, cool and filter. Wash the precipitate with distilled water. Collect the filtrate and washings in a 250 mL conical flask. Add 10 mL of ammonical buffer and 2 drops/a pinch of EBT indicator and titrate against EDTA solution taken in the burette. The end point is the change of color from wine red to steel blue. Repeat the titration for concordancy and note the concordant titre value as V<sub>3</sub> mL.

$$\text{Permanent Hardness in 1000 ml sample} \equiv \frac{20}{V_1} \times V_3 \times \frac{1000}{100} \text{ mg of CaCO}_3$$

Temporary Hardness = Total Hardness – Permanent Hardness

## ***Lecture session 3: Topics: Requirements of boiler feed water. Disadvantages of hard water in boilers and heat exchangers-Scales and sludges.***

### **BOILER FEED WATER**

Water is largely used in boilers (as feed) for the production of steam. The presence of impurities in water sample renders it hard (and corrosive too in some cases) which cannot be used as boiler feed as it may pose the problems of corrosion, embrittlement of the boiler vessel etc. Water with some specifications, used in boilers for steam generation is called boiler feed water.

### **Requisites of boiler feed water**

- (i) It should be free from suspended solids and dissolved corrosive gases such as CO<sub>2</sub>, SO<sub>x</sub>, NO<sub>x</sub>, halogens, hydrogen halide etc.
- (ii) Hardness should be less than 0.1 ppm

- (iii) Alkalinity (soda and caustic alkalinity values) should be in the range 0.1 – 1 ppm ; less than 0.5 ppm alkalinity is preferable
- (iv) It should be free from dissolved salts and oily / soapy matter that reduces the surface tension of water.
- (v) Boiler feed water should be free from hardness producing substances.

### Disadvantages of using hard water in boiler:

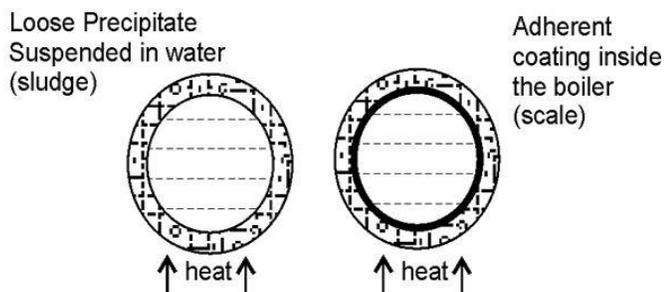
If hard water is fed directly into the boiler it leads to the following boiler troubles which reduce the efficiency of the boiler. The main destructive effects of using hard water in boilers are

- (i) Formation of scales and sludges
- (ii) Boiler corrosion
- (iii) Caustic embrittlement
- (iv) Priming and foaming.

## BOILER TROUBLES

### SCALES AND SLUDGES:

In boiler, water is converted to steam. During this process, when the volume of water decreases, a saturation point is reached and all the dissolved salts precipitate out. Depending on the physical and chemical nature of the impurity (salt) it may form a loose, slimy, non-adhering precipitate (Sludge) or hard strongly adhering precipitate (Scale)



### Sludge

Loose, slimy and non adhering precipitate due to presence of salts like  $MgCl_2$ ,  $MgSO_4$ ,  $CaCl_2$ ,  $MgCO_3$ . It forms in colder portions of boilers and the portion where water flow rate is low.

### Disadvantages:

1. Sludges are poor conductor of heat.
2. Excess of sludge formation decreases the efficiency of boiler.

### Prevention and removal

1. By using softened water
2. By performing frequent blow down operation

### Scale

Hard, adherent coating due to presence of salts like  $Mg(HCO_3)_2$ ,  $Mg(OH)_2$ ,  $Ca(HCO_3)_2$ ,  $CaSO_4$

### Disadvantages:

1. Wastage of fuel: Scales are poor conductors (almost insulators) of heat and result in a low heat transfer rates. To maintain steady heat supply to water, greater heat energy has to be supplied. This results in over-heating of the boiler and also increased fuel consumption. The extent of fuel wastage depends on the thickness and nature of the scale, as evidenced from the following table:

Scale thickness (mm)	0.325	0.625	1.5	2.5
Fuel wastage (%)	10	15	50	80

2. Decrease in efficiency: Scales, if deposited in the boiler components such as valves, condensers etc., choke in fluid paths and hence lead to decreased efficiency of the boiler.
3. Lowering of boiler safety: Scale formation demands over-heating of the boiler for maintaining a constant supply of steam. Boiler plates, initially maintained at a temperature of  $180^\circ\text{C}$  in the absence of scales has to be heated to a temperature of  $370^\circ\text{C}$  to maintain the steam supply, if covered with 12 mm thick scale. The over-heating of the boiler tubes renders the boiler material softer and weaker and hence the boiler becomes unsafe at high steam pressures.
4. Danger of explosion: when scales undergo cracking due to uneven expansion, water comes in contact with overheated boilerplates suddenly. This results in sudden formation of large amount of steam and hence the development of high pressure of steam, which may cause the boiler explosion.

### Prevention and removal

- i) By dissolving in acids like HCl,  $H_2SO_4$
- ii) By applying external and internal treatment.
- iii) Removed by scrapping, wire brushes etc.

**Lecture session 4 : Topics: Boiler troubles- Priming and Foaming, caustic embrittlement explanation with the elimination of these problems.**

**PRIMING & FOAMING**

- ✓ During the production of steam in the boiler, due to rapid boiling, some droplets of liquid water are carried along with steam.
- ✓ Steam containing droplets of liquid water is called wet steam. These droplets of liquid water carry with them some dissolved salts and suspended impurities.
- ✓ This phenomenon is called carry over. This leads to priming and foaming.

**Priming:** When steam is produced rapidly in boilers the steam velocity suddenly increases and some droplets of liquid water are carried along with steam. Steam containing droplets of liquid water is called wet steam. The process of wet steam formation is called Priming.

Priming is caused by

- Presence of large amount of dissolved solids.
- High steam velocity.
- Sudden boiling.
- Improper boiler design.

Priming can be prevented by

- Using treated water.
- Controlling the velocity of steam.
- Fitting mechanical steam purifiers.
- Maintaining low water level.
- Good boiler design.

**Foaming:** Oil or any other polymeric substance present in boiler feed water, reduces surface tension of water forming bubbles which do not break easily in boilers giving a foam appearance. This process is called foaming.

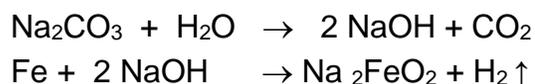
Foaming is caused by

- Presence of oil & grease.
- Presence of finely divided sludge particles.

Foaming can be prevented by adding coagulants like sodium aluminate, ferrous sulphate etc.

## CAUSTIC EMBRITTLEMENT:

Caustic embrittlement means intercrystalline cracking of boiler metal. Boiler water usually contains a small proportion of  $\text{Na}_2\text{CO}_3$ . In high pressure boilers this undergoes decomposition to give  $\text{NaOH}$ . This  $\text{NaOH}$  flows into the minute hair cracks and crevices, usually present on the boiler material, by capillary action and dissolves the surrounding area of iron as sodium ferroate. This causes brittleness of boiler parts, particularly stressed parts like bends, joints, rivets, etc., causing even failure of the boiler.



Caustic embrittlement can be prevented by

- i) using sodium phosphate as softening agent instead of sodium carbonate.
- ii) by adding tannin, lignin to the boiler water, which blocks the cracks.

***Lecture session 5 : Topics: Boiler corrosion due to various agents and its prevention, Softening of hard water (external)- zeolite process – advantages and limitations.***

## BOILER CORROSION:

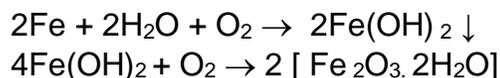
Boiler corrosion is decay of boiler material by chemical or electrochemical attack of its environment.

Boiler corrosion is due to presence of

- Dissolved oxygen
- Dissolved carbon dioxide
- Dissolved salts like magnesium chloride

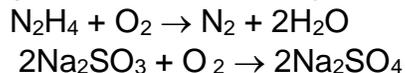
### 1. Dissolved oxygen (DO):

When water containing dissolved oxygen is fed into boilers the following reaction occurs corroding the boiler material (rust formation)

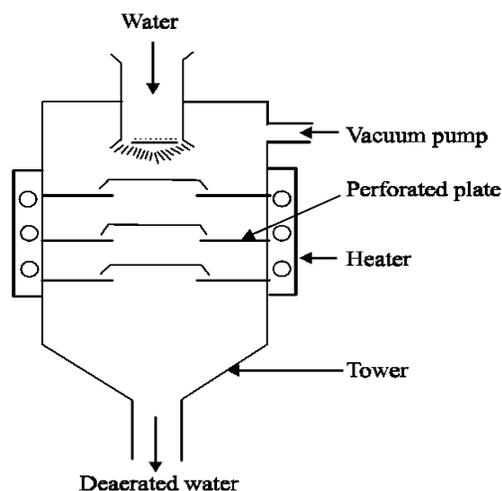


D. O. oxygen can be reduced

i) By adding hydrazine / sodium sulphite

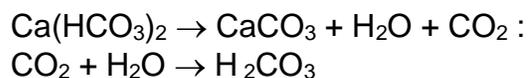


ii) By mechanical deaeration method.



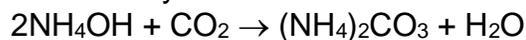
## 2. Dissolved carbon dioxide:

When water containing bicarbonates is heated, carbon dioxide is evolved which makes the water acidic. This is detrimental to the metal. It leads to corrosion called of boiler material.



Prevention methods for removing dissolved carbon dioxide:

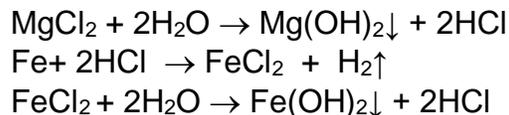
By treatment with ammonium hydroxide:



Can be removed by mechanical deaeration method along with oxygen.

## 3. Dissolved $\text{MgCl}_2$ :

Acids produced from salts that are dissolved in water are mainly responsible for the corrosion of boilers. Salts like magnesium and calcium chloride undergo hydrolysis at high temperature to give HCl, which corrodes the boiler. Presence of HCl is more damaging due to chain reaction.



$\text{MgCl}_2$  can be removed by i) internal conditioning and ii) external conditioning

### EXTERNAL CONDITIONING:

Three types of external conditioning methods in use are

- (i) Lime-soda process
- (ii) Permutit or zeolite process and
- (iii) Demineralization process.

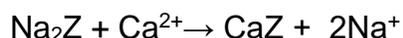
The first process is based the precipitation of hardness causing ions by the addition of soda ( $\text{Na}_2\text{CO}_3$ ) and lime ( $\text{Ca(OH)}_2$ ) whereas the second and third process is based ion exchange mechanism (ion exchange process).

An ion exchange process may be defined as a reversible exchange of ions between a liquid phase and a solid phase. Materials capable of exchanging cations are called cation exchangers and those which are capable of exchanging anions are called anion exchangers. Both anion and cation exchangers are used in water treatment.

### NATURAL AND SYNTHETIC ZEOLITE PROCESS.

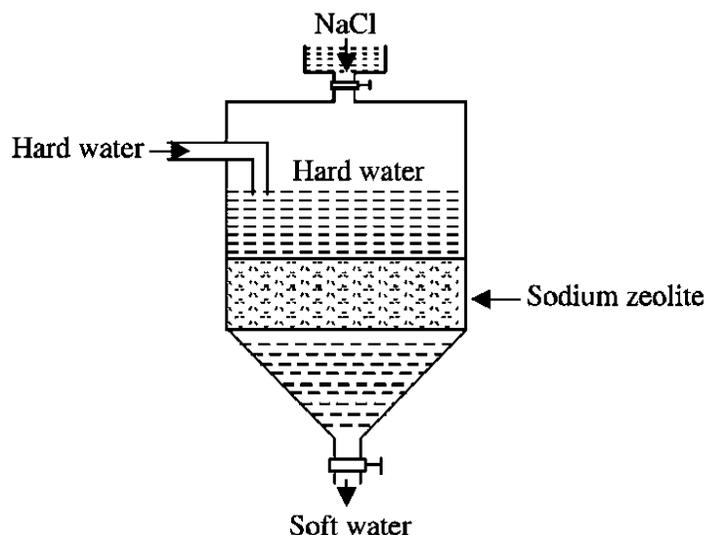
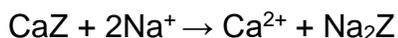
- ✓ Zeolites are of two types - natural zeolites and Synthetic zeolites.
- ✓ Natural Zeolites are non porous materials Ex. Natrolite  $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2 \cdot 3\text{H}_2\text{O}$ .
- ✓ Synthetic Zeolites also called permutits are porous and poses a gel structure. Ex- Sodium Zeolite. Synthetic Zeolites have higher exchange capacity per unit weight.
- ✓ Sodium Zeolites are used for water softening and they have general chemical structure as  $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot x\text{SiO}_2 \cdot y2\text{H}_2\text{O}$  wher  $x= 2-10$ :  $y=2- 6$
- ✓ They are considered as hydrated sodium aluminosilicates which are capable of exchanging their sodium ions for divalent ions of metals present in water
- ✓ Zeolites are represented as  $\text{Na}_2\text{Z}$ . Where Z is insoluble zeolite frame work.

**Process:** Hardwater is allowed to percolate through a bed of Zeolite kept in a cylinder. The hardness causing ions are taken up by the zeolite and simultaneously releasing the equivalent sodium ions in exchange for them.



**Regeneration:** When the zeolite bed is exhausted (i.e saturated with  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ) it cannot soften water further.

Exhausted Zeolites is reclaimed by treating the bed with a concentrated NaCl solution(10% brine)

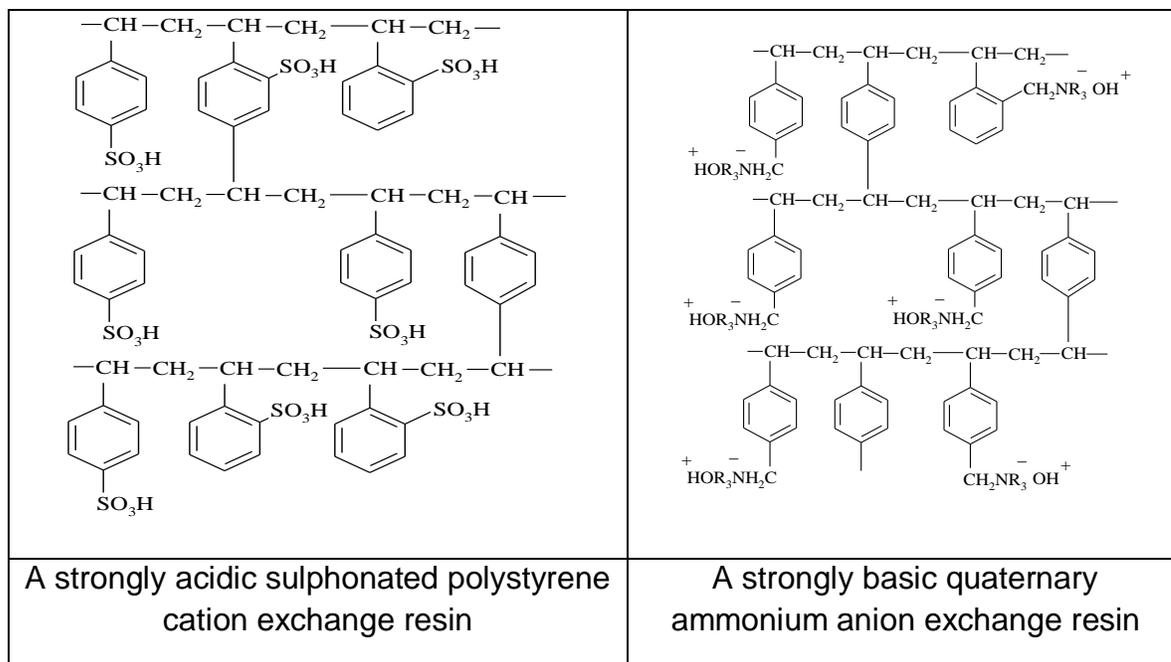


***Lecture session 6 : Topics: Demineralization (Ion exchange) process – explanation with mechanisms – regeneration:***

### **DIMINERALISATION USING ION EXCHANGE RESINS**

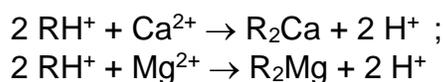
Dimineralisation or Deionisation can be carried out using ion exchange resins (IER). IE resins are insoluble, cross-linked long chain organic polymers with micro-porous structure. The functional groups attached to the polymeric chain have the tendency to exchange the (hardness causing) ions. Acidic functional groups such as carboxyl (-COOH), sulphonic acid (-SO<sub>3</sub>H) have the capacity to exchange cations whereas basic functional groups such as amines (-NH<sub>2</sub>), hydroxyl (-OH) have the capacity to exchange anions. Ion exchange resins are generally synthesized such as styrene-divinyl benzene copolymers

The copolymer has the structure of alternate styrene and divinyl benzene units with the aromatic rings bearing the substituents of acidic / basic functional groups such as sulphonic acid, carboxylic acid, (substituted) amines etc.

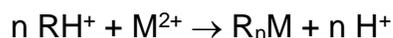


**Process:** It is the process of removal of any mineral (cation or anion) from the water sample. Water sample is first passed through a column called cation exchanger, which is packed with cation exchange resins. This causes the removal of cations by ion exchange process, but renders the water sample acidic. The cation exchange resins are synthesized by the carboxylation or sulphonation of styrene-divinyl benzene copolymers. The structure of these resins is given below

Cation exchange resin is generally represented as  $RH^+$ ; the ion exchange process is represented as

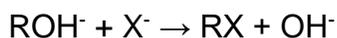
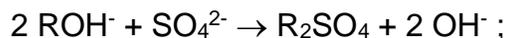


The exchange of any metallic cation ( $M^{n+}$ ) can be written as

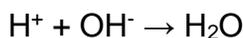


The acidic water coming out of the cation exchanger is then fed to a column called anion exchanger, which is packed with anion exchange resins. This causes the removal of anions by ion exchange process and also neutralizes the acidity of the water sample, explained as follows. The anion exchange resins are synthesized by the

hydroxylation or amination of styrene-divinyl benzene copolymers. Anion exchange resin is generally represented as  $\text{ROH}^-$ ; the ion exchange process is represented as

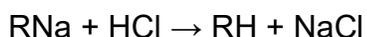
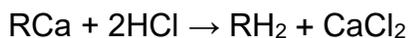


The ultimate reaction taking place on passing the water sample through the cation and anion exchanger systems is

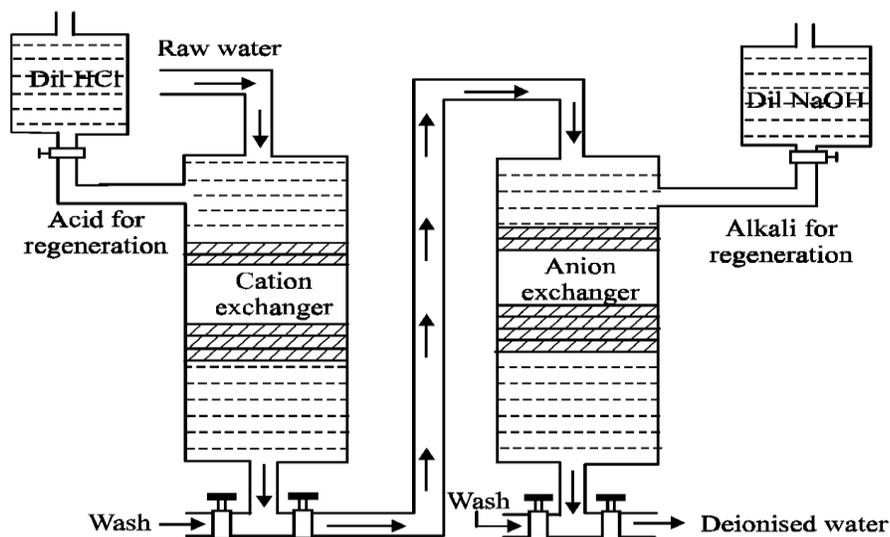


### Regeneration

When the cation exchange resin is exhausted, it can be regenerated by passing a solution of dil HCl or dil  $\text{H}_2\text{SO}_4$ .



Similarly, when the anion exchange resin is exhausted, it can be regenerated by passing a solution of dil NaOH.



## **Lecture session .7: Topics: Internal conditioning methods –principles:**

### **INTERNAL CONDITIONING OR SEQUESTRATION**

Internal conditioning is treating the water after feeding into the boiler. An internal treatment is accompanied by adding a appropriate chemical to the boiler water either (a)to precipitate the scale forming impurities in the form of sludges, which can be removed by blow down operation or (b) to convert them into compounds which will stay in dissolved form without causing harm to the boiler.

Internal treatment methods are, generally, followed by blow-down operation, so that accumulated sludge is removed. Important internal conditioning/treatment methods are

#### ➤ **Carbonate conditioning:**

Scale forming salts like  $\text{CaSO}_4$  present in the water adheres more strongly on the surface of the boiler. This can be prevented by precipitating Ca as  $\text{CaCO}_3$  which gives rise to a loosely adhering scale, by adding  $\text{Na}_2\text{CO}_3$ .



#### **Disadvantage / Limitation:**

1. Applicable only for low pressure boiler
2. Causes caustic embrittlement and corrosion in high pressure boilers as the un-reacted  $\text{Na}_2\text{CO}_3$  will be converted in to  $\text{NaOH}$  and  $\text{CO}_2$ .

#### ➤ **Phosphate Conditioning:**

In high-pressure boilers, scale formation can be avoided by the addition of sodium phosphate to the water sample. Here, calcium (and also magnesium) ions (responsible for hardness) are precipitated as their phosphates (sludges) and can be removed easily by filtration. Three types of phosphates conditioning– mono, di and trisodium phosphates are employed in phosphate conditioning.

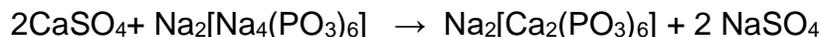
The advantages of phosphate conditioning over carbonate conditioning are (i) it can be applied to high-pressure boilers and (ii) it can be used for softening / conditioning acidic, neutral or alkaline water sample.



If acidic water is to be conditioned, trisodium phosphate can be used. For neutral and alkaline water samples disodium phosphate and monosodium phosphate can be used respectively.

#### ➤ **Calgon conditioning:**

It is the process of addition of *calgon* or *sodium hexametaphosphate* to the boiler feed water. The calcium ions (responsible for scale / sludge formation) are complexed by calgon to form a soluble complex and hence prevented from their scale forming action.



This phenomenon of complexing of the ions is called sequestration. Calgon is the sequestering agent used. The other internal conditioning agents used are ethylenediamine tetracetic acid (EDTA) and sodium aluminate ( $\text{NaAlO}_2$ ). EDTA functions by sequestration phenomenon whereas sodium aluminate functions by precipitation phenomenon.

➤ **Colloidal conditioning:**

In low pressure boilers scale formation can be avoided by adding organic substances like kerosene, tannin, agar-agar etc. They get coated over the scale forming precipitates, converting into loose deposits which can be easily removed blow-down operations.

**Drinking water quality standards**

- Planet needs drinking water to survive and that water may contain many harmful constituents, there are no universally recognized and accepted international standards for drinking water.
- Even where standards do exist, and are applied, the permitted concentration of individual constituents may vary by as much as ten times from one set of standards to another (World Health Organization (**WHO**) and **BIS**).

Access to safe drinking-water is essential to health, a basic human right and a component of effective policy for health protection.

The importance of water, sanitation and hygiene for health and development has been reflected in the outcomes of a series of international policy forums.

**WHO** published four editions of the Guidelines for drinking-water quality (in 1983–1984, 1993–1997, 2004, and 2011).

The primary goal of the Guidelines is to protect public health associated with drinking-water quality. The overall objectives of the Guidelines are to:

- provide an authoritative basis for the effective consideration of public health in setting national or regional drinking-water policies and actions;

- provide a comprehensive preventive risk management framework for health protection, from catchment to consumer, that covers policy formulation and standard setting, risk-based management approaches and surveillance;
- emphasize achievable practices and the formulation of sound regulations that are applicable to low-income, middle-income and industrialized countries alike;
- summarize the health implications associated with contaminants in drinking- water, and the role of risk assessment and risk management in disease prevention and control;
- summarize effective options for drinking-water management; and
- provide guidance on hazard identification and risk assessment.

Parameter	Table	World Health Organization	European Union	United States	China	Canada
1,2-dichloroethane		"	3.0 µg/l	5 µg/l	"	"
Acrylamide		"	0.10 µg/l	"	"	"
Aluminium	Al		0,2 mg/l			no limit listed
Antimony	Sb	ns	5.0 µg/l	6.0 µg/l	"	6.00 µg/l
Arsenic	As	10µg/l	10 µg/l	10µg/l	50µg/l	10.0 µg/l
Barium	Ba	700µg/l	ns	2 mg/L	"	1.00 mg/L
Benzene		10µg/l	1.0 µg/l	5 µg/l	"	"
Benzo(a)pyrene		"	0.010 µg/l	0.2 µg/l	0.0028 µg/l	"
Beryllium	Be					"
Boron	B	2.4 mg/l	1.0 mg/L	"	"	5.00 mg/L
Bromate		"	10 µg/l	10 µg/l	"	"
Cadmium	Cd	3 µg/l	5 µg/l	5 µg/l	5 µg/l	5.00 µg/l
Calcium	Ca					200 mg/L
Chromium	Cr	50µg/l	50 µg/l	0.1 mg/L	50 µg/l (Cr6)	0.050 mg/L
Cobalt	Co					"
Copper	Cu	"	2.0 mg/l	TT	1 mg/l	1.00 mg/L
Cyanide		"	50 µg/l	0.2 mg/L	50 µg/l	"
Epichlorohydrin		"	0.10 µg/l	"	"	"
Fluoride		1.5 mg/l	1.5 mg/l	4 mg/l	1 mg/l	"
Gold	Au					no limit listed
hardness	CaCO <sub>3</sub>					0–75 mg/L=soft
Iron	Fe		0,2 mg/l			0.300 mg/L
Lanthanum	La					no limit listed
Lead	Pb	"	10 µg/l	15 µg/l	10 µg/l	10.0 µg/l
Magnesium	Mg					50.0 mg/L
Manganese	Mn		0, 05 mg/l			0.050 mg/L
Mercury	Hg	6 µg/l	1 µg/l	2 µg/l	0.05 µg/l	1.00 µg/l
Molybdenum	Mo					no limit listed

Nickel	Ni	“	20 µg/l	“	“	no limit listed
Nitrate		50 mg/l	50 mg/l	10 mg/L (as N)	10 mg/L (as N)	“
Nitrite		“	0.50 mg/l	1 mg/L (as N)	“	“
Pesticides — Total		“	0.50 µg/l	“	“	“
Pesticides (individual)		“	0.10 µg/l	“	“	“
pH						6.5 to 8.5
Phosphorus	P					no limit listed
Potassium	K					no limit listed
Scandium	Sc					no limit listed
Selenium	Se	40 µg/l	10 µg/l	50 µg/l	10 µg/l	10.0 µg/l
Silicon	Si					no limit listed
Silver	Ag					0.050 mg/L
Sodium	Na					200 mg/L
Strontium	Sr					no limit listed
Tin	Sn					no limit listed
Titanium	Ti					no limit listed
Tungsten	W					no limit listed
Uranium	U					0.10 mg/L
Vanadium	V					no limit listed
Zinc	Zn					5.00 mg/L
vinyl chloride			0,50 µg/l			
chlorides			250 mg/l			

For India these standards are set by the Bureau of Indian Standards - BIS, Indian Standards Institute – ISI. The relevant BIS standard is BIS: 10500 available from the BIS site [www.bis.org.in](http://www.bis.org.in)

Parameters	USEPA	WHO	ISI	ICMR
pH (mg/l)	6.5-8.5	6.5-8.5	6.5-8.5	6.5-9.2
Turbidity NTU	-	-	10	25
Conductivity (mg/l)	-	-	-	-
Alkalinity (mg/l)	-	-	-	-
Total hardness (mg/l)	-	500	300	600
Iron *mg/l)	-	0.1	0.3	1.0
Chlorides (mg/l)	250	200	250	1000
Nitrate (mg/l)	-	-	45	100
Sulfate (mg/l)	-	-	150	400
Residual (mg/l) free Chlorine	-	-	0.2	-
Calcium (mg/l)	-	75	75	200
Magnesium (mg/l)	-	50	30	-
Copper (mg/l)	1.3	1.0	0.05	1.5
Fluoride (mg/l)	4.0	1.5	0.6-1.2	1.5
Mercury (mg/l)	0.002	0.001	0.001	0.001
Cadmium (mg/l)	0.005	0.005	0.01	0.01
Selenium (mg/l)	0.05	0.01	-	-
Arsenic (mg/l)	0.05	0.05	0.05	0.05
Lead (mg/l)	-	0.05	0.10	0.05
Zinc (mg/l)	-	5.0	5.0	0.10
Chromium (mg/l)	0.1	-	0.05	-
<i>E. coli</i> (MPN/100 ml)	-	-	-	-

**Lecture session .8: Topics: Treatment of water for domestic use:  
Treatment of water for domestic use (Large-scale water treatment)**

Constituent	Unit Processes
Turbidity and particles	Coagulation/ flocculation, sedimentation, granular filtration
Major dissolved inorganics	Softening, aeration, membranes
Minor dissolved inorganics	Membranes
Pathogens	Sedimentation, filtration, disinfection
Major dissolved organics	Membranes, adsorption

**Treatment of water for domestic supply:**

Drinking or portable water, fit for human consumption, should satisfy the following essential requirements

1. It should be clear and odourless
2. It should be pleasant in taste
3. Turbidity should not exceed 10 ppm
4. It should be free from dissolved gas like H<sub>2</sub>S
5. It should be free from Cr, Pb Mn etc.,
6. TDS should be less than 500 ppm
7. It should free from disease-producing micro-organisms, etc.

**Purification of water for domestic use**

Removing various types of impurities the following treatment process are employed

**Screening:**

It is a process of removing the floating material like leaves, wood pieces, etc. from water.

**Aeration:**

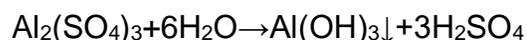
The process of mixing water with air is known as aeration. This leads to remove gases like CO<sub>2</sub>, H<sub>2</sub>S.

**Sedimentation:**

It is a process of removing suspended impurities by allowing the water to stand undisturbed for 2-6 hours in a big tank.

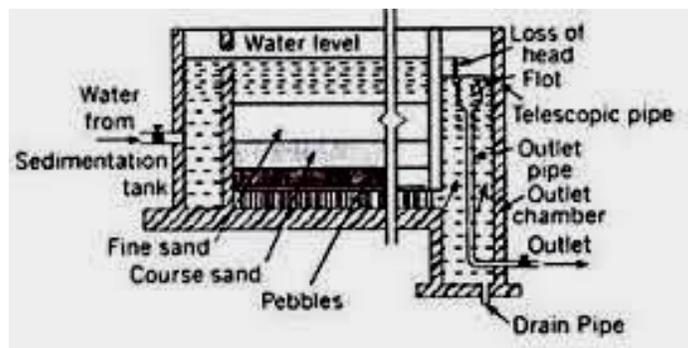
**Coagulation:**

In this method certain chemicals called coagulants, like alum, added to the water. Coagulant, when added to water, forms an insoluble gelatinous, flocculant precipitate, which descent through the water, combine to form a bigger flocs, which settle down easily



**Filtration:**

It is the process of removing bacteria, colour, taste, odour by passing water through bed of fine sand and other proper sized granular materials. Filtration is carried out by using sand filter which is shown in Fig. 1.



**Fig. 1 Sand Filtration**

**Sterilization (or) disinfection:**

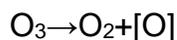
The process of destroying the harmful bacteria is known as sterilization.

**1. By boiling:**

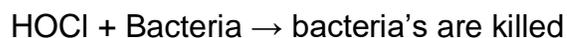
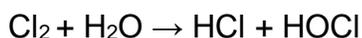
Water boiled for 10-15 minutes, all the harmful bacteria are killed and the water becomes safe for use. However it is not practically possible to boil huge amounts of water. Moreover it cannot take care of future possible contaminations.

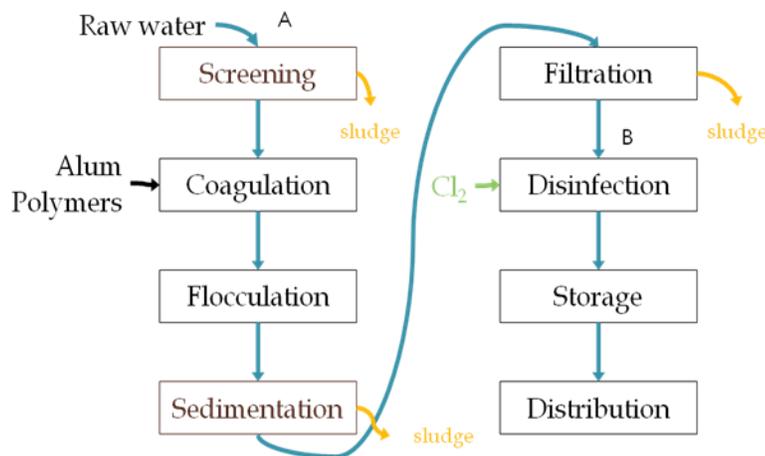
**2. By Ozonation:**

Ozone is a powerful disinfectant and is readily absorbed by water, which produce nascent oxygen. The nascent oxygen is very powerful oxidizing agent and kills all the bacteria's as well as oxidizes the organic matter present in water.

**3. By Chlorination**

Chlorine with water produces hypochlorous acid, which is powerful germicide. The germicidal action of chlorine is explained by the recent theory of Enzymatic hypothesis, according to which the chlorine enters the cell walls of bacteria and kill the enzymes which are essential for the metabolic processes of living organisms.





**Flow chart of Water Treatment process**

### Break point chlorination:

It involves in addition of sufficient amount of chlorine to oxidises: (a) organic matter, (b) reducing substances ( $\text{Fe}^{2+}$ ,  $\text{H}_2\text{S}$  etc) and (c) free ammonia in raw water; leaving behind mainly free chlorine, which possesses disinfecting action against disease-producing bacteria's.

Chlorination, used at both household and large-scale levels, is one of the most effective and widely used methods for disinfecting water and making it safe to drink. Whatever the level, it is important that the correct quantity of chlorine is added to remove all impurities.

When the dosage of applied chlorine to the water rich in organic compounds or ammonia is gradually increased, the results obtained can be depicted in Fig. 2, which consists of four stages as follows

### Between points 1 and 2

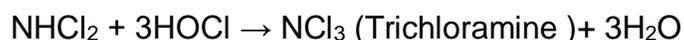
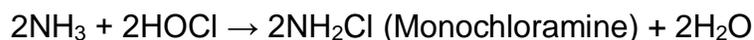
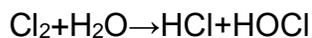
When you first add chlorine to water, it immediately begins to oxidize metals like iron and manganese, which reduce chlorine. This initial reaction wipes out a certain portion of chlorine, which is why nothing shows up on the graph until point (A).

The water reacts with reducing compounds in the water, such as hydrogen sulfide. These compounds use up the chlorine, producing no chlorine residual.

### Between points 2 and 3

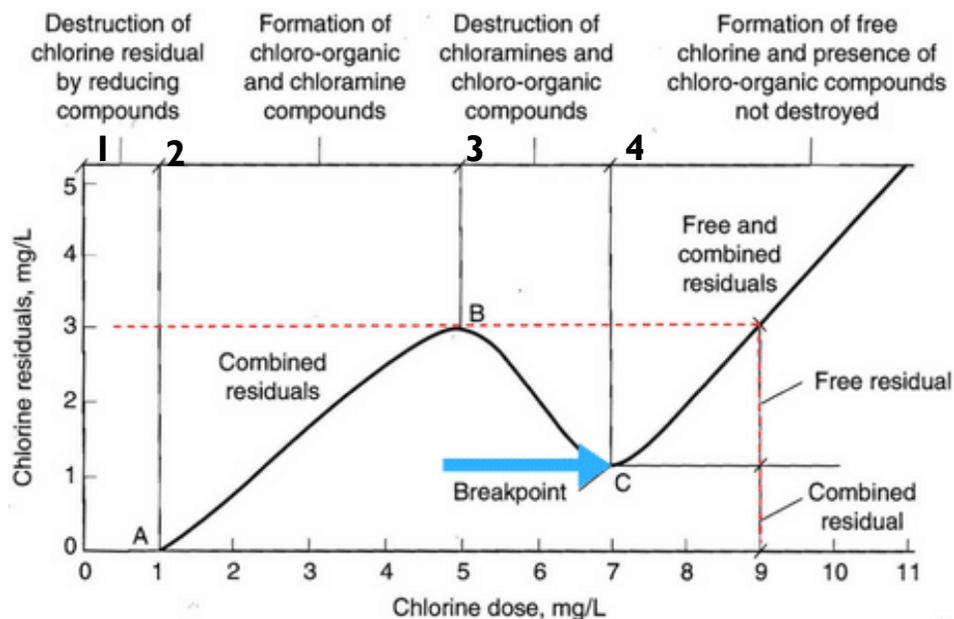
The chlorine reacts with organics and ammonia naturally found in the water. Some combined chlorine residual is formed - chloramines. Note that if chloramines were to be used as the disinfecting agent, more ammonia would be added to the water

to react with the chlorine. The process would be stopped at point 3. Using chloramine as the disinfecting agent results in little trihalomethane production but causes taste and odor problems since chloramines typically give a "swimming pool" odor to water.



### Between points 3 and 4

The chlorine will break down most of the chloramines in the water, actually lowering the chlorine residual. Finally, the water reaches the breakpoint, shown at point 4. The breakpoint is the point at which the chlorine demand has been totally satisfied - the chlorine has reacted with all reducing agents, organics, and ammonia in the water. When more chlorine is added past the breakpoint, the chlorine reacts with water and forms hypochlorous acid in direct proportion to the amount of chlorine added. This process, known as breakpoint chlorination, is the most common form of chlorination, in which enough chlorine is added to the water to bring it past the breakpoint and to create some free chlorine residual.



Chlorine residuals Vs Chlorine dose

At municipal level, various terms are used to describe the aspects of chlorination process. Chlorine dosage is the amount of chlorine added to the water system in milligrams per litre (mg/l). Chlorine demand is the amount of chlorine that combines with the impurities and therefore is no longer available as a disinfecting agent. The chlorine that remains in the water after the chlorine demand has been satisfied is called free chlorine residual. A certain amount of residual chlorine is a good idea because it protects against future recontamination.

**The *benefits* of point-of-use chlorination include:**

- Chlorine is proven to be effective in the reduction of bacteria and most viruses.
- The residual chlorine is effective in protection against recontamination.
- It is easy to use.
- Chlorine is easily available at low cost.

**The *drawbacks* of chlorine treatment include:**

- It provides relatively low protection against some viruses and parasites.
- Lower effectiveness in water contaminated with organic and certain inorganic compounds.
- Potential objections to taste and odour.
- Some people have concerns about the potential long-term carcinogenic effects of chlorination byproducts.

***Lecture session 9: Topics: Desalination: Reverse Osmosis & Electrodialysis***

➤ **Desalination:**

Water sample is classified as a three major categories namely fresh water, brackish water and sea water depending upon the total dissolved salt (TDS) content.

Water type	TDS content (g / l)
Fresh water	1-10
Brackish water	10-35
Sea water	≥ 35

A water sample is said to be saline if it has much of dissolved salt content. Desalination is the process of removal of salinity – dissolved content from a water sample. Four methods of desalination are employed such as distillation, freezing, reverse osmosis and electrodialysis.

➤ **Reverse Osmosis (RO):**

**Principle:**

Osmosis can be defined as the phenomenon of spontaneous flow of solvent molecules from dilute solution side to concentrated solution side, when they are separated by a semi-permeable membrane. The driving force for this phenomenon is called osmotic pressure. If a hydrostatic pressure in excess of osmotic pressure is applied on the concentrated solution side, the direction of solvent flow can be reversed i.e higher concentration to lower concentration and the process is called reverse osmosis. This method is sometimes also called as **super-filtration** or **hyper-filtration**.

**Method:**

In this process, pressure (of the order 15 to 40 kg/cm<sup>2</sup>) is applied to the sea water to force its pure water out through the semi-permeable membrane; leaving behind the dissolved solids (both ionic and non ionic). The membrane consists of very thin films of cellulose acetate, polymethacrylate and polyamide polymers. The principle of reverse osmosis, as applied for treating sea /saline water, is illustrated in Fig.3

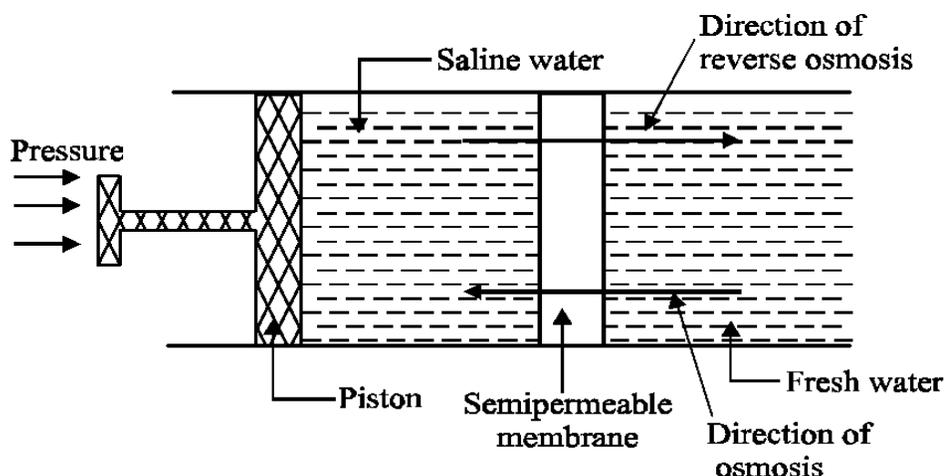


Fig.3 Reverse Osmosis process

**Advantages:**

1. The life time of the membrane is high.
2. Membrane can be replaced within short time.
3. It removes all types of impurities
4. Water obtained by this process is used for high pressure boilers
5. Process is used for converting sea water into drinking water.
6. low capital cost

**Electrodialysis (ED)****Principle:**

It is used to transport salt ions from one solution through ion-exchange membranes to another solution under the influence of an applied electric potential difference.

**Method:**

- ✓ The cell consists of a feed (dilute) compartment and a concentrate (brine) compartment formed by an anion exchange membrane and a cation exchange membrane placed between two electrodes.
- ✓ When direct electric current is passed through saline water, the sodium ions ( $\text{Na}^+$ ) start moving towards negative electrode (cathode); while the chloride ions ( $\text{Cl}^-$ ) start moving towards the positive electrode (anode), through the ion exchange membrane
- ✓ As a result, the concentration of brine decreases in the central compartment; while it increases two side compartments and the pure water is removed from the central compartment from time to time; while concentrated (side compartments) brine is replaced by fresh brine (illustrated as in Fig.4).
- ✓ multiple electrodialysis cells are arranged into a configuration called an electrodialysis stack
- ✓ for more efficient separation ions-selective membranes are employed

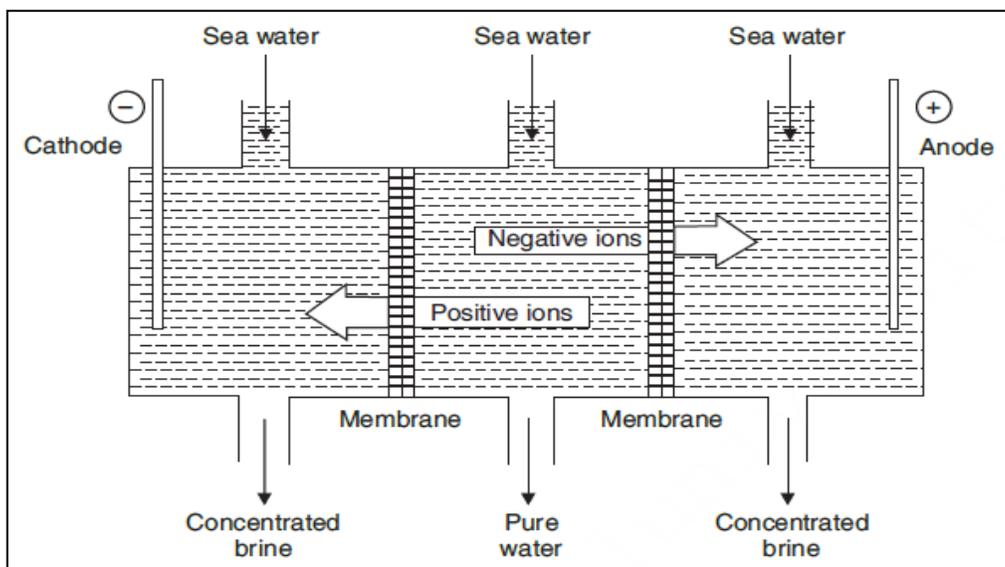


Fig. 4 Line diagram of electro-dialysis

### Advantages:

- It is most compact unit
- The cost of installation of the plant and its operation is economical
- Electricity is easily available, it is best suited
- Large scale brackish and seawater desalination and salt production could be done.
- Small and medium scale drinking water production (e.g., towns & villages, construction & military camps, nitrate reduction, hotels & hospitals, industries)
- Agricultural water (e.g., water for greenhouses, hydroponics, irrigation, livestock)
- Glycol desalting (e.g., antifreeze / engine-coolants, capacitor electrolyte fluids, oil and gas dehydration, conditioning and processing solutions, industrial heat transfer fluids, secondary coolants from heating, venting, and air conditioning (HVAC))

### Limitations

Electrodialysis has inherent limitations, working best at removing low molecular weight ionic components from a feed stream. Non-charged, higher molecular weight, and less mobile ionic species will not typically be significantly removed.