Water Supply Engineering

Chapter 6

Water Treatment

Lecture 11 (Week 11)

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Softening, Removal of temporary hardness, Removal of permanent hardness, Miscellaneous treatments, Removal of iron and manganese, Removal of color, odor and taste

Learning Objectives:

By the end of this chapter, students will be able to:

- Explain the purpose of water softening.
- Describe methods to remove temporary hardness (boiling and lime treatment).
- Describe methods to remove permanent hardness
- Explain the purpose and methods of aeration.
- Identify methods for removing iron and manganese.
- Explain techniques for removing color, odor, and taste from water.

6.8 Softening

- Water softening is a treatment process used to reduce the hardness of water. Hard water contains high levels of dissolved minerals, mainly calcium and magnesium, which can cause scaling in pipes, reduce soap effectiveness, and damage appliances.
- Hardness is caused by the presence of bicarbonates, sulphates, chlorides and nitrates of calcium, magnesium and strontium.

6.8.1 Purpose of softening

The main goal of softening is to eliminate or reduce minerals like calcium and magnesium that cause water hardness. By doing this, we can prevent scale buildup in pipelines and equipment, improve the efficiency of soap and detergents, and protect household or industrial systems from damage. Softened water is also more suitable for various domestic, industrial, and laboratory uses.

6.8.2 Removal of temporary hardness

Temporary hardness in water is mainly due to the presence of dissolved bicarbonates of calcium and magnesium. It can be removed by simple physical or chemical methods, as these salts break down upon heating or with specific chemical treatment.

6.8.2.1 Boiling Method

Boiling water causes the bicarbonates of calcium and magnesium to decompose into insoluble carbonates, which settle as precipitates. This process removes the hardness-causing ions, making the water softer. It is suitable for small-scale or household use.

Reaction (example):

$Ca(HCO_3)_2$+Heat->$CaCO_3$+CO_2+H_2O

$Mg(HCO_3)_2$+ Heat ->$MgCO_3$ + CO_2 + H_2O

6.8.2.2 Lime Treatment Method

In this method, lime ($Ca(OH)_2$) is added to hard water. Lime reacts with bicarbonates, converting them into insoluble carbonates that can be filtered out. This method is suitable for treating larger quantities of water. (Kansakar, 2015)

Reaction (example):

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

$Mg(HCO_3)_2$+$Ca(OH)_2$->$CaCO_3$+$MgCO_3$+$2H_2O$

This process not only removes hardness but also helps in partial disinfection and pH adjustment.

6.8.3 Removal of Permanent Hardness

Permanent hardness in water is caused by the presence of calcium and magnesium salts such as chlorides, sulfates, and nitrates. Unlike temporary hardness, it cannot be removed by boiling and requires chemical treatment.

6.8.3.1 Lime Soda Method

The lime soda process is a widely used chemical method for removing permanent hardness. In this method, lime [$Ca(OH)_2$] and soda ash [Na_2CO_3] are added to the hard water. These chemicals react with calcium and magnesium salts to form insoluble compounds that can be separated from water.

Key Steps:

- Lime and soda are mixed thoroughly with hard water.
- The water is gently agitated for 30 to 60 minutes to allow complete reactions.

- Reactions convert soluble calcium and magnesium salts into $CaCO_3$ (calcium carbonate) and $Mg(OH)_2$ (magnesium hydroxide), which are insoluble and settle out.

Typical Reactions:

- $CO_2 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + H_2O$
- $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3\downarrow + 2H_2O$
- $Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + MgCO_3\downarrow + 2H_2O$
- $MgCO_3 + Ca(OH)_2 \rightarrow Mg(OH)_2\downarrow + CaCO_3\downarrow$
- $MgSO_4 + Ca(OH)_2 \rightarrow Mg(OH)_2\downarrow + CaSO_4$
- $CaSO_4 + Na_2CO_3 \rightarrow CaCO_3\downarrow + Na_2SO_4$
- $MgCl_2 + Ca(OH)_2 \rightarrow Mg(OH)_2\downarrow + CaCl_2$
- $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3\downarrow + 2NaCl$

Final Step:

- The precipitated compounds ($CaCO_3$ and $Mg(OH)_2$) are removed by sedimentation, filtration, or both.
- The process is usually applied before sedimentation tanks, particularly before the chemical mixing unit in treatment systems using coagulation.

Note: Other by-products like NaCl and Na_2SO_4 remain in solution but do not contribute to hardness.

Advantages of lime soda method:

- ❖Amount of coagulant will be reduced for coagulation process.
- ❖Simple and economical.
- ❖Increases pH value of water which decreases corrosion of pipes.
- ❖Suitable for turbid and acidic waters for which zeolite cannot be prepared.

- ❖Iron and manganese are removed and pathogenic bacteria are killed to some extent.
- ❖Mineral content of water is reduced.
- ❖Suitable for extremely hard waters.

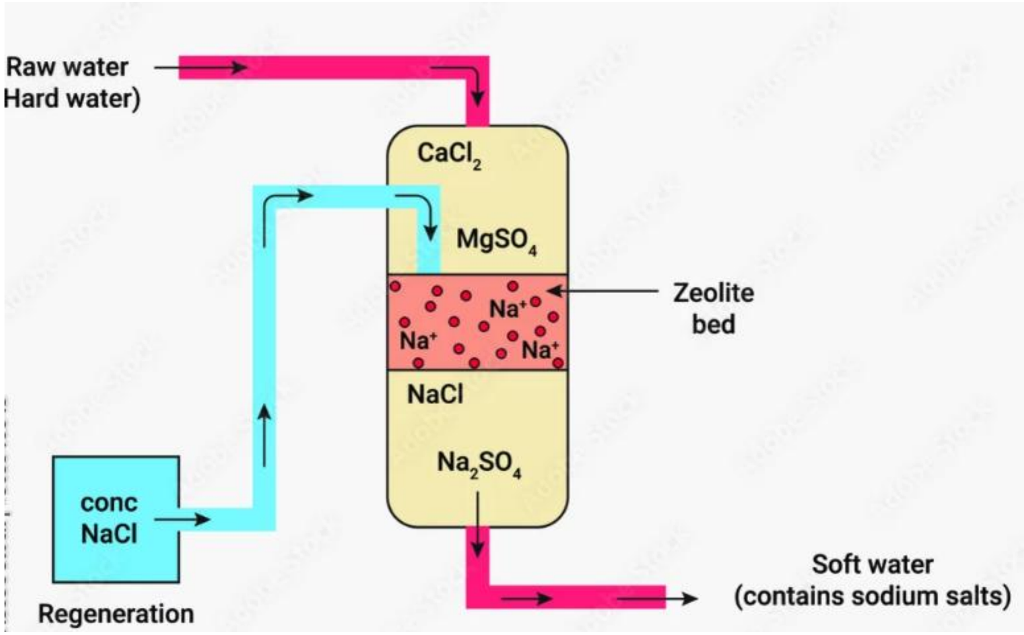
Disadvantages of lime soda method:

- ❖Large quantity of sludge is formed which creates difficulty in its disposal.
- ❖Requires skilled supervision for its successful operation.
- ❖Requires recarbonation of sedimentation effluent to prevent incrustation of pipes and clogging of sand filters.
- ❖Does not remove the hardness to zero level.

6.8.3.2 Zeolite method

- Zeolite is complex compound of aluminium,silica and soda which has chemical formula - $2SiO_2Al_2O_3Na_20$.
- It is a cation exchange process
- During its ion exchange, sodium ion present in zeolite is exchanged with calcium or magnesium ion present in the hardness of water.
- Naturally available zeolite is green in color so also known as green sand or glauconite. It's exchange value is 6500 to 9000 gm of hardness per m3 of zeolite.
- Commonly used synthetic zeolite is Permutit.
- Permutit when used the process is known as Permutit process.

➢ Exchange value of Permutit is 35,000 to 40,000 gm of hardness per m^3 of zeolite.



Source:https://stock.adobe.com/images/the-zeolite-softening-process-is-used-for-removing-both-the-temporary-and-permanent-hardness-of-the-water-by-precipitating-the-calcium-and-magnesium-present-in-water-as-insoluble-zeolites/503546843

$$2SiO_2Al_2O_3Na_2O + Ca(HCO_3)_2 = 2SiO_2Al_2O_3CaO + 2NaHCO_3$$

$$2SiO_2Al_2O_3Na_2O + CaSO_4 = 2SiO_2Al_2O_3CaO + Na_2SO_4$$

$$2SiO_2Al_2O_3Na_2O + CaCl_2 = 2SiO_2Al_2O_3CaO + 2NaCl$$

$$2SiO_2Al_2O_3Na_2O + Mg(HCO_3)_2 = 2SiO_2Al_2O_3MgO + 2NaHCO_3$$

$$2SiO_2Al_2O_3Na_2O + MgSO_4 = 2SiO_2Al_2O_3MgO + Na_2SO_4$$

$$2SiO_2Al_2O_3Na_2O + MgCl_2 = 2SiO_2Al_2O_3MgO + 2NaCl$$

- By zeolite process the hardness reduces to zero but it is not suitable for public water supplies.
- It is useful for water softening plants in boilers and textile industries

- By continuous use of zeolite, the sodium gets exhausted after which it fails to remove the hardness of water.
- zeolite is regenerated by passing a solution of salt (in the form of brine solution (5-10%)) through it.

Rxn^s :

$$2SiO_2Al_2O_3CaO + 4NaCl = 2SiO_2Al_2O_3Na_2O + CaCl_2$$

$$2SiO_2Al_2O_3MgO + 4NaCl = 2SiO_2Al_2O_3Na_2O + MgCl_2$$

- Sodium replaces calcium and magnesium of the exhausted zeolite.
- The zeolite water softeners resemble rapid sand filters of either pressure type or gravity type.
- The thickness of zeolite varies from 75 to 150 mm

Advantages

- No sludge formed
- No deposition of layer of CaC03 as in lime treatment method
- Zero hardness(~10 ppm) can be achieved
- Automatic process and low initial cost and high skilled personnel is not required.
- Free from danger of excess chemicals
- Requires less time

Disadvantages

- Removes only hardness contributing ions but leaves behind the sodium salts
- Cannot be used in high pressure boilers(causes embrittlement), if the water is even slightly acidic

- Incrustation of pipes and clogging of filters if the water is turbid
- Likelihood of growth of bacteria on the bed of zeolite

6.8.3.3 Ionization method

The ionization method, also known as the **ion exchange method**, is an effective chemical process used to remove permanent hardness from water by replacing hardness-causing ions with non-hardness ions.

How It Works:

- Hard water is passed through a column filled with ion exchange resins.
- These resins contain sodium (Na^{+}) or hydrogen (H^{+}) ions.
- As water flows through, the resins exchange their sodium or hydrogen ions with the calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions present in the hard water.

- This replacement softens the water because sodium and hydrogen ions do not form scale.

Example Reactions:

- $Ca^{2+} + 2Na^{+}$-resin → Ca-resin + $2Na^{+}$
- $Mg^{2+} + 2Na^{+}$-resin → Mg-resin + $2Na^{+}$

Regeneration:

- After prolonged use, the resin becomes saturated with Ca^{2+} and Mg^{2+}.
- It is regenerated by flushing with sodium chloride (NaCl) solution, which restores sodium ions to the resin, making it reusable.

Advantages:

- Produces very soft water.
- Suitable for domestic and industrial use.
- Compact and easy to maintain.

Limitations:

- Costly compared to other methods.
- Requires regular regeneration and maintenance.

6.9 Miscellaneous treatments

6.9.1Aeration

- is the process of mixing water with air by allowing water in intimate contact with air so as to absorb oxygen and remove CO_2 gas.
- It remove odour and tastes, increase dissolved oxygen content in water, remove CO_2 , reduces corrosions and removes methane and other flammable gases.

6.9.1.1Purpose

Aeration is the process of bringing water and air into close contact to improve water quality. The main **purposes of aeration** are:

1. **Increase Dissolved Oxygen (DO):**

   Boosts oxygen levels in water, which is essential for aquatic life and beneficial bacteria in treatment processes.

2. **Remove Dissolved Gases:**

   Helps eliminate undesirable gases like carbon dioxide (CO_2), hydrogen sulfide (H_2S), and methane (CH_4), which may cause odor or corrosion.

3. **Oxidation of Metals:**

   Converts soluble forms of metals like iron (Fe^{2+}) and manganese (Mn^{2+}) into insoluble forms (Fe^{3+}, Mn^{4+}), making them easier to filter out.

4. **Improves Taste and Odor:**

   Removes or reduces unpleasant tastes and smells caused by gases or organic matter.

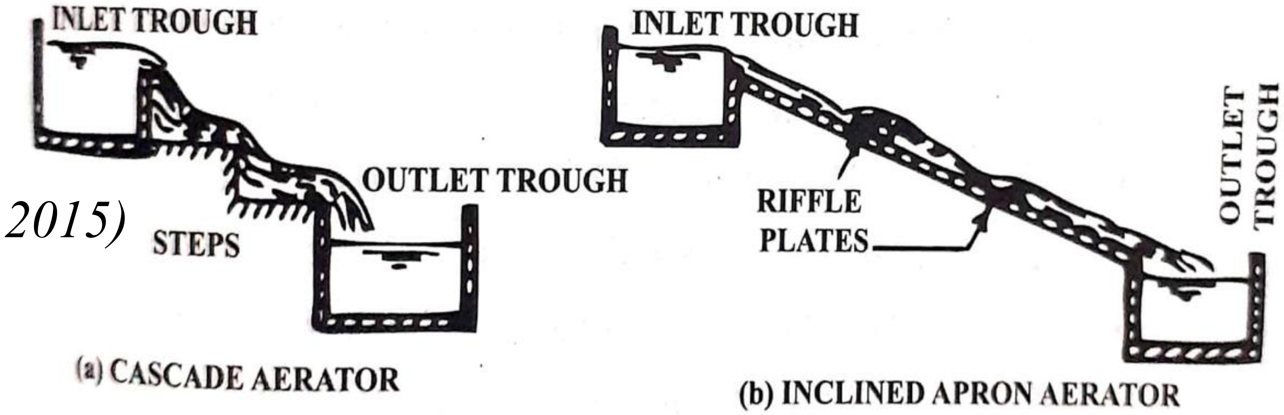
5. **Enhances Water Aesthetics and Quality:**

   Results in clearer, fresher, and more palatable water, suitable for domestic and industrial use.

6.9.1.2 Methods of aeration

a) Gravity Aerators

- **Cascade Aerators**
  - Consists of a series of three or four steps of concrete or walls
  - Water is allowed to fall through a height of 1 to 3 meters
  - Reduction of C02 (50 to 60%) occurs by contact with air



Source: *(Kansakar, 2015)*

- **Inclined Apron Aerators**
  - Water is allowed to fall along an inclined plane or apron
  - Studded with riffle plates in herring bone fashion
  - Agitation of water is induced by breaking up of water due to aprons which results in consequent aeration

Slat tray Aerators

- ➢ Most commonly used
- ➢ closed round or square structure containing a series of perforated trays arranged about 30 cm intervals.
- ➢ Every tray consists of 30 cm deep coke or gravel bed and water falls from one tray to another.

- Water enters from top and is evenly distributed over top tray and air is supplied from bottom through a blower
- Ventilator discharges gases to atmosphere and Water is collected in collector pan

- **Multiple tray Aerators**

- Used in small communities and households
- Consists of number of trays made of metal or plastic with perforated bottom
- Water flowing through riser pipe flows through each tray and collects at basin
- Number of trays= 4 to 9
- Tray Spacing= 300 to 750 mm
- During each fall, aeration takes place
- Reduction in CO_2 is 65% to 90%

- ➢ Coarse media like gravel and coke are used to increase the efficiency
- **Gravel Bed Aerators**
- ➢ More efficient than other methods
- ➢ Water is applied at top and trickles down while air is blown upwards
- ➢ Thickness of gravel may be 1 to 1.5 m

b) Spray Aerators

- also known as foundation aerators
- Each nozzle is 2.5 to 4 cm diameter discharging about 18 to 36 l/h.
- Reduces CO_2 by 70 to 90% or more

Figure 1: Spray Areator Source:©Sunil Rakhal

c)Air Diffusion Aerators

- It consists of a tank with perforated pipes, tubes or diffuser plates, fixed at the bottom to release fine air bubbles compressor unit.
- The tank depth is kept as 3to 4 m and tank width is within 1.5 times its depth.

- If depth is more, the diffusers must be placed at 3 to 4 m depth below water surface.
- Time of aeration is 10 to 30 min and 0.2 to 0.4 litres of air is required for 1 litre of water.

6.9.2 Removal of iron and manganese

- Iron and manganese, although essential to the human diet, if excess, can stain clothes, discolor plumbing fixtures and can add rusty taste.

Source:www.slideshare.net/slideshow/removal-of-iron-manganese/53828188

- Mostly found in groundwater
- According to NDWQS, Iron and manganese should not be more than 0.3 to 0.2 mg/l
- There are various methods to remove iron and manganese from water:

A. Aeration

- Iron and manganese present in water without organic matter can be removed by aeration followed by coagulation, sedimentation and filtration
- For iron:

$4Fe(HCO_3)_2 + 2H_2O + O_2 = 4Fe(OH)_{3\ (PPT)} + 8CO_2$

- For manganese:

$$6Mn(HCO_3)_2 + 3O_2 = 6MnO_{2\,(PPT)} + 2CO_2 + 2H_2O$$

- Insoluble precipitates are removed by filtration
- Occasionally, strong chemical oxidants like chlorine or potassium permanganate are used to enhance the oxidation

B. Base exchange method

- In this method, raw water passes through bed of zeolite, where the iron and manganese ions substitute the sodium ion in zeolite
- Manganese and iron are converted to insoluble hydrated oxides, which are removed by filtration
- Regeneration of bed is required occasionally

C. Chlorination

- Iron and manganese are removed by oxidation using chlorine and then followed by sedimentation and filtration
- Oxidation can be achieved by the use of potassium permanganate

6.9.3 Removal of color, odor and taste

In water supply systems, colour, odour, and taste are undesirable characteristics that arise from various sources such as organic matter, industrial discharges, domestic sewage, dissolved gases, minerals, and microbial activity (Garg, 2009; WHO, 2017). Their removal is crucial for both health and aesthetic reasons.

Although some degree of removal occurs during sedimentation, coagulation, filtration, and pre-chlorination, advanced techniques like activated carbon treatment and the use of copper sulphate are employed for more effective results (AWWA, 2011).

1. Activated Carbon Treatment

Activated carbon is widely used for improving the aesthetic quality of water by removing organic impurities responsible for colour, odour, and taste. Its effectiveness lies in its adsorptive properties, which capture and hold impurities on its surface (Sawyer, McCarty, & Parkin, 2003).

a. Manufacturing Process:

Activated carbon is manufactured by heating sawdust, paper mill waste, or similar materials at about 500°C in the absence of oxygen (carbonization), followed by controlled activation at around 800°C, which increases its porosity and surface area (Garg, 2009).

b. Forms and Application:

- Powdered Activated Carbon (PAC): Added directly into water before filtration.
- Granular Activated Carbon (GAC): Used as a filter media in water treatment plants.

c. Functional Benefits:

- Adsorbs organic matter, pesticides, and disinfection by-products.
- Removes volatile organic compounds (VOCs), chlorinated solvents, and taste/odour-causing compounds such as geosmin and MIB (AWWA, 2011).

- Does not add harmful substances to the water (WHO, 2017).

Activated carbon is particularly effective when other treatments are insufficient for removing dissolved organics (Sawyer et al., 2003).

2. Use of Copper Sulphate

Copper sulphate ($CuSO_4$) is used mainly as an algaecide and bacteriostatic agent in raw water storage and distribution systems. Algal growth not only gives rise to unpleasant taste and odour but also reduces dissolved oxygen levels (WHO, 2017).

a. Characteristics and Solubility:

Available in powder or crystalline form, copper sulphate is highly soluble in water and can be easily applied in measured doses (Garg, 2009).

b. Application Techniques:

- Applied in reservoirs, swimming pools, and distribution systems.

- Recommended dose ranges between 0.3 to 0.65 ppm (parts per million) (AWWA, 2011).
- Excessive application can be toxic to aquatic life and may require post-treatment monitoring.

The use of copper sulphate is effective for biological control, but must be carefully dosed to prevent environmental harm (WHO, 2017).

Conclusion

To ensure water is not only safe but also pleasant to consume, it is essential to integrate activated carbon treatment and controlled application of copper sulphate into the water purification system. These methods complement conventional treatments and are vital for removing persistent taste, odour, and colour-causing substances.

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Thank You!!!