International Journal of Research in Engineering, Science and Management
Volume-2, Issue-6, June-2019
www.ijresm.com | ISSN (Online): 2581-5792

Analysis of Water Softening Methods

B. Aute Vishvajit[1], P. Gaikwad Pradeep[2], A. Chikhalthane Rohit[3], M. Khiladkar Priyanka[4], M. P. Wagh[5]

[1,2,3,4]Student, Department of Civil Engineering, Vikhe Patil College of Engineering, Ahmednagar, India

[5]Professor, Department of Civil Engineering, Vikhe Patil College of Engineering, Ahmednagar, India

***Abstract*: Water is a very important component of our lives and of the earth. 70% of our body is composed of water. 71% of the earth is water. We have different bodies of water, from oceans, seas, lakes, rivers and many more. As the global warming continues, the glaciers in the Arctic are will melt; water will envelop all the land areas. Day by day sources of potable waters are found to be less and need to convert the groundwater into soft water. The present project deals with a study of different methods available to convert the hard water into soft water. As per the World Health Organization (WHO) 842, 000 deaths per year from waterborne diseases. Water has been and will always be an important component of our lives. In this project, we will also design particular filter media to convert the hard water into soft water (portable, clean, safe water). Especially in remote areas, where sanitation is a big concern, water is unsafe for drinking and unhygienic. Analysis of water softening methods will be carried out by selecting different water resources. According to Results and analysis, the Zeolite Method, in zeolite method the hardness is removed maximum then the other softening method hence we conclude that the Zeolite Method is most efficient for the Treatment.**

***Keywords*: water softening methods**

1. Introduction

Water is god's gift to all living creatures, from unicellular to multicellular and from plants to animals on earth. The Earth's 71% surface area is occupied by water and the remaining 29% by land. The oceans contain nearly 97% of water as compared to that available on earth's surface. But ocean water, being saline, can't be used directly for drinking, agricultural and industrial purposes. Hence, we are totally dependent on rainwater and it is necessary to store water available from rains. The quality of water is of vital concern for humans since it is directly linked with human health. Water plays an important role in various life processes in the human body. In our daily life water is used for drinking, bathing, cooking and washing purposes. Water is also the best solvent (also called as universal solvent) and it is used in many industries such as boiler industry for steam generation, textile, paper, pharmaceutical industry, etc. for various solutions/slurries; as a coolant in power plants, condensers, etc. Thus it is evident that pure water is required by plants, animals to a human being not only for self-use but also for purposes of different manufacturing industries. Hence the purity of water is of almost importance because the rainwater can't remain in the same state of purity when it falls on the surface of the earth. The water thus contaminated needs to be treated.

A. Characteristics of soft water

The municipal supply of water should have the following characteristics or specific standards:

- Colorless and odorless,
- Good in taste,
- Turbidity is less than 10 ppm,
- Free from objectionable dissolved gases like H2S,
- Free from objectionable minerals such as lead, arsenic, chromium and manganese salts,
- Alkalinity is not high. pH in the range of 7.0 – 8.5.
- Total hardness is less than 500 ppm.
- Free from disease-producing micro-organisms.

B. Problem statement

1. A high level of calcium and magnesium can affect several organs in the body and cause health problems.
2. The most severe effect of hard water is an increased risk of cardiovascular disease according to several international studies both heart disease and high blood pressure can be caused by hard water.
3. Effect on skin
4. Effect of cooking, more consumption of fuel.
5. Digestion problem
6. Throat infection
7. Water born disease, chances of kidney failure
8. Increased scaling on water pipes, boilers, and affect the odor and taste of drinking water.

C. Characteristics of ground water

1. It has Color and odor,
2. Bad in taste,
3. Turbidity is Greater than 10 ppm,
4. It has objectionable minerals such as lead, arsenic, chromium and manganese salts,
5. Alkalinity is high. pH in the range is more than 8.5.
6. Total hardness is greater than 500 ppm.
7. It has disease-producing micro-organisms.

D. Objective of project

- To find the characteristics of hard water to give the proper treatment.

- To learn the different analyses of water softening methods.

2. Methodology of softening of water

A. Lime-soda process

Principle: In this method hard water is treated with calculated amounts of slaked lime, [$Ca(OH)_2$] and soda ash [Na_2CO_3] in reaction tanks, so as to convert hardness producing chemicals into insoluble compounds which are then removed by settling and filtration.

Lime required for softening is calculated by using formula, as,

$$L = \frac{74}{100} [\text{ Temporary } Ca^{+2} + 2 \times \text{Temporary } Mg^{+2}$$

$$+ \text{ Permanent } (Ca^{+2} + Mg^{+2} + Al^{+3} + Fe^{+2})$$

$$+ CO_2 + H^+ (HCl \text{ or } H_2SO_4) + HCO^-_3 - NaAlO_2]$$

(all in term of their $CaCO_3$ equivalents.)

Soda required for softening,

$$S = \frac{106}{100} [\text{ Permanent } (Ca^{+2} + Mg^{+2} + Al^{+3} + Fe^{+3})$$

$$+ H^+ (HCl \text{ or } H_2SO_4) + AlCl_3 - HCO_3^- - NaHCO_3]$$

(all in term of their $CaCO_3$ equivalents.)

Normally, about 10 % excess of chemicals are added in the reaction tanks to complete the reactions quickly

B. Reactions with lime

Lime reacts in following ways, during softening of water.

1. To neutralise any free acid present. For example

$$2HCl + Ca(OH)_2 \longrightarrow CaCl_2^* + 2 H_2O$$

$$H_2SO_4 + Ca(OH)_2 \longrightarrow CaSO_4^* + 2H_2O$$

2. To precipitate iron and aluminium salts, if any, as hydroxides.

$$Al_2(SO_4)_3 + 3 Ca(OH)_2 \longrightarrow 2 Al(OH)_3\downarrow + 3 CaSO_4$$

$$FeSO_4 + Ca(OH)_2 \longrightarrow Fe(OH)_2\downarrow + CaSO_4$$

$$2 Fe(OH)_2 + H_2O + \frac{1}{2} O_2 \longrightarrow Fe(OH)_3\downarrow$$

3. To precipitate dissolved CO_2 as $CaCO_3$

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

4. To precipitate calcium bicarbonate as $CaCO_3$

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

* $CaCl_2$, $CaSO_4$ and $Ca(NO_3)_2$ produced are to be treated as permanent hardness

C. Reactions with soda

Soda removes all the soluble permanent hardness due to calcium salts as

$$CaCl_2 + Na_2CO_3 \longrightarrow CaCO_3\downarrow + 2NaCl$$

$$CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3\downarrow + Na_2SO_4.$$

$$Ca(NO_3)_2 + Na_2CO_3 \longrightarrow CaCO_3\downarrow + 2NaNO_3.$$

Natural waters mainly have temporary hardness which is conveniently and economically removed by lime treatment, as lime is cheap and removes temporary hardness efficiently without adding soluble salts in water. Thus, the net outcome of lime-soda treatment is,

1. Reduction of soluble impurities imparting hardness to water by converting them to insoluble salts, and
2. Permanent calcium hardness by producing insoluble $CaCO_3$.

However the acid radicals which are converted to their respective soluble sodium salts (e.g. NaCl, Na_2SO_4) remain in water.

Water with traces of soluble salts such as NaCl. Na_2SO_4 cannot be used in high pressure boilers.

The chemical reactions taking place during lime-soda treatment are slow and precipitates of $CaCO_3$ and $Mg(OH)_2$ are fine and produce super saturated solution.

As a result after deposition occurs in pipes, boiler tubes etc. their diameters are reduced and the valves get clogged and thus corrosion occurs. In order to avoid this, following steps are taken :

1. Thorough mixing of chemicals and hard water.
2. Sufficient time allowed to complete reactions.
3. Accelerators i.e. substances that bring down the fine particles of precipitates e.g. activated charcoal are used.
4. Coagulants or flocculants i.e. substances which help in the formation of coarse precipitates are added e.g. alum.
5. Provision of proper sedimentation chamber for precipitates to settle, before filtration being carried out.

D. Zeolite or Permutit Process

The name zeolite (Greek : Zein-boiling, lithos-stone) means boiling stone. The chemical formula of sodium zeolite may be represented as,

$Na_2O.Al_2O_3{\cdot}xSiO_2 \times yH_2O$ (where x = 2 to 10 and y = 2 to 6).

(Zeolite = hydrated sodium alumino silicate)

"Zeolite is hydrated sodium alumino silicate capable of exchanging reversibly their sodium ions for hardness producing ions in water." Zeolites are also known as permutits. Zeolites are of two types:

1) Natural zeolites
2) Synthetic zeolites.

1) Natural zeolites

They are amorphous and non-porous. They are derived from green sands by washing, heating and treating with NaOH. The natural zeolites are more durable and are as follows:

e.g. Natrolite.

Formula for natrolite = $Na_2O\ Al_2O_3\ 4SiO_2\ 2H_2O$

a. Thomsonite: (Na_2O, CaO) $Al_2O_3{\cdot}2\ SiO_2{\cdot}2\frac{1}{2}\ H_2O$

b. Natrolite: Na_2O. $Al_2O_3{\cdot}4\ SiO_2{\cdot}2\ H_2O$

c. Laumontite: CaO. $Al_2O_3{\cdot}4\ SiO_2{\cdot}4\ H_2O$

d. Harmotome: ($BaO.K_2O$). $Al_2O_3{\cdot}5\ SiO_2{\cdot}5\ H_2O$

e. Stilbite: (Na_2O,CaO), $Al_2O_3.6\ SiO_2{\cdot}6\ H_2O$
f. Brewsterite: $(BaO.SrO.CaO)$ $Al_2O_3{\cdot}6\ SiO_2{\cdot}5\ H_2O$
g. Ptilolite: $(CaO,\ K_2O,Na_2O)$, $Al_2O_3{\cdot}0\ SiO_2{\cdot}5\ H_2O$

2) Synthetic zeolites.

They are porous and possess gel structure. They are prepared by heating together:

a) China clay, felsh par and soda ash and granulating the resultant mass after cooling.
b) Solutions of sodium silicate, aluminium sulphate and sodium aluminate.
c) Solutions of sodium silicate and aluminium sulphate.
d) Solutions of sodium silicate and sodium aluminate.

Synthetic zeolites have higher exchange capacity per unit weight.

Principle of zeolite-permutit process

When hard water is passed over a bed of sodium zeolite, Ca^{2+} and Mg^{2+} ions present in it are taken up by the zeolite simultaneously releasing equivalent Na^+ ions in exchange for them. The water gets free from hardness causing cations, but gets more concentrated with sodium salts. When zeolite gets exhausted it is regenerated and can be used again for softening water. Restored by treatment with 10 % brine solution is called as regeneration."

Process of softening water by zeolite-permutit method

It operates alternatively as the softening run and the regeneration.

During softening process the hard water from top enter at a specified rate and passes over a bed of sodium zeolite kept in a cylinder.

Softened water containing sodium salts is collected at the bottom of the cylinder and is taken out from time to time.

The cations Ca^{+2} and Mg^{+2} are retained in zeolite bed and soft water rich in Na^{+2} is collected. After some time the zeolite bed gets exhausted.

When zeolite bed gets exhausted, the softening run is discontinued and regeneration is started. During regeneration process, the following three operations are carried out.

(a) Back washing
(b) Salting (or brining) and
(c) Rinsing to get regenerated bed for reuse.

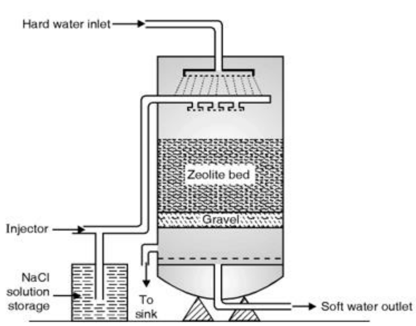


Fig. 1. Zeolite Softer

Advantages of zeolite process

1. Water of about less than 15 (0 – 15) ppm hardness is produced.
2. The process automatically adjusts itself for different hardness of incoming water.
3. Water obtained is quite clear
4. It requires less skill in maintenance as well as operation.
5. The equipment is compact, occupying less space.
6. No sludge formation because the impurities are not precipitated.

Disadvantages of zeolite process

1. The treated water contains more sodium salts.
2. The method only replaces Ca^{2+} and Mg^{2+} ions by Na^+ ions, but leaves all acidic ions (HCO_3^- and CO_3^{-2}) in soft water. Such soft water containing ($NaHCO_3$, Na_2CO_3) etc. when used in boilers, $NaHCO_3$ decomposes to give CO_2 which causes boiler corrosion and Na_2CO_3 hydrolyses to NaOH, causing caustic embrittlement.

Ion Exchange Process

In this process, a reversible exchange of ions occur between the stationary ion-exchange phase and the external liquid mobile phase.

"Ion-exchange resins are insoluble, cross-linked, long-chain high molecular weight organic polymers which are permeable due to their micro porous structure, and the functional groups attached to the chains are involved in the ion-exchanging properties."

The purely synthetic organic exchangers are made by

(a) Polycondensation and (b) Polymerisation.

The functional groups are then introduced into the cross-linked resin network. It is these functional groups which decide the nature of the resin exchanger i.e. cationic or anionic.

The ion-exchange resins on the basis of their acidity or basicity are classified as follows:

(1) Cation exchange resins (RH_2)/ (RH^+)

Resins containing acidic functional groups (– COOH, $-SO_3H$, etc.) exchange their H^+ ions with other cations, which come in their contact are known as cation exchange resins. These are represent as $RH^{\oplus}$ or RH_2.

These resins are capable of exchanging rapidly cations like Ca^{2+} and Mg^{2+} by hydrogen ions. For example : Divinely benzene copolymer, formaldehyde resins, Amberlite IR – 120, Zeocarb, Dowex-50, Duolite, Sulphated or carboxylate styrene etc. are some of the commercially available cation exchange resins.

Their exchange reactions with cations (Ca^{2+} and Mg^{2+}) are as follows:

$$RH_2 + Ca^{2+} \longrightarrow RCa + 2H^+$$

$$RH_2 + Mg^{2+} \longrightarrow RMg + H^+$$

(2)Anion exchange resins (R′(OH))

The resin containing basic functional groups (e.g. – NH_2, = NH, etc. as hydrochloride) exchange their anions with other anions, which come in their contact are called as anion exchange resins.

Table 1
Anion exchange resins

Types of ion-exchange	Functional groups
(1) Cation-exchangers	
(a) Strongly acidic	SO_3H
(b) Weakly acidic	COOH or – OH
(2) Anion-exchangers	
(a) Strongly basic	$\overset{+}{NR_3}$, $-CH_3$, $\equiv P^+$ etc.
(b) Weakly basic	$-NH_2$, $-(C_2H_4)_x$, $(NH)_y^-$

Principle of ion exchange process

- When hard water is first passed through cation exchange bed which removes all cations
- Thus, sulphates, cholorides and bicarbonates are converted into corresponding acids HCl, H_2SO_4 and H_2CO_3. In order words, water collected from cation exchanger is free collected from all cations, but is acidic.
- After this, the acidic hard water is passed through an anion exchange bed which.
- Thus, the water coming out from anion exchange bed becomes free of cations as well as from anions.
- The resulting ion-free water is deionised water or demineralised water.
- The water is finally freed from dissolved gases by passing it through a degasifier, which is a tower heated from both sides and is connected to a vacuum pump.

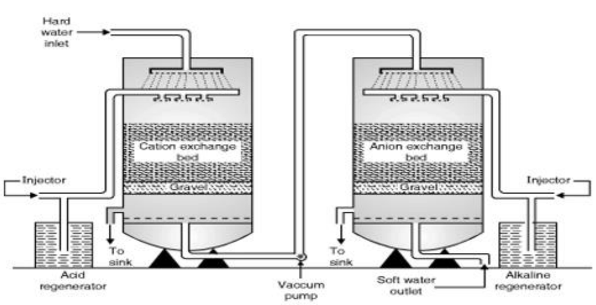


Fig. 2. Demineralization of water

- High temperature and low pressure reduces the quantity of dissolved gases.
- Water obtained by this process is very near to distilled water, which the requirement of boiler is feed water. This process is very good for high pressure boilers.
- Regeneration of exhausted resins
- The capability of these ion-exchange resins to exchange ions from hard water is based on their ion-exchange capacities.
- When their ion-exchange capacities are lost, they are said to be exhausted.
- When the resins are exhausted, the supply of water is stopped. The exhausted cation exchanger is regenerated by passing dilute HCl or H_2SO_4 solution.

Process of ion-exchange/demineralisation

- The hard water is first passed through cation exchange column and then through anion exchange column.
- The soft water thus obtained is free from all the cations and anions.
- When column gets exhausted, it is set to regeneration; and the process is continued. The water obtained is near to the distilled water quality (0 – 2 ppm.)
- The exchange bed is washed with deionised water and washings (containing Ca^{2+}, Mg^{2+}, and Cl^- or SO_4^{2-}) are passed to sink or drain.
- The exhausted anion exchanger is regenerated by treating it with a dilute NaOH solution.

The exchanger bed is washed with deionised water and washings (containing NaCl or Na_2SO_4) are passed to sink or drain.

- The regenerated ion-exchange resins are used again. If water contains sufficient temporary hardness, it is advisable to remove such hardness first by treating with lime.

E. Reverse Osmosis (RO)

Membrane technique (Reverse osmosis):

- Various membrane techniques are available, which selectively separate the solutes or contaminants on the basis of pore size.
- The types of membrane separation technologies include reverse osmosis, hyper filtration, ultrafiltration, etc. But reverse osmosis is commonly used.

Principle of reverse osmosis (RO):

- The reversal of solvent flow, from higher concentration solution to lower concentration solution through a semipermeable membrane, by applying an external pressure slightly higher than the osmotic pressure of higher-concentration solution, is known as reverse osmosis.
- Normal osmosis process, is shown in Figure, where the solvent flows from low concentration solution to higher concentration solution, through the semipermeable membrane, until difference in water levels creates a sufficient pressure to counteract the original flow. The difference in levels represents osmotic pressure of the solution.

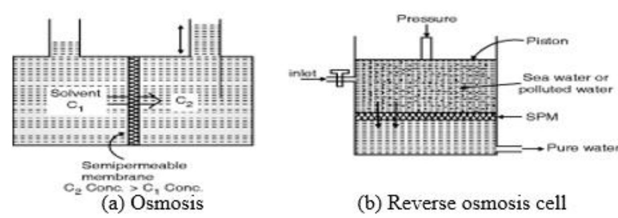


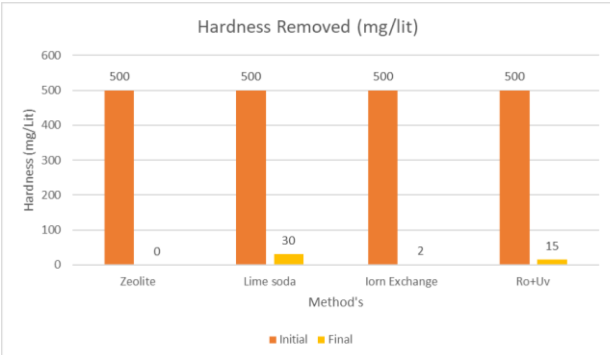
Fig. 3. Reverse Osmosis (RO)

Lime Soda Method: Lime softening is the process in which lime is added to hard water to make it softer. (Initial Hardness = 500 mg/lit, Final Hardness = 30 mg/lit)

Iron Exchange Method: In this method, magnesium and calcium are removed. (Initial Hardness = 500 mg/lit, Final Hardness = 2 mg/lit)

Ro+Uv Reverse osmosis (RO): takes advantage of hydrostatic pressure gradients across a special membrane. UV technology is used to remove bacteria. (Initial Hardness = 500 mg/lit, Final Hardness = 15mg/lit)

Zeolite Method: Hard water is percolated at a specified rate through a bed of zeolite, kept in a cylinder. The hardness causing ions (Ca^{2+}, Mg^{2+}, etc.) are retained by the zeolite as CaZe and MgZe; while the outgoing water contains sodium salts. (Initial Hardness = 500 mg/lit, Final Hardness = 0 mg/lit)



3. Conclusion

"The hard water is converted in to the soft water.'' According to Results and analysis, in zeolite method the hardness is removed maximum then the other softening method hence we conclude that the Zeolite Method is most efficient for the Treatment.

- Process of removal of hardness is easy and efficient.
- No maintenance is required.
- No Sludge generation.
- Automatically operated.

Acknowledgment

We are honored to express our deep sense of gratitude towards our Principal DR. U.P. NAIK and our guide DR. M.P. WAGH, department of civil engineering, D.V.V.P. College of Engineering, Ahmednagar, for his creative suggestion, helpful discussion, unfailing advice, and constant encouragement during the project work. We consider our self-privileged to have worked under him as he always shared his experience so generously and patiently in spite of his busy schedule. We sincerely appreciate the interactive help, received from him by the way of advice, suggestion. We have been always graced by our parents, their support and blessing have driven our performance and success. We are grateful to our family and friends for their kind support and motivation have helped us to completing this work successfully.

References

[1] "Ion Exchange Treatment of Drinking Water". Des.nh.gov. 2009.
[2] Krauter, P. W.; Harrar, J. E.; Orloff, S. P.; Bahowick, S. M. (1996). "Test of a Magnetic Device for the Amelioration of Scale Formation at Treatment Facility D". Osti.gov.
[3] "Common Water Quality Problems and Their Treatment" Retrieved 2013-06-23.
[4] Arai, H. (1966) Study of detergency: I. Effect of the concentration and the kind of detergent in hard water. Journal of the American Oil Chemists' Society, 43, 312–314.
[5] Brown, D.M., Cameron, B.A., Meyer, S.S. & Umber, J.J. (1991) The effects of water hardness level on washing quality using commercial laundry detergents. Journal of Consumer Studies & Home
[6] Gray N.F. Drinking water quality. Second edition. Cambridge University Press; 2008.
[7] Shweta Tyagi, Rajendra Dobhal (2013) Water Quality Assessment in terms of (WQI)
[8] Lenntech: water treatment solutions [Internet]. c.1998-2016. Water hardness calculator.
[9] Water Treatment Principles and Design. Second edition. United States of America: John Wiley & Sons; 2005.
[10] Cameron, B.A., (1991) The effects of water hardness level on washing quality using commercial laundry detergents.
[11] Bahowick, S. M. (1996). "Test of a Magnetic Device for the Amelioration of Scale Formation at Treatment.