

BOILER PROBLEMS & SOFTENING METHODS

1. Boiler Problems

When hard water is used in boilers, it causes several problems due to the deposition of salts and impurities.

(i) Scale and Sludge Formation

- **Scales:** Hard, adherent deposits formed due to precipitation of **CaSO₄, CaCO₃, and Mg(OH)₂**.
 - Effects: Reduces heat transfer, decreases boiler efficiency, overheating, and tube failure.
- **Sludge:** Loose, non-adherent deposits formed by **MgCl₂, MgSO₄, and CaCl₂** in lower temperatures.
 - Effects: Causes corrosion and decreases boiler efficiency.

(ii) Boiler Corrosion

- Caused by dissolved **oxygen (O₂), carbon dioxide (CO₂), and acidic water**.
- Effects: Weakens boiler material, leading to failure.

(iii) Caustic Embrittlement

- Caused by NaOH accumulation, making the boiler brittle.
- Effects: Cracks and metal failure.

(iv) Priming and Foaming

- **Priming:** Water droplets carried with steam due to high surface tension (caused by dissolved salts).
- **Foaming:** Formation of stable bubbles due to oils and suspended solids.
- Effects: Reduces efficiency and damages turbine blades.

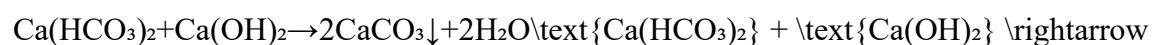
2. Water Softening Methods

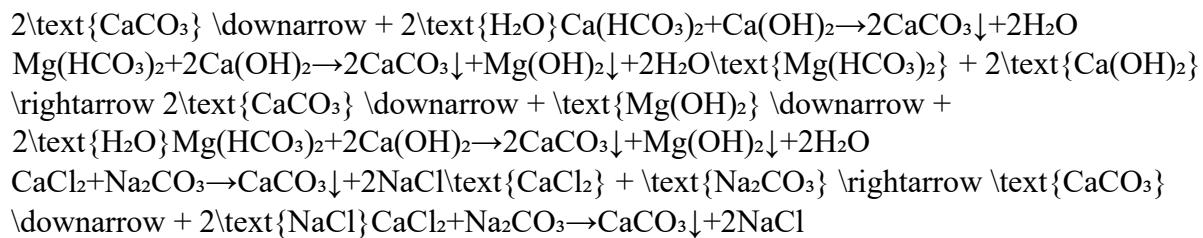
To remove hardness and prevent boiler problems, water softening is essential.

(i) Lime-Soda Process

- **Principle:** Addition of **Ca(OH)₂ (lime)** and **Na₂CO₃ (soda ash)** to precipitate Ca^{2+} and Mg^{2+} as insoluble salts.

Reactions:



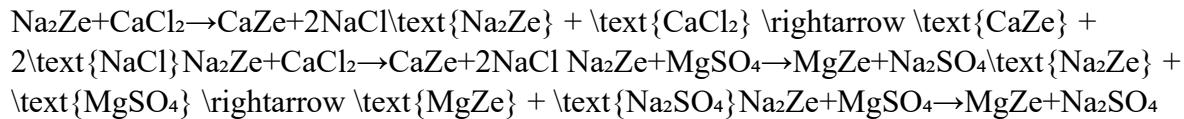


- **Types:**
 1. **Cold Lime-Soda Process:** Carried out at room temperature, requires longer settling time.
 2. **Hot Lime-Soda Process:** Performed at high temperature and pressure, gives faster results.
 - **Advantages:** Cheap, removes temporary and permanent hardness.
 - **Disadvantages:** Sludge formation, requires further filtration.
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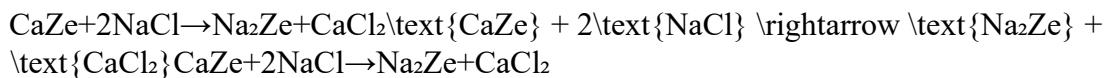
(ii) Zeolite Process (Permutit Process)

- **Principle:** Hardness-causing ions (Ca^{2+} , Mg^{2+}) are exchanged with Na^+ using **zeolite (sodium alumino-silicate)**.

Reaction:



- **Regeneration:**



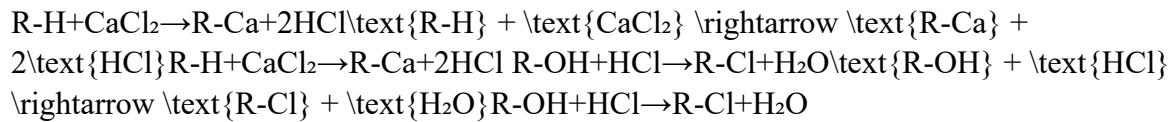
Zeolite is regenerated using NaCl solution.

- **Advantages:** Continuous process, complete removal of hardness, no sludge formation.
 - **Disadvantages:** Cannot remove Fe^{2+} , Mn^{2+} , and dissolved gases.
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(iii) Ion Exchange Process

- **Principle:** Uses resins to exchange ions:
 - **Cation exchange resin ($\text{R}-\text{H}^+$)** removes Ca^{2+} , Mg^{2+} .
 - **Anion exchange resin ($\text{R}-\text{OH}^-$)** removes SO_4^{2-} , Cl^- .

Reactions:



- **Regeneration:**
 - Cation resin: Treated with **HCl or H₂SO₄**.
 - Anion resin: Treated with **NaOH**.
 - **Advantages:** Removes all ions, produces **deionized (demineralized) water**.
 - **Disadvantages:** Expensive, requires chemicals for regeneration.
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Outcomes:

- Understanding boiler problems and their effects on efficiency.
- Learning different softening techniques and their principles.
- Ability to select appropriate water treatment methods for industrial applications.

. Boiler Troubles

- **Sludge & Scale Formation**
 - When hard water is heated in a boiler, dissolved salts precipitate out, forming sludge and scale.
 - **Sludge Formation**
 - Forms in **low-temperature zones**
Consists of **MgCl₂, MgCO₃, CaCl₂, and CaSO₄**
Soft, loose deposits
Easily removable by blowdown
 - **Prevention:**
 - ✓ Use **softened water**
 - ✓ Add **phosphates** to convert sludge into a non-adherent form
 - ✓ **Blowdown method** – removes sludge periodically
 - **Scale Formation**
 - Forms in **high-temperature zones**
Consists of **CaSO₄, CaCO₃, and Mg(OH)₂**
Hard, adherent deposits
Decreases heat transfer efficiency, leading to overheating and tube failure
 - **Prevention:**
 - ✓ **Lime-soda process** – Removes scale-forming salts
 - ✓ **Phosphate treatment** – Converts CaSO₄ into soft sludge
 - ✓ **EDTA treatment** – Forms soluble complexes with Ca²⁺ and Mg²⁺
 - ✓ **Descaling agents** – Dissolve scales chemically
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2 Priming & Foaming • Priming (Water Carryover with Steam)

Cause:

- ✓ High steam velocity
- ✓ High water level in the boiler
- ✓ Sudden boiling

Effects:

- Carries water droplets into the steam engine
- Reduces boiler efficiency

Prevention:

- ✓ Maintain proper water level
 - ✓ Use anti-priming baffles
 - ✓ Reduce steam velocity
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3 Foaming (Stable Foam Formation on Water Surface)

Cause:

- ✓ High dissolved solids (oil, soap, alkali)
- ✓ High concentration of NaCl

Effects:

- Lowers heat transfer
- Leads to wet steam, damaging turbines

Prevention:

- ✓ Blowdown method – Reduces dissolved solids
 - ✓ Anti-foaming agents – E.g., sodium aluminates
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4 Boiler Corrosion

- Deterioration of boiler metal due to chemical reactions.

Causes of Boiler Corrosion

1. Dissolved Oxygen Corrosion

- ✓ Oxygen reacts with iron to form rust:
- $$4\text{Fe} + 3\text{O}_2 + 6\text{H}_2\text{O} \rightarrow 4\text{Fe(OH)}_3$$
- $$4\text{Fe(OH)}_3 \rightarrow 4\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$$
 (rust).

Prevention:

- ✓ Remove O₂ using sodium sulfite:
$$\text{Na}_2\text{SO}_3 + \text{O}_2 \rightarrow \text{Na}_2\text{SO}_4$$

$$\text{Na}_2\text{SO}_4 + \text{O}_2 \rightarrow \text{Na}_2\text{SO}_4$$
 - ✓ Use deaerators to remove dissolved O₂
 - ✓ Maintain pH between 8.5-9.5
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2. Acidic Water Corrosion

- ✓ Acidic water (low pH) reacts with Fe, forming soluble Fe²⁺ ions:

- $\text{Fe} + 2\text{H}^+ \rightarrow \text{Fe}^{2+} + \text{H}_2$
- **Prevention:**
 - ✓ Add **alkaline buffers** (e.g., NaOH) to maintain pH
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 - 3. Carbon Dioxide (CO₂) Corrosion** • ✓ CO₂ dissolves in water, forming carbonic acid (**H₂CO₃**), which attacks metal:
 - $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$
 - $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$
 - $\text{Fe} + \text{H}_2\text{CO}_3 \rightarrow \text{Fe}(\text{HCO}_3)_2$
 - $\text{Fe} + \text{H}_2\text{CO}_3 \rightarrow \text{Fe}(\text{HCO}_3)_2$
 - **Prevention:**
 - ✓ Remove CO₂ using **deaeration**
 - ✓ Maintain **alkalinity with NaOH**
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 - Outcomes:**
 - ✓ Understand the major boiler troubles and their impact
 - ✓ Learn preventive measures for scale, sludge, priming, foaming, and corrosion
 - ✓ Apply water treatment methods for effective boiler operation

Caustic Embrittlement & Softening of Water

1. Caustic Embrittlement

Definition:

Caustic embrittlement is a type of **intergranular cracking** that occurs in **high-pressure boilers** due to the accumulation of **NaOH (sodium hydroxide)** in certain areas. It weakens the boiler metal, making it brittle.

Cause:

- **High concentration of NaOH** in boiler water (due to improper water softening or excessive use of Na₂CO₃ in the Lime-Soda process).
- **Formation of minute cracks** due to differential concentration of NaOH.

Mechanism (Due to High NaOH concentration)

1. **Na₂CO₃ from softening methods decomposes in boiler water:**

$$\text{Na}_2\text{CO}_3 + \text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{CO}_2$$

$$\text{NaOH} + \text{CO}_2 \rightarrow \text{Na}_2\text{CO}_3 + \text{H}_2\text{O}$$
2. **NaOH seeps into cracks via osmosis, concentrating at stressed areas.**
3. **Hydroxide ions (OH⁻) attack iron in boiler metal:**

$$\text{Fe} + 2\text{NaOH} \rightarrow \text{Na}_2\text{FeO}_2 + \text{H}_2\uparrow$$

$$\text{Fe} + 2\text{NaOH} \rightarrow \text{Na}_2\text{FeO}_2 + \text{H}_2\uparrow$$
4. **Sodium ferrite (Na₂FeO₂) forms, weakening metal structure and leading to cracking.**

Prevention Methods:

- Use sodium phosphate instead of Na_2CO_3 for softening.
 - Maintain proper alkalinity levels.
 - Use inhibitors like tannin or lignin to block cracks.
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2. Softening of Water

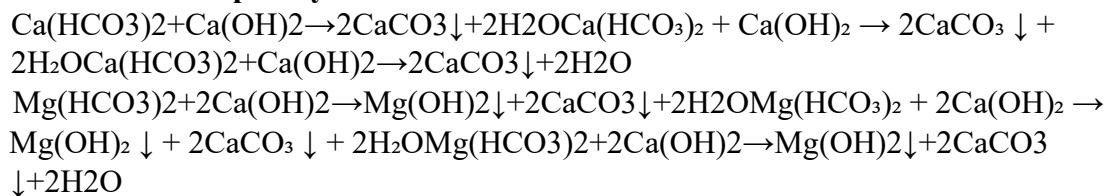
Hard water contains dissolved Ca^{2+} and Mg^{2+} ions, which lead to scale formation. Softening removes these ions to prevent damage to boilers and pipes.

2.1 Lime-Soda Process

Principle: Converts Ca^{2+} and Mg^{2+} into **insoluble precipitates** using **lime (Ca(OH)_2)** and **soda ash (Na_2CO_3)**.

Reactions:

1. Removal of Temporary Hardness:



2. Removal of Permanent Hardness:

$$\begin{aligned}\text{CaCl}_2 + \text{Na}_2\text{CO}_3 &\rightarrow \text{CaCO}_3 \downarrow + 2\text{NaCl} \\ \text{CaCO}_3 \downarrow + 2\text{NaCl} &\rightarrow \text{CaCO}_3 \downarrow + 2\text{NaCl} \\ \text{MgSO}_4 + \text{Ca(OH)}_2 &\rightarrow \text{Mg(OH)}_2 \downarrow + \text{CaSO}_4 \\ \text{MgSO}_4 + \text{Ca(OH)}_2 &\rightarrow \text{Mg(OH)}_2 \downarrow + \text{CaSO}_4\end{aligned}$$

Advantages: Cheap, removes acidity.

Disadvantages: Sludge formation, requires skilled operation.

2.2 Zeolite Process

Principle: Ion exchange of Ca^{2+} and Mg^{2+} with Na^+ using zeolite (hydrated aluminosilicates).

Reactions:

1. **Softening Reaction:** $\text{Ca}^{2+} + \text{Na}_2\text{Z} \rightarrow \text{CaZ} + 2\text{Na}^+ + \text{Ca}^{2+} + \text{Na}_2\text{Z} \rightarrow \text{CaZ} + 2\text{Na}^+$
 $\text{Mg}^{2+} + \text{Na}_2\text{Z} \rightarrow \text{MgZ} + 2\text{Na}^+ + \text{Mg}^{2+} + \text{Na}_2\text{Z} \rightarrow \text{MgZ} + 2\text{Na}^+$
2. **Regeneration with NaCl:** $\text{CaZ} + 2\text{NaCl} \rightarrow \text{Na}_2\text{Z} + \text{CaCl}_2$
 $\text{CaCl}_2 + \text{Na}_2\text{Z} \rightarrow \text{Na}_2\text{Z} + \text{CaCl}_2$
 $\text{MgZ} + 2\text{NaCl} \rightarrow \text{Na}_2\text{Z} + \text{MgCl}_2$
 $\text{MgCl}_2 + \text{Na}_2\text{Z} \rightarrow \text{Na}_2\text{Z} + \text{MgCl}_2$

Advantages: No sludge, easy operation.

Disadvantages: Doesn't remove silica and acids.

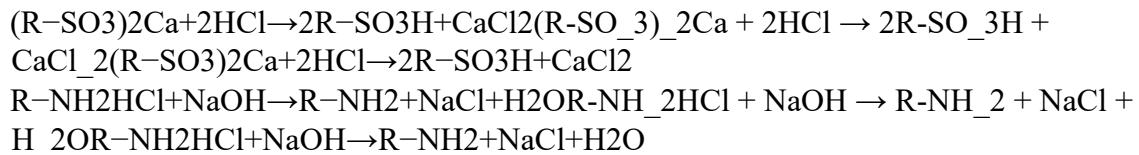
2.3 Ion Exchange Process

Principle: Uses **cation-exchange resins (R-SO₃H)** for Ca²⁺/Mg²⁺ removal and **anionexchange resins (R-NH₂)** for anions.

Reactions:

1. **Cation Exchange:** $2R-SO_3H + Ca^{2+} \rightarrow (R-SO_3)_2Ca + 2H^+ + 2R-SO_3H + Ca^{2+} \rightarrow (R-SO_3)_2Ca + 2H^+$
2. **Anion Exchange:** $R-NH_2 + Cl^- \rightarrow R-NH_2Cl \rightarrow R-NH_2 + Cl^- \rightarrow R-NH_2Cl$

Regeneration:



Advantages: Produces deionized water.

Disadvantages: Expensive, requires acids/bases for regeneration.

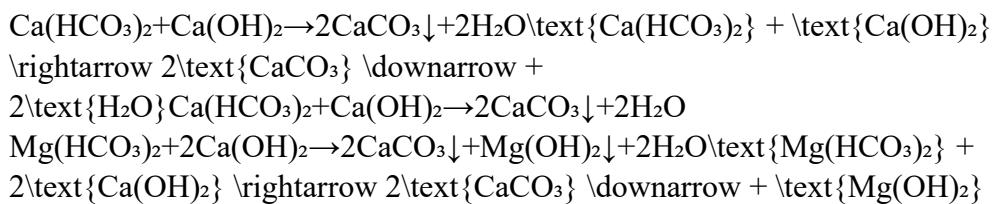
Outcomes:

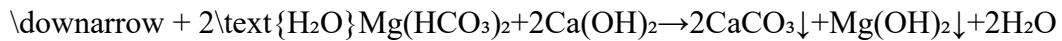
- Understanding **Caustic Embrittlement** and its prevention.
- Knowledge of **Lime-Soda, Zeolite, and Ion Exchange** methods for water softening.
- Importance of **water softening in industrial applications** to prevent damage.

1. Lime-Soda Method

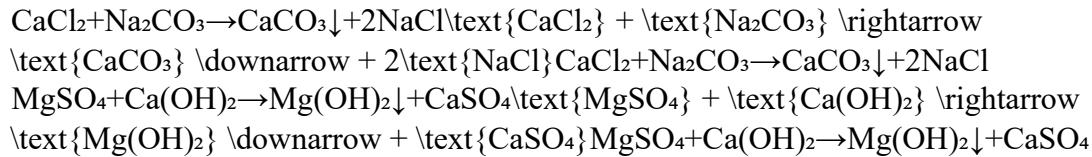
A chemical softening process that removes both **temporary** and **permanent** hardness using **lime (Ca(OH)₂)** and **soda ash (Na₂CO₃)**. **Chemical Reactions**

1. For Temporary Hardness (Ca and Mg Bicarbonates)





2. For Permanent Hardness (Ca and Mg Chlorides/Sulfates)



Numerical Problem Formula (Lime & Soda Calculation)

1. Amount of Lime Required

$$\begin{aligned} \text{Lime (kg)} &= 100/74 \times \text{Equivalent Weight of CaCO}_3 \times \text{Total Hardness (in mg/L)} \times \text{Water Volume (ML)} \\ \text{Lime (kg)} &= \frac{100}{74} \times \text{Equivalent Weight of CaCO}_3 \times \text{Total Hardness (in mg/L)} \times \text{Water Volume (ML)} \\ \text{Lime (kg)} &= \text{Equivalent Weight of CaCO}_3 \times 100/74 \\ &\times \text{Total Hardness (in mg/L)} \times \text{Water Volume (ML)} \end{aligned}$$

2. Amount of Soda Required

$$\begin{aligned} \text{Soda (kg)} &= 106/100 \times \text{Equivalent Weight of CaCO}_3 \times \text{Permanent Hardness} \times \text{Water Volume} \\ \text{Soda (kg)} &= \frac{106}{100} \times \text{Equivalent Weight of CaCO}_3 \times \text{Permanent Hardness} \times \text{Water Volume} \\ \text{Soda (kg)} &= \text{Equivalent Weight of CaCO}_3 \times 106/100 \\ &\times \text{Permanent Hardness} \times \text{Water Volume} \end{aligned}$$

2. Zeolite (Permutit) Method

A cation-exchange process that replaces **Ca²⁺** and **Mg²⁺** ions with **Na⁺** ions using **sodium zeolite (Na₂Z)**.

Chemical Reactions

- Softening Reaction:** $\text{Ca}^{2+} + \text{Na}_2\text{Z} \rightarrow \text{CaZ} + 2\text{Na}^+$ $\text{Ca}^{2+} + \text{Na}_2\text{Z} \rightarrow \text{CaZ} + 2\text{Na}^+$
 $\text{Mg}^{2+} + \text{Na}_2\text{Z} \rightarrow \text{MgZ} + 2\text{Na}^+$ $\text{Mg}^{2+} + \text{Na}_2\text{Z} \rightarrow \text{MgZ} + 2\text{Na}^+$
- Regeneration with Brine (NaCl Solution):** $\text{CaZ} + 2\text{NaCl} \rightarrow \text{Na}_2\text{Z} + \text{CaCl}_2$ $\text{CaZ} + 2\text{NaCl} \rightarrow \text{Na}_2\text{Z} + \text{CaCl}_2$
 $\text{MgZ} + 2\text{NaCl} \rightarrow \text{Na}_2\text{Z} + \text{MgCl}_2$ $\text{MgZ} + 2\text{NaCl} \rightarrow \text{Na}_2\text{Z} + \text{MgCl}_2$

Numerical Problem Formula (Zeolite Calculation)

1. Amount of Zeolite Required

$\text{Zeolite (kg)} = \frac{\text{Hardness (in mg/L)} \times \text{Water Volume (ML)}}{\text{Exchange Capacity of Zeolite (mg/L per kg)}}$
 $\text{Zeolite (kg)} = \frac{\text{Exchange Capacity of Zeolite (mg/L per kg)} \times \text{Hardness (in mg/L)}}{\text{Water Volume (ML)}}$

2. Amount of NaCl Required for Regeneration

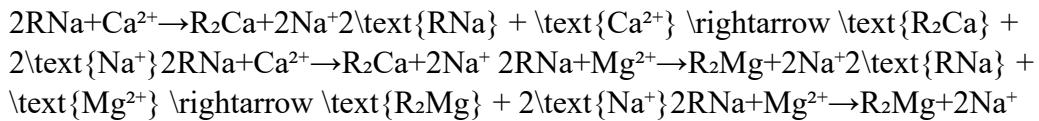
$\text{NaCl (kg)} = \frac{\text{Total Hardness (kg)} \times \text{NaCl required per kg of hardness} \times \text{Efficiency Factor}}{\text{Efficiency Factor}}$
 $\text{NaCl (kg)} = \frac{\text{Total Hardness (kg)} \times \text{Efficiency Factor}}{\text{NaCl required per kg of hardness}}$

3. Ion Exchange (Resin) Method

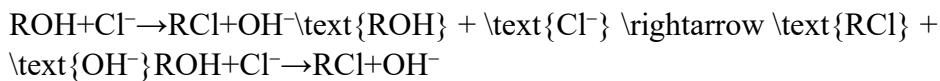
A modern softening technique using synthetic resins to exchange ions.

Two-Step Process:

1. Cation Exchange Resin: Removes Ca^{2+} and Mg^{2+}



2. Anion Exchange Resin: Removes SO_4^{2-} , Cl^- , NO_3^-



3. Regeneration of Resins:

- Cation resin regenerated with NaCl solution.
- Anion resin regenerated with NaOH solution.

Numerical Problem Formula (Ion Exchange Calculation)

1. Amount of Cation Resin Required

$\text{Resin (kg)} = \frac{\text{Hardness (mg/L)} \times \text{Water Volume (ML)}}{\text{Resin Exchange Capacity (mg/L per kg)}}$
 $\text{Resin (kg)} = \frac{\text{Resin Exchange Capacity (mg/L per kg)} \times \text{Hardness (mg/L)}}{\text{Water Volume (ML)}}$

2. Amount of Regenerant (NaCl) Required

$$\text{NaCl (kg)} = \text{Resin Used (kg)} \times \text{NaCl per kg Resin} \times \text{Efficiency Factor}$$

4. Expected Outcomes

- Understand and apply chemical reactions in softening processes.
- Solve numerical problems related to water softening methods.
- Calculate lime, soda, zeolite, resin, and NaCl requirements for softening.
- Differentiate between lime-soda, zeolite, and ion-exchange methods.

5. Summary Notes (Organized Table)

Method	Reaction	Key Features	Numerical Formula
Lime-Soda	$\text{Ca}(\text{HCO}_3)_2 + \text{Ca}(\text{OH})_2 \rightarrow \text{CaCO}_3 \downarrow + \text{H}_2\text{O}$	Removes temporary & permanent hardness	$\text{Lime} = (100/74) \times \text{Hardness} \times \text{Water Volume}$
Zeolite	$\text{Ca}^{2+} + \text{Na}_2\text{Z} \rightarrow \text{CaZ} + 2\text{Na}^+$	Cation exchange with Na ⁺	$\text{Zeolite} = \text{Hardness} \times \text{Water Volume} / \text{Zeolite Capacity}$
Ion Exchange	$2\text{RNa} + \text{Ca}^{2+} \rightarrow \text{R}_2\text{Ca} + 2\text{Na}^+$	Removes all ions (softens & deionizes)	$\text{Resin} = \text{Hardness} \times \text{Water Volume} / \text{Resin Capacity}$