MODULE 5. Water Analysis

Course : Chemistry I
Course Code: KAS 102/202
Course Credits : 03
Class : B.Tech.

Prof. Ashok Kumar Srivastava
Head & Dean
Department of Chemistry
Faculty of Engineering & Technology
VBS Purvanchal University
Jaunpur-222003

COURSE CONTENT (S):

- Hard & Soft Water
- Temporary & permanent Hardness of Water
- Quality Aspect of Water
- Technique of Water Softening (i.e. Lime Soda, Zeolite and Ion Exchange Resin)

COURSE OBJECTIVE

After Learning of this Module you will be able to understand about:

- Hard & Soft Water
- Cause of Hardness of Water
- Impact of Hard Water on Human life
- Understand the mechanism of Hardness removal
- Type of hardness of water
- Quality Aspect of drinking water
- Learn about the Techniques used to remove the hardness of water and make it suitable for different purpose for life

WHAT IS HARD WATER?

Water containing more than 50-60 mg/L of calcium/Magnesium carbonate is termed as hard water. In our country the concentration of calcium/Magnesium concentration (120-180 mg/L) in water is HARD WATER.

WHAT IS SOFT WATER?

Water containing calcium carbonate at concentrations below 60 mg/l is generally considered as **SOFT WATER**

- **Soft Water is below 60 mg/L Ca/Mg ion concentration**
- **Moderate Hard Water is 60-120 mg/L of Ca/Mg ion concentration**
- **Very Hard Water is more than 180 mg/L Concentration of Ca/Mg ion**

TYPE OF WATER HARDNESS

The hardness of water can be classified into two types:

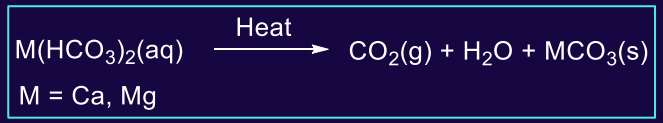
1. TEMPORARY HARDNESS (due to presence of dissolved BICARBONATE MINERALS like Calcium bicarbonate & Magnesium bicarbonate) * This type of hardness can be easily removed by means of heating/boiling of the water. Therefore, it is called THW.
2. PERMANENT HARDNESS (due to the presence of presence of calcium sulfate/calcium chloride and/or magnesium sulfate/magnesium chloride) * This kind of hardness can not be removed by simple heating of the water sample because this salt can not be precipitate out simply on heating. Therefore, it is called PERMANENT HARDNESS of water.

Point to Remember:

Temporary Water Hardness:	$Ca(HCO_3)_2$ & $Mg(HCO_3)_2$
Permanent Water Hardness:	$CaSO_4/MgSO_4$ & $CaCl_2/MgCl_2$

Difference Between Temporary & Permanent Hardness

#	Temporary Hardness		Permanent Hardness
01	Temporary hardness is caused by the presence of salts of Ca(HCO3)2 & Mg(HCO3)2.	01	It is due to presence of dissolved chlorides and sulphates of calcium, magnesium, iron and other heavy metals.
02	Temporary hardness can be removed by boiling when bicarbonates are decomposed yielding insoluble ppt. Of respective carbonates .	02	Permanent hardness cannot be removed by boiling.
03	Temporary hardness is called as carbonate or alkaline hardness	03	It is also known as non-carbonate or non-alkaline hardness



DISADVANTAGE OF HARDNESS OF WATER

Hardness of water cause adverse effect on different way of the human life:

WASHING :

Hard water does not lather freely with soap rather it produce sticky precipitates of Calcium (Ca) and Magnesium (Mg) soap. This cause wastage of soap being used. Moreover, the sticky precipitate (of calcium and magnesium soaps) adheres on the fabric/cloth giving spots and streaks. Also presence of iron salts may cause staining of cloth.

BATHING:

No cleansing properties of the soap with hard water.

COOKING:

Due to the presence of dissolved hardness-producing salts, the boiling point of water is elevated. Consequently, more fuel and time are required for cooking certain foods such as pulses, beans and peas do not cook soft in hard water. Also tea or coffee, prepared in hard water, has an unpleasant taste and muddy-looking extract. Moreover, the dissolved salts are deposited as carbonates on the inner walls of the water heating utensils.

DRINKING:

Hard water causes bad effect on our digestive system. Moreover, the possibility of forming calcium oxalate crystals in urinary tracks is increased.

QUALITY ASPECT OF WATER

Water is the second most important need for life to exist after air. Based on its source, water can be divided in to two major category:

1. Ground Water **2. Surface Water**

Both types of water can be exposed to contamination risks from agricultural, industrial, and domestic activities, which may include many types of pollutants such as heavy metals, pesticides, fertilizers, hazardous chemicals, and oils.

Water quality can be classified in to four types:

1. Potable water 2. Palatable water 3. contaminated (polluted) water 4. Infected water

The most common scientific definitions of these types of water quality are as follows:

1. Potable Water: It is safe to drink, pleasant to taste, and usable for domestic purposes .

2. Palatable Water: It is esthetically pleasing; it considers the presence of chemicals that do not cause a threat to human health .

3. Contaminated (polluted) water: It is that water containing unwanted physical, chemical, biological, or radiological substances, and it is unfit for drinking or domestic use .

4. Infected water: It is contaminated with pathogenic organism

Quality Aspect of Water

Parameters of water quality:

There are three types of water quality parameters

1. Physical **2. Chemical** **3. Biological**

1. Physical Parameter of Water Quality:

   A. Turbidity
   B. Color
   C. Test & Odor
   D. Solid residue
   E. Oil content

Quality Aspect of Water

2. Chemical Parameter of Water Quality:

A. PH
B. Conductivity
C. Dissolved
D. Nitrate
E. Orthophosphate
F. Chemical Oxygen Demand (COD)
G. Biological Oxygen Demand (BOD)
H. Pesticides

Quality Aspect of Water

3. Biological Properties

A. Bacteriological Parameter
B. Coliforms
C. Fecal Coliforms
D. Specific pathogens
E. Viruses

Standard Characteristics of Drinking Water

#	Characteristic's	Desirable Limit
A	Physio-Chemical Characteristics	
a	**PH**	**6.5-8.5**
b	**Total Dissolved Solid (TDS)**	**500 ppm**
c	Total Hardness (as $CaCO_3$)	300 ppm
d	Nitrate (NO_3)	45 ppm
e	**Chloride (Cl)**	**250 ppm**

Standard Characteristics of Drinking Water

#	Characteristic's	Desirable Limit
A	Physio-Chemical Characteristics	
f	Fluoride (F)	1.0 ppm
g	Sulphate (SO4)	200 ppm
B	Biological Characteristics	
a	Escherichia Coli (E. Coli)	Not at all
b	Coliforms	10 (In 100 mL water)

Techniques of Water Softening

A Lime Softening (Clark's process):

- Lime soda method is combination of Clark's method and soda ash method. In this method both temporary and permanent hardness of water is removed.
- The lime reacts with bicarbonates and carbonate while the soda ash reacts with chlorides and sulphate to produce insoluble carbonates. Thus the water becomes soft.

Reaction :

- $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O$
- $Mg(HCO_3)_2 + 2Ca(OH)_2 \rightarrow Mg(OH)_2 + 2CaCO_3 + 2H_2O$
- $MgCl_2 + Na_2CO_3 \rightarrow MgCO_3 + 2NaCl$
- $CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$
- $MgSO_4 + Na_2CO_3 \rightarrow MgCO_3 + Na_2SO_4$
- $MgCO_3 + Ca(OH)_2 \rightarrow CaCO_3 + Mg(OH)_2$

The Process of removing soluble salts of calcium and magnesium from hard water is known as softening of water.

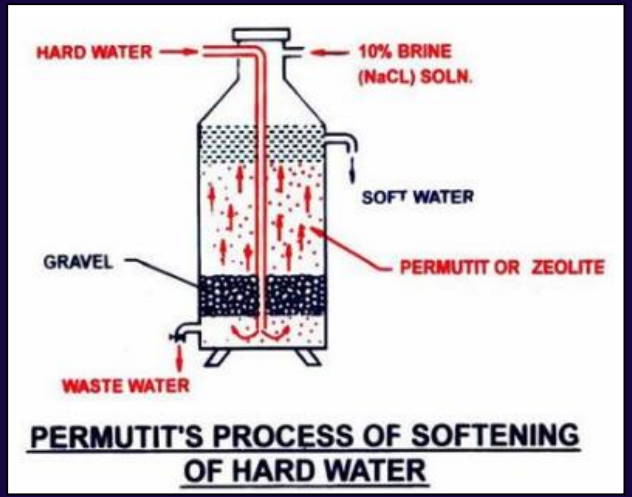
Techniques of Water Softening

B Zeolite Methods

Zeolite is inorganic Micropores material used as water softening agents. The most common Zeolite used for water softening is "SODIUM ZEOLITE". This hydrated form of sodium alumino silicate with general formula "**Na2O. Al2O3.xSiO2.yH2O**"

X → 2-20 Y → 2-6

When Ca2+ and Mg2+ ions containing hard water is passed through a bed of sodium zeolite, the sodium ions are replaced by the calcium and magnesium ions.



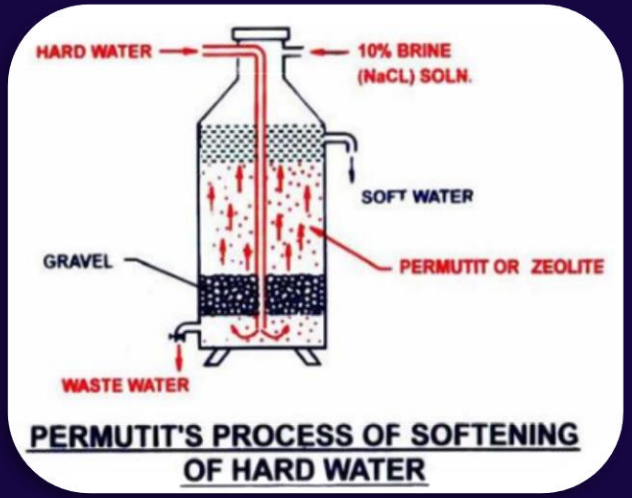
Techniques of Water Softening

B Zeolite Methods

Reaction:

$Na_2Z + Ca(HCO_3)_2 \rightarrow 2NaHCO_3 + CaZ$
$Na_2Z + Mg(HCO_3)_2 \rightarrow 2NaHCO_3 + MgZ$
$Na_2Z + CaSO_4 \rightarrow Na_2SO_4 + CaZ$
$Na_2Z + MgSO_4 \rightarrow Na_2SO_4 + MgZ$
$Na_2Z + CaCl_2 \rightarrow 2NaCl + CaZ$
$Na_2Z + MgCl_2 \rightarrow 2NaCl + MgZ$
$Na_2Z + Fe(HCO_3)_2 \rightarrow 2NaHCO_3 + FeZ$
$Na_2Z + Mn(HCO_3)_2 \rightarrow 2NaHCO_3 + MnZ$

Z → ZEOLITE



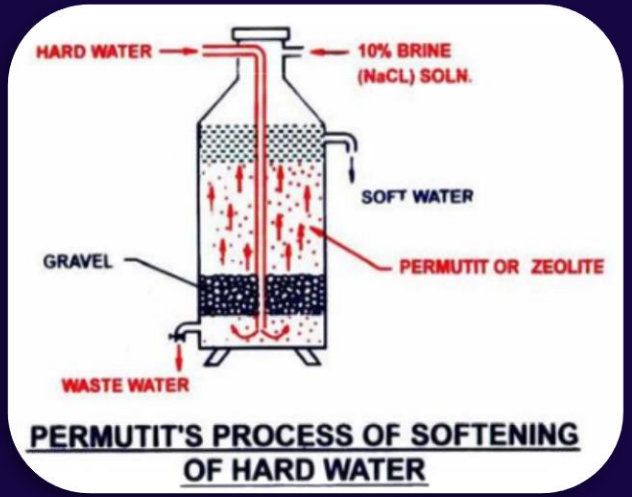
Techniques of Water Softening

B Zeolite Methods

When all sodium ions are replaced by calcium and magnesium ions, the zeolite becomes inactive. Then the zeolite needs to be regenerated. zeolite can be easily regenerated by passing brine solution (10% NaCl) through the bed of inactivated zeolite.

REACTION:

$$CaZ + 2NaCl \rightarrow Na_2Z + CaCl_2$$
$$MgZ + 2NaCl \rightarrow Na_2Z + MgCl_2$$

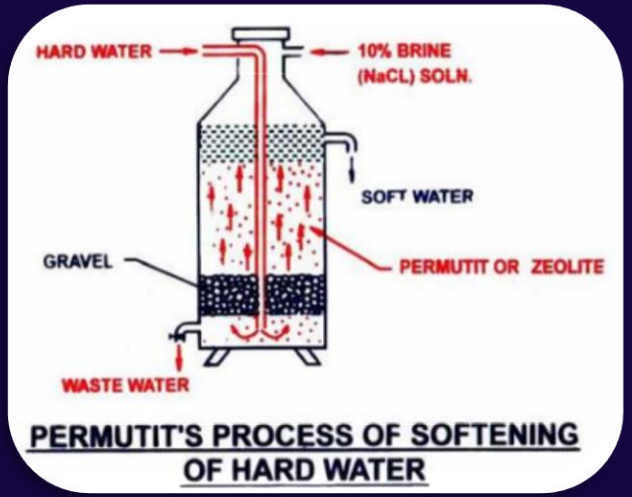


Techniques of Water Softening

B Zeolite Methods (Permutit Methods)

Merits of Zeolite Process: This method have the following advantage:

a. Efficient removal of Hardness (up to 10 ppm)
b. The equipment used in this process is very compact and occupied less space for operation
c. Used for the large scale of water treatment without formation of sludge at on latter stage because there is no chance for the precipitation

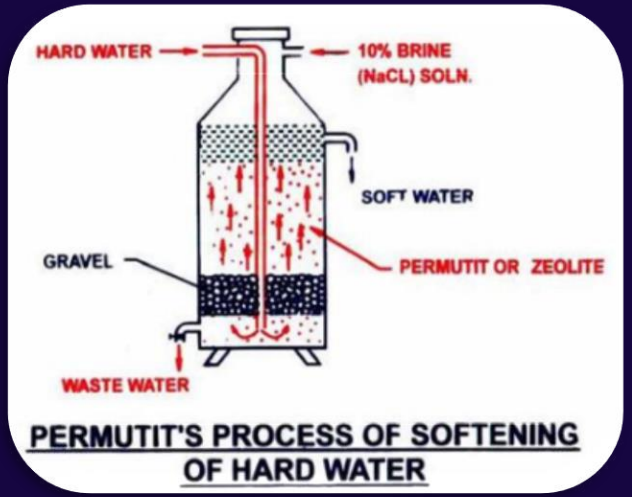


Techniques of Water Softening

B Zeolite Methods (Permutit Methods)

Demerit of Zeolite Process: This method have the following disadvantage:

- **a.** Water is highly acidic
- **b.** Fe and Mn cannot be effectively recovered
- **c.** High turbidity water cannot be treated efficiently by this method, because fine impurities get deposited on the zeolite bed, thereby creating problem for its working.



Techniques of Water Softening

C **Ion exchange or de-ionization or de-mineralization process**

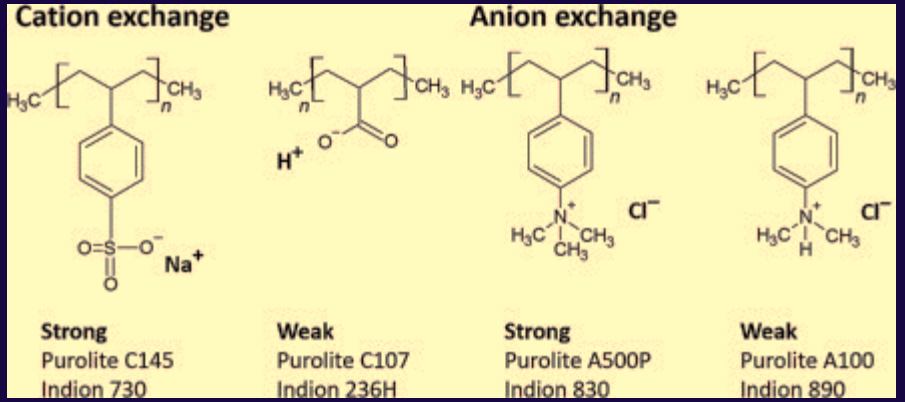
Ion exchange resins are insoluble, micro porous, cross linked of bifunctional organic copolymers. The functional groups attached to the backbone of the polymeric material are responsible for the ion-exchange suspended in hard water.

Type of Ion Exchanger:

A. **Cation Exchanger** (sites are negatively charged, positive ion can be separated)
B. **Anion Exchanger (**sites are Positively charged, Negative ion can be separated)

Techniques of Water Softening

C Ion exchange or de-ionization or de-mineralization process



Structure of Resins

Techniques of Water Softening

C **Ion exchange or de-ionization or de-mineralization process**

Process:

a. The hard water is passed first through cation exchange column, which removes all the cations like Ca^{2+}, Mg^{2+}, etc. from it, and equivalent amount of H^+ ions are released from this column to water.

b. After cation exchange column, the hard water is passed through anion exchange column, which removes all the anions like SO_4^{2-}, Cl^-, etc. present in the water and equivalent amount of OH– ions are released from this column to water.

*The water coming out from the exchanger is free from cations as well as anions. Ion-free water, is known as deionized or demineralized water.

Techniques of Water Softening

C **Ion exchange or de-ionization or de-mineralization process**

Process:

a. The hard water is passed first through cation exchange column, which removes all the cations like Ca^{2+}, Mg^{2+}, etc. from it, and equivalent amount of H^+ ions are released from this column to water.

b. After cation exchange column, the hard water is passed through anion exchange column, which removes all the anions like SO_4^{2-}, Cl^-, etc. present in the water and equivalent amount of OH– ions are released from this column to water.

*The water coming out from the exchanger is free from cations as well as anions. Ion-free water, is known as deionized or demineralized water.

Techniques of Water Softening

C Ion exchange or de-ionization or de-mineralization process

Regeneration:

A. Cation exchange resin is regenerated by treatment with acid, then washing with water

B. Anion exchange resin is regenerated by treatment with NaOH, then washing with water

Techniques of Water Softening

C Ion exchange or de-ionization or de-mineralization process

Advantage:

A. It is a very effective and efficient method of water softening.
B. Most of the heavy metals can be reused.
C. Most of the heavy metals can be reused.
D. It produces water of low hardness (up to 10 ppm)

Disadvantage:

A. The level of acidity in the water can be increased because of entry of sodium ions into the softened water. It may make the water not to be very safe for use.
B. The iron exchangers also require high operational costs.
C. Used only small scale of purification.

Techniques of Water Softening

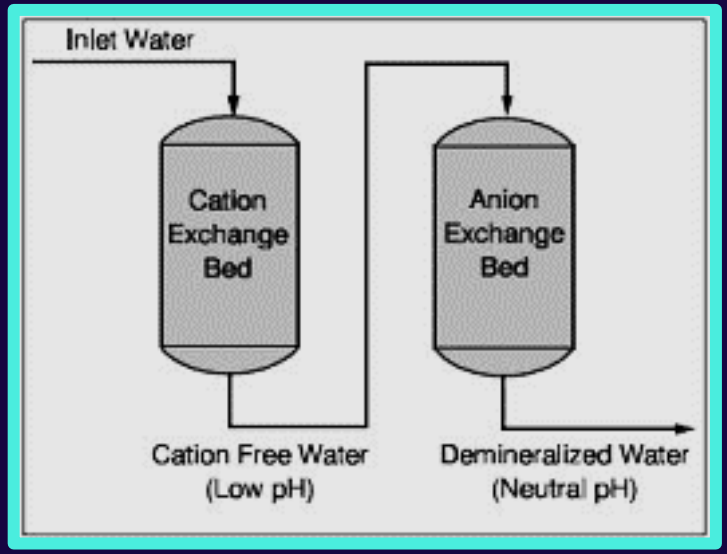
C Ion exchange or de-ionization or de-mineralization process

Just as the name suggests, ion exchange is a water softening method that softens hard water to soft water by exchanging the magnesium and calcium ions with sodium ions.

Techniques of Water Softening

C Ion exchange or de-ionization or de-mineralization process

Diagram of Ion Exchanger



Reference:

1. A Text Book of Engineering Chemistry S S Dara & S S Umare, S.Chand & Co.
2. Engineering Chemistry Jain & Jain , Dhanpat Rai & Co.
3. Engineering Chemistry S. Chawla, Dhanpat Rai & Co.

Calgon Process:

- Calgon is a trade name of a complex salt, sodium hexametaphosphate $(NaPO_3)_6$. It is used for softening hard water. Calgon ionizes to give a complex anion:

$$(NaPO_3)_6 \text{ or } Na_2(Na_4P_6O_{18}) \longrightarrow 2Na^+ + \underbrace{Na_4P_6O_{18}^{2-}}_{\text{complex anion}}$$

- The addition of Calgon to hard water causes the calcium and magnesium ions of hard water to displace sodium ions from the anion of Calgon.

$$\underbrace{Ca^{2+}}_{\text{from hard water}} + \underbrace{Na_4P_6O_{18}^{2-}}_{\text{anion of calgon}} \longrightarrow 2Na^+ + \underbrace{CaNa_2\,P_6O_{18}^{2-}}_{\text{goes into solution}}$$

The effect is the extraction from hard water, in the form of a Calgon complex, of calcium and magnesium ions. It softens the water and releases sodium ions.

Self Assessment

1. Discuss Zeolite method of softening hard water with diagram and chemical reactions involved in it? Also write advantages and disadvantages of the process.
2. What are ion-exchangers. Discuss softening of hard water by ion exchange method with the help of neat labeled diagram. Also write advantages and disadvantages of the process.
3. Discuss Lime Soda process of softening hard water with the help of neat labeled diagram and chemical reactions involved in it?

Thank you For Reading


STAY SAFE,
EVERYONE!