

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 CaSO_4 , CaCO_3 , and Mg(OH)_2 .
 - Effects: Reduces heat transfer, decreases boiler efficiency, overheating, and tube failure.
- **Sludge:** Loose, non-adherent deposits formed by MgCl_2 , MgSO_4 , and CaCl_2 in lower temperatures.
 - Effects: Causes corrosion and decreases boiler efficiency.

(ii) Boiler Corrosion

- Caused by dissolved **oxygen (O_2)**, **carbon dioxide (CO_2)**, 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.

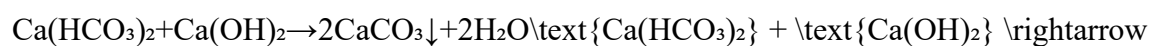
2. Water Softening Methods

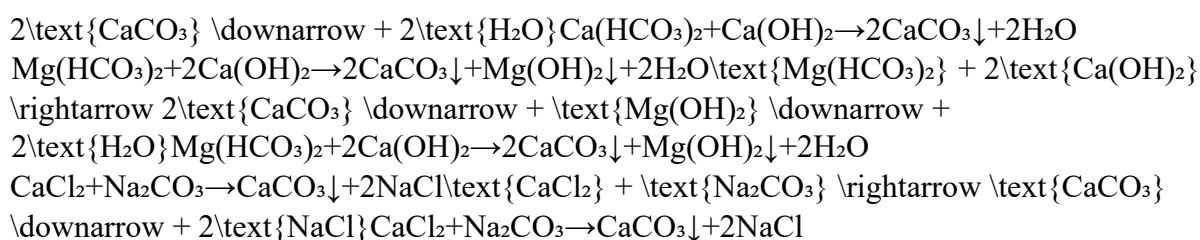
To remove hardness and prevent boiler problems, water softening is essential.

(i) Lime-Soda Process

- **Principle:** Addition of Ca(OH)_2 (**lime**) and Na_2CO_3 (**soda ash**) to precipitate Ca^{2+} and Mg^{2+} as insoluble salts.

Reactions:



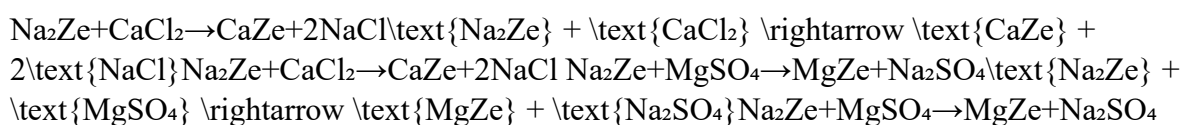


- **Types:**
 1. **Cold Lime-Soda Process:** Carried out at room temperature, requires longer settling time.
 2. **Hot Lime-Soda Process:** Performed at high temperature and pressure, gives faster results.
- **Advantages:** Cheap, removes temporary and permanent hardness.
- **Disadvantages:** Sludge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

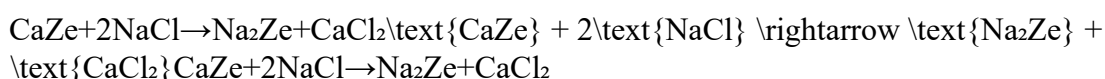
(ii) Zeolite Process (Permutit Process)

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

Reaction:



- **Regeneration:**



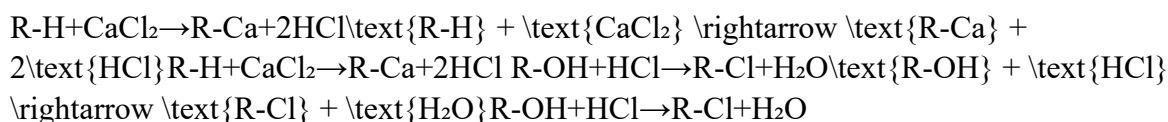
Zeolite is regenerated using NaCl solution.

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

(iii) Ion Exchange Process

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

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

- **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**

- **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

- **3☐ 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**:
- $$4\text{Fe} + 3\text{O}_2 + 6\text{H}_2\text{O} \rightarrow 4\text{Fe}(\text{OH})_3$$
- ✓ $\text{Fe}(\text{OH})_3$ further dehydrates to form $\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$ (rust).

- **Prevention:**

- ✓ Remove O_2 using **sodium sulfite**:
- $$\text{Na}_2\text{SO}_3 + \text{O}_2 \rightarrow \text{Na}_2\text{SO}_4$$
- ✓ Use **deaerators** to remove dissolved O_2
- ✓ Maintain **pH between 8.5-9.5**

- **2. Acidic Water Corrosion**

- ✓ Acidic water (low pH) reacts with **Fe**, forming soluble Fe^{2+} ions:

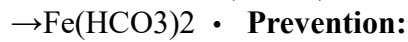
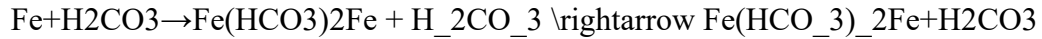
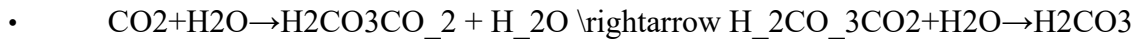


- **Prevention:**

- ✓ 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:



- ✓ 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:

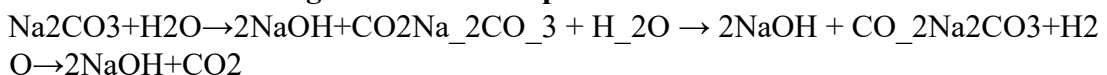
Caustic embrittlement is a type of **intergranular cracking** that occurs in **high-pressure boilers** due to the accumulation of **NaOH (sodium hydroxide)** in certain areas. It weakens the boiler metal, making it brittle.

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:**



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

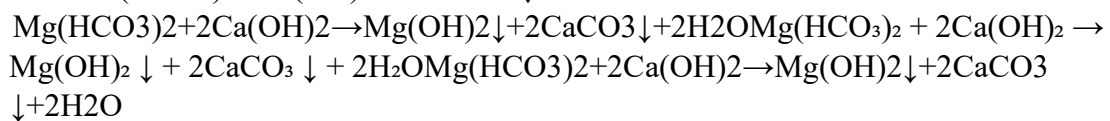
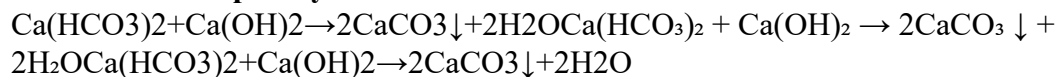
Hard water contains dissolved Ca^{2+} and Mg^{2+} ions, which lead to scale formation. Softening removes these ions to prevent damage to boilers and pipes.

2.1 Lime-Soda Process

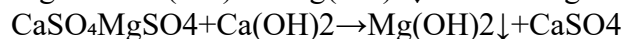
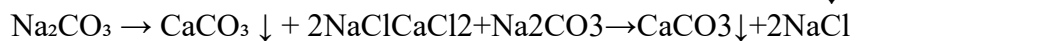
Principle: Converts Ca^{2+} and Mg^{2+} into insoluble precipitates using lime ($\text{Ca}(\text{OH})_2$) and soda ash (Na_2CO_3).

Reactions:

1. **Removal of Temporary Hardness:**



2. **Removal of Permanent Hardness:**



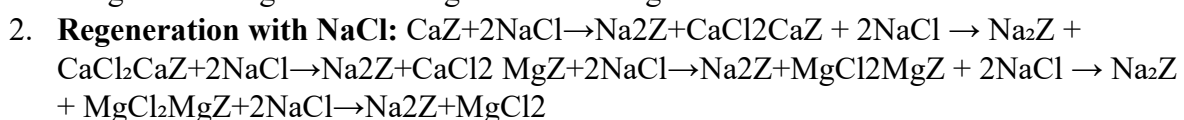
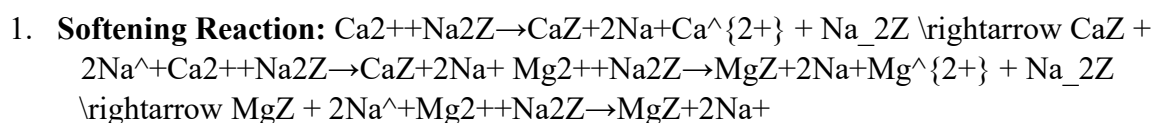
Advantages: Cheap, removes acidity.

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:



Advantages: No sludge, easy operation.

Disadvantages: Doesn't remove silica and acids.

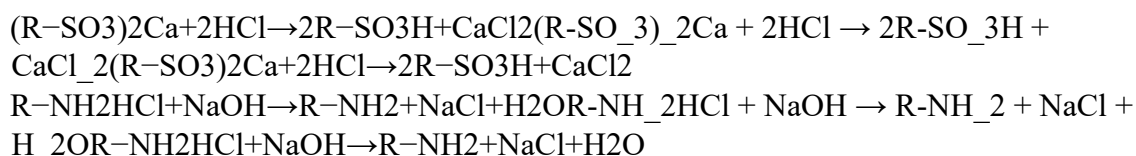
2.3 Ion Exchange Process

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

Reactions:

1. **Cation Exchange:** $2\text{R-SO}_3\text{H} + \text{Ca}^{2+} \rightarrow (\text{R-SO}_3)_2\text{Ca} + 2\text{H}^+$
 $\text{R-SO}_3\text{H} + \text{Ca}^{2+} \rightarrow (\text{R-SO}_3)_2\text{Ca} + 2\text{H}^+$
2. **Anion Exchange:** $\text{R-NH}_2 + \text{Cl}^- \rightarrow \text{R-NH}_2\text{HCl}$
 $\text{R-NH}_2\text{HCl} + \text{Cl}^- \rightarrow \text{R-NH}_2\text{HCl}$

Regeneration:



Advantages: Produces deionized water.

Disadvantages: Expensive, requires acids/bases for regeneration.

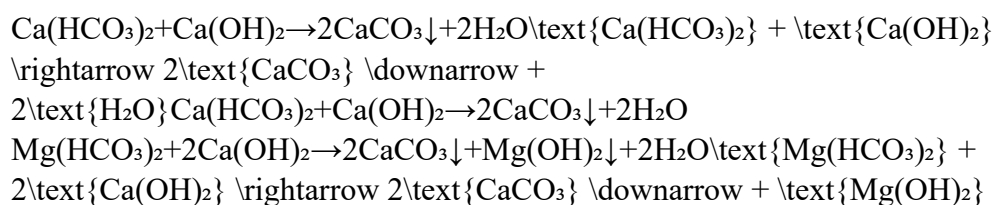
Outcomes:

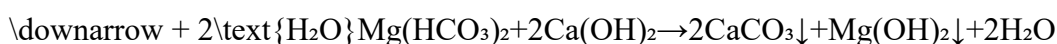
- Understanding **Caustic Embrittlement** and its prevention.
- Knowledge of **Lime-Soda, Zeolite, and Ion Exchange** methods for water softening.
- Importance of **water softening in industrial applications** to prevent damage.

1. Lime-Soda Method

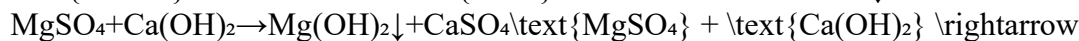
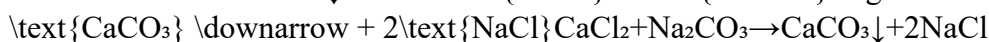
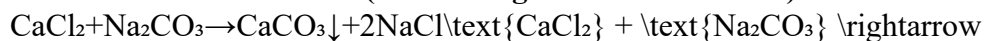
A chemical softening process that removes both **temporary** and **permanent** hardness using **lime (Ca(OH)₂)** and **soda ash (Na₂CO₃)**. **Chemical Reactions**

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

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

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

2. Amount of Soda Required

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

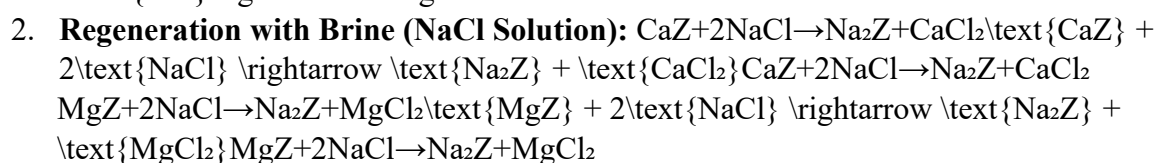
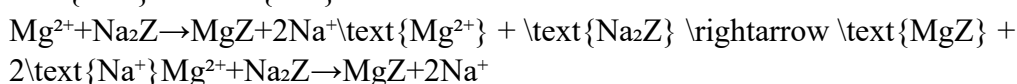
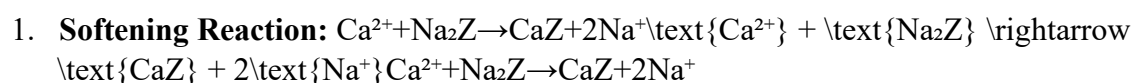
$$\text{Soda (kg)} = \frac{106}{100} \times \text{Equivalent Weight of CaCO}_3 \times \text{Permanent Hardness} \times \text{Water Volume}$$

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2. Zeolite (Permutit) Method

A cation-exchange process that replaces Ca^{2+} and Mg^{2+} ions with Na^+ ions using sodium zeolite (Na_2Z).

Chemical Reactions



Numerical Problem Formula (Zeolite Calculation)

1. Amount of Zeolite Required

Zeolite (kg) = Hardness (in mg/L) × Water Volume (ML) / Exchange Capacity of Zeolite (mg/L per kg)

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

Zeolite (kg) = Exchange Capacity of Zeolite (mg/L per kg) × Hardness (in mg/L) × Water Volume (ML)

2. Amount of NaCl Required for Regeneration

NaCl (kg) = Total Hardness (kg) × NaCl required per kg of hardness / Efficiency Factor

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

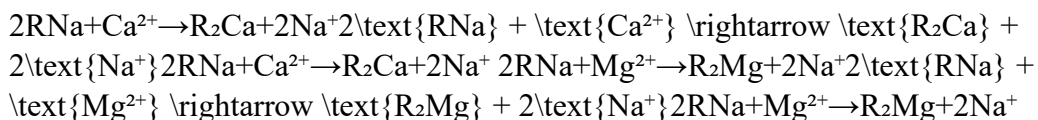
NaCl (kg) = Total Hardness (kg) × Efficiency Factor × NaCl required per kg of hardness

3. Ion Exchange (Resin) Method

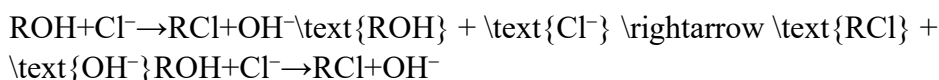
A modern softening technique using synthetic resins to exchange ions.

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

Resin (kg) = Hardness (mg/L) × Water Volume (ML) / Resin Exchange Capacity (mg/L per kg)

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

Resin (kg) = Resin Exchange Capacity (mg/L per kg) × Hardness (mg/L) × 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.
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5. Summary Notes (Organized Table)

Method	Reaction	Key Features	Numerical Formula
Lime-Soda	$\text{Ca(HCO}_3)_2 + \text{Ca(OH)}_2 \rightarrow \text{CaCO}_3 \downarrow + \text{H}_2\text{O}$	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)	$\text{Resin} = \text{Hardness} \times \text{Water Volume} / \text{Resin Capacity}$