# Lecture 3: Water Softening

# Water Treatment Technology

## Water Resources Engineering
## Civil Engineering
## ENGC 6305

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# Water Softening

## 1. Hardness definition:

A. Hardness is the term often used to characterize a water that :

- Dose form a foam or lather well and cause soap scum

$$Ca^{2+} + (Soap)^{-} \leftrightarrow Ca(Soap)_{2\ (s)}$$

This increase the amount of soap needed for washing

- cause scaling on pipes and hot boilers.
- cause valves to stick due to the formation of calcium carbonate crystals
- leave stains on plumbing fixtures

# Water Softening

B. Hardness is defined as the sum of the divalent metal cations (in consistent units) existing in water such as :

$Ca^{2+}$, $Mg^{2+}$, $Fe^{2+}$, $Mn^{2+}$

Practically most hardness is due to $Ca^{2+}$, $Mg^{2+}$ ions (the predominant minerals in natural waters)

C. Total Hardness = $Ca^{2+}$ hardness+ $Mg^{2+}$ hardness

where the concentration of each ion is in consistent units such as mg/L as Ca $CO_3$, or meq/L.

# Water Softening

## D. Hard water classification

| Description | Hardness range (mg/L as $CaCO_3$) |
| --- | --- |
| Soft | 0 - 75 |
| Moderately hard | 75 - 100 |
| Hard | 100 - 300 |
| Very hard | > 300 |

# Water Softening

## E. Formation of Hardness

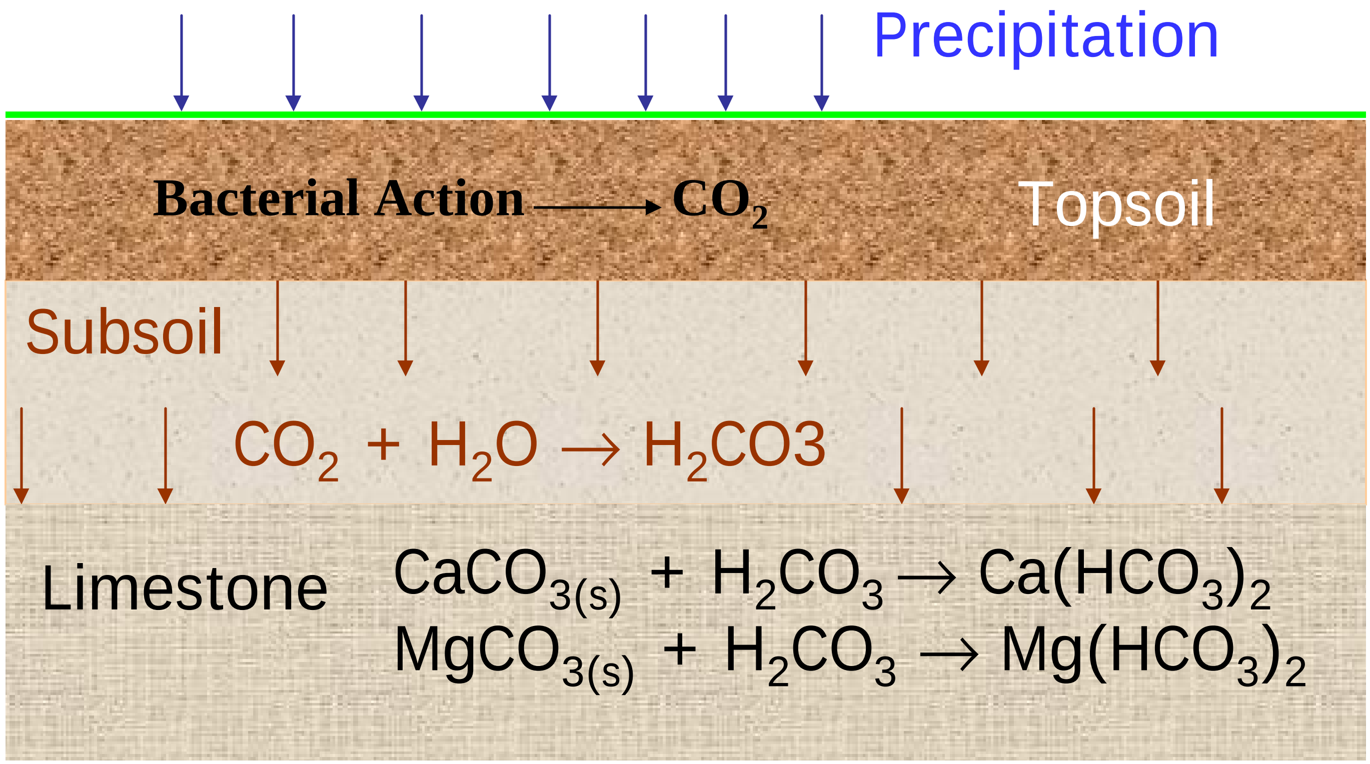



Fig. 3.1

# Water Softening

## F. Carbonate and non carbonate Hardness

- Carbonate Hardness ( CH)
  - $Ca^{2+}$, $Mg^{2+}$ associated with $HCO_3^-$, $CO_3^{2-}$
  - Often called "temporary hardness" because heating the water will remove it. When the water is heated, the insoluble carbonates will precipitate and tend to form bottom deposits in water heaters.
- Non-Carbonate Hardness ( NCH)
  - $Ca^{2+}$, $Mg^{2+}$ associated with other ions, $Cl^-$, $NO_3^-$, $SO_4^{2-}$
  - NCH = TH – CH

# Water Softening

## F. Hardness Units

**Total Hardness =** $\sum (Ca^{2+} + Mg^{2+})$

The hardness unit is the same as that consistent unit used for both of the above ions. The most used units are:

a. $$\boxed{\text{mg/L as } CaCO_3 = (\text{mg/L as species})\frac{\text{EW of } CaCO_3}{\text{EW of species}}}$$

**EW = equivalent weight**

**Species = Ion or Radical or Compound**

**Radical: such as $CO_3^{2-}$, $SO_4^{2-}$**

**Compounds: such as $CO_2$, $CaSO_4$**

# Water Softening

$$EW = \frac{MW}{\text{Electrical Charge}}$$ → For radicals and compounds

$$EW = \frac{MW}{\text{Valance}}$$ → For ions

**MW = molecular weight of the Species**

**Example 3.1 : a) Find the EW of $Mg^{2+}$ that has a concentration of 10 mg/L as the ion in water. b) Find the EW of $CaCO_3$ c) find concentration of $Mg^{2+}$ as mg/L $CaCO_3$.**

## a) Finding the EW for $Mg^{2+}$ :

$$MW = 24.3 \ \frac{g}{mole} \longrightarrow MW = 24.3 \ \frac{mg}{mmole}$$

$$\text{Valance}\,(n) = \frac{2\ eq}{mole} \longrightarrow \text{Valance}\,(n) = \frac{2\ meq}{mmole}$$

$$EW = \frac{MW}{\text{Valance}} \longrightarrow EW = \frac{24.3\ mg}{mmole} . [\frac{1}{2\ \ meq/mmole}] \longrightarrow EW = 12.15 \ \frac{mg}{meq}$$

# Water Softening

## b) **Finding the EW for $CaCO_3$ :**

$$MW = 100 \ \frac{g}{mole} \longrightarrow MW = 100 \ \frac{mg}{mmole}$$

$$\text{Electrical charge (n)} = \frac{2 \ eq}{mole} \longrightarrow \text{Electrical charge} = \frac{2 \ meq}{mmole}$$

$$EW = \frac{MW}{\text{Electrical Charge}} \longrightarrow EW = \frac{100 \ mg}{mmole} \cdot \left[\frac{1}{2 \ \ meq/mmole}\right] \longrightarrow EW = 50 \ \frac{mg}{meq}$$

## D) **Finding the $Mg^{2+}$ concentration as $CaCO_3$ :**

$$\boxed{mg/L \ \text{as} \ CaCO_3 = (mg/L \ \text{as species}) \frac{EW \ \text{of} \ CaCO_3}{EW \ \text{of species}}}$$

$Mg^{2+}$ conc.

$$(Mg2+) \ \text{in} \ mg/L \ \text{as} \ CaCO_3 = (10 \ mg/L \ \text{as} \ Mg \ 2+) \frac{50 \ mg/meq}{12.15 \ mg/meq} \longrightarrow 41.15 \ mg/L \ \text{as} \ CaCO_3$$

| NAME | SYMBOL OR FORMULA | ATOMIC OR MOLECULAR WEIGHT | EQUIVALENT WEIGHT |
|---|---|---|---|
| Aluminum | $Al^{3+}$ | 27.0 | 9.0 |
| Calcium | $Ca^{2+}$ | 40.1 | 20.0 |
| Carbon | $C$ | 12.0 | |
| Hydrogen | $H^+$ | 1.0 | 1.0 |
| Magnesium | $Mg^{2+}$ | 24.3 | 12.2 |
| Manganese | $Mn^{2+}$ | 54.9 | 27.5 |
| Nitrogen | $N$ | 14.0 | |
| Oxygen | $O$ | 16.0 | |
| Phosphorus | $P$ | 31.0 | |
| Sodium | $Na^+$ | 23.0 | 23.0 |
| Ammonium | $NH_4^+$ | 18.0 | 18.0 |
| Bicarbonate | $HCO_3^-$ | 61.0 | 61.0 |
| Carbonate | $CO_3^{2-}$ | 60.0 | 30.0 |
| Hydroxyl | $OH^-$ | 17.0 | 17.0 |
| Hypochlorite | $OCl^-$ | 51.5 | 51.5 |
| Nitrate | $NO_3^-$ | 62.0 | 62.0 |
| Orthophosphate | $PO_4^{3-}$ | 95.0 | 31.7 |
| Sulfate | $SO_4^{2-}$ | 96.0 | 48.0 |
| Aluminum hydroxide | $Al(OH)_3$ | 78.0 | 26.0 |
| Calcium bicarbonate | $Ca(HCO_3)_2$ | 162 | 81.0 |
| Calcium carbonate | $CaCO_3$ | 100 | 50.0 |
| Calcium sulfate | $CaSO_4$ | 136 | 68.0 |
| Carbon dioxide | $CO_2$ | 44.0 | 22.0 |
| Ferric hydroxide | $Fe(OH)_3$ | 107 | 35.6 |
| Hydrochloric acid | $HCl$ | 36.5 | 36.5 |
| Magnesium carbonate | $MgCO_3$ | 84.3 | 42.1 |
| Magnesium hydroxide | $Mg(OH)_2$ | 58.3 | 29.1 |
| Magnesium sulfate | $MgSO_4$ | 120 | 60.1 |
| Sodium sulfate | $Na_2SO_4$ | 142 | 71.0 |

# Water Softening

b. $$eq/L = \frac{g/L \text{ as ion}}{EW \text{ of the ion}}$$ **or** $$meq/L = \frac{mg/L \text{ as ion}}{EW \text{ of the ion}}$$

$$eq/L = \frac{g/L \text{ as Compound or Radical}}{EW \text{ of the Compound or Radical}}$$

**or** $$meq/L = \frac{mg/L \text{ as Compound or Radical}}{EW \text{ of the Compound or Radical}}$$

**Example 3.3 :** **for example 3.1 find the concentration of Mg $^{2+}$ as meq/L .**

$$meq/L = \frac{mg/L \text{ as ion}}{EW \text{ of the ion}} \longrightarrow (Mg2+) \text{ concentration} = \frac{10 \text{ mg/L as (Mg2+)}}{12.15 \text{ mg/meq}}$$

$$= 0.82 \text{ meq/L}$$

Mg $^{2+}$ conc.

# Water Softening

## F. Alkalinity

Alkalinity is a very important parameter in water chemistry and related very closely to hardness and softening process. The following equation is used to measure the alkalinity in water:

- Alkalinity = $(HCO_3^-) + (CO_3^{2-}) + (OH^-) - (H^+)$
- Where the concentrations are in meq/L or mg/L as $CaCO_3$

  Usually the $(OH^-)$ and $(H^+)$ are negligible.
- The relation between the alkalinity species is given by the following three equations:

$$\boxed{10^{-10.33} = \frac{[H^+][CO_3^{2-}]}{[\text{HCO3-}]}} \quad , \quad \boxed{10^{-14} = \left[H^+\right] \bullet \left[OH^-\right]} \quad , \quad \boxed{\left[H^+\right] = 10^{-pH}}$$

Where the concentrations are moles/ L in these three equations

## Various Forms of alkalinity and $CO_2$ relative to pH in water at 25 ºC.

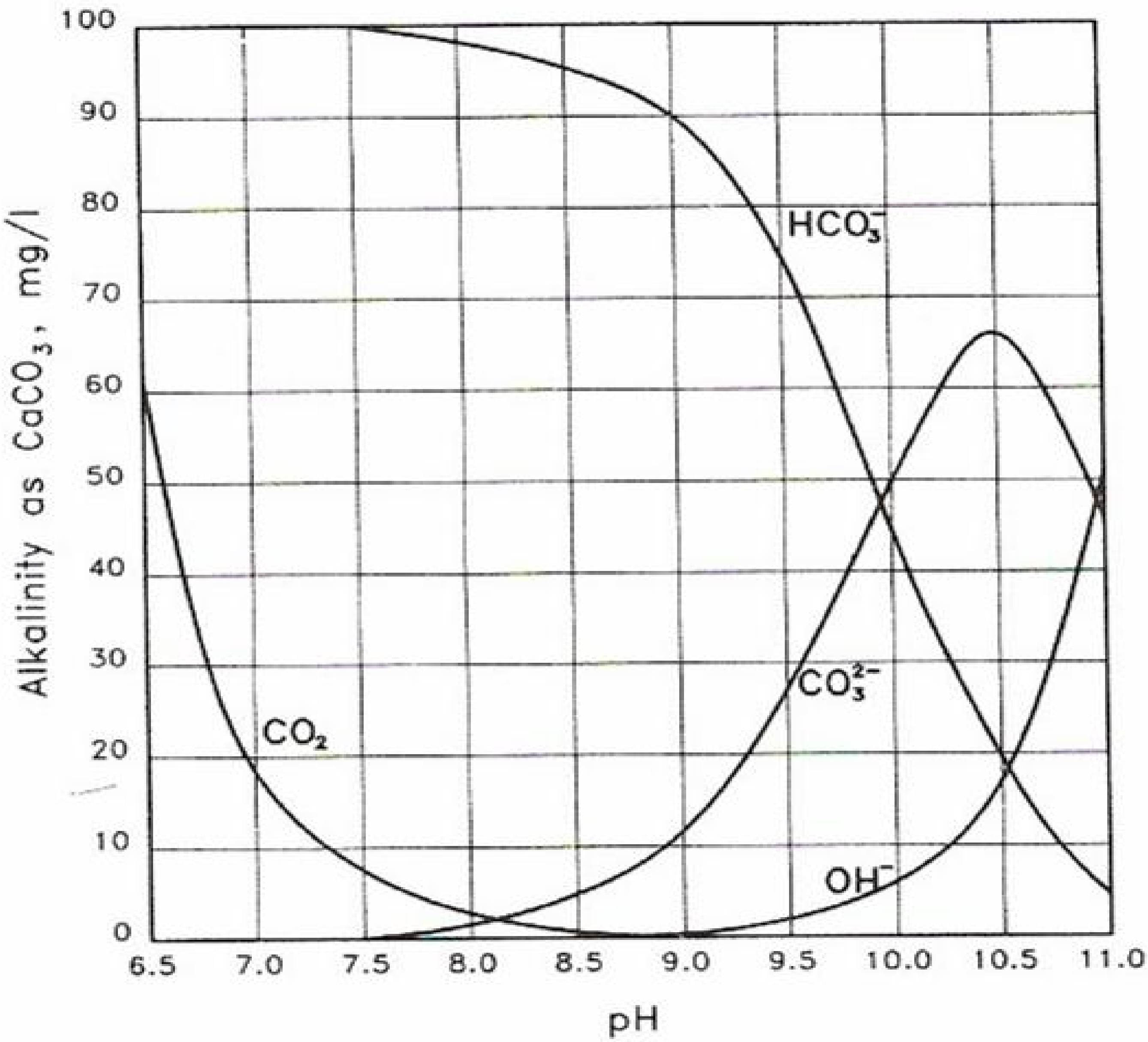



Fig. 3.

# Water Softening

## Example 3.3

- A sample of water having a pH of 7.2 has the following concentrations of ions

| | |
|---|---|
| $Ca^{2+}$ | 40 mg/L |
| $Mg^{2+}$ | 10 mg/L |
| $Na^{+}$ | 11.8 mg/L |
| $K^{+}$ | 7.0 mg/L |
| $HCO_3^{-}$ | 110 mg/L |
| $SO_4^{2-}$ | 67.2 mg/L |
| $Cl^{-}$ | 11 mg/L |

- Construct a bar chart of the ions in term of mg/L $CaCO_3$
- Calculate the TH, CH, NCH, Alkalinity

# Water Softening

**Example 3.3 ..cont'**

| Ion | Conc. mg/L | M.W. mg/mmol | \|n\| | Eq. Wt. mg/meq | Conc. meq/L | Conc. mg/L as $CaCO_3$ |
|---|---|---|---|---|---|---|
| $Ca^{2+}$ | 40.0 | 40.1 | 2 | 20.05 | 1.995 | 99.8 |
| $Mg^{2+}$ | 10.0 | 24.3 | 2 | 12.15 | .823 | 41.2 |
| $Na^{+}$ | 11.8 | 23.0 | 1 | 23.0 | .51 | 25.7 |
| $K^{+}$ | 7.0 | 39.1 | 1 | 39.1 | .179 | 8.95 |
| $HCO_3^{-}$ | 110.0 | 61.0 | 1 | 61.0 | 1.80 | 90.2 |
| $SO_4^{2-}$ | 67.2 | 96.1 | 2 | 48.05 | 1.40 | 69.9 |
| $Cl^{-}$ | 11.0 | 35.5 | 1 | 35.5 | .031 | 15.5 |

Note : Examples 3.1 and 3.2 are sample calculations for $Mg^{2+}$ in this Example

# Water Softening

**Example 3.3 ..cont'**

## Check The ionic balance:

Σ(cations) = Σ(anions)

175.6 = 175.6 mg/L as $CaCO_3$ O.K

3.51 = 3.23 meq/L O.K

Note: (error in the range of ± 10% is accepted)

Note: one check is enough ( either as {mg/L as CaCO3 } or as {meq/L} )

- Total Hardness = $\Sigma$ $(Ca^{2+}) + (Mg^{2+}) = 99.8 + 41.2$

  TH =141 mg/L as $CaCO_3$

  or $\longrightarrow$ TH= 1.995 + 0.823 = 2.818 meq/L

# Water Softening

## Example 3.3 ..cont'

- Alkalinity = $(HCO_3^-) + (CO_3^{2-}) + (OH^-) - (H^+)$

**a.** Since pH = 7.2 $\rightarrow$

$[H^+] = 10^{-pH} = 10^{-7.2}$ mole/L = $10^{-7.2}$ g/L

$$\boxed{eq/L = \frac{g/L \text{ as ion}}{EW \text{ of the ion}}} = \boxed{eq/L = \frac{10^{-7.2}\ g\ H^+/L}{1\ g/eq}} \longrightarrow \boxed{(H^+) = 10^{-7.2}\ eq/L}$$

**b.** $$\boxed{10^{-14} = [H^+]\bullet[OH^-]} = \boxed{10^{-14} = 10^{-7.2}\bullet[OH^-]} \longrightarrow \boxed{[OH^-] = 10^{-6.8}\ mole/L}$$

$$\boxed{[OH^-] = 10^{-6.8}\ mole/L = 17 * 10^{-6.8}\ g/L} \longrightarrow \boxed{eq/L = \frac{17 * 10^{-6.8}\ g\ OH^-/L}{17\ g/eq}} \longrightarrow \boxed{(OH^-) = 10^{-6.8}\ eq/L}$$

**c.** **$(HCO_3^-)$** = 1.80 meq/L = **$1.80 * 10^{-3}$ eq/L** from this example calculations as in the table.

g/L **as $HCO_3^-$** = EW * eq/L = (61 g/eq) * 1.80 $*10^{-3}$ g/L = 109.8 * $10^{-3}$ g/L

**$[HCO_3^-]$** = (109.8 * $10^{-3}$ g/L)/(61g/mole) = **$1.80 * 10^{-3}$ mole/L**

# Water Softening

**Example 3.3 ..cont'**

d. Find the carbonate concentration:

$$10^{-10.33} = \frac{[H^+][CO_3^{2-}]}{[HCO3-]} \longrightarrow 10^{-10.33} = \frac{10^{-7.2}\, x [CO_3^{2-}]}{1.8 \, x \, 10^{-3}} \longrightarrow$$

$[CO_3^{2-}]$= 1.33 x $10^{-6}$ mole/L = 79.8 x $10^{-6}$ g/L

$CO_3^{2-}$ in $\boxed{eq/L = \frac{79.8 * 10^{-6} \; g/L}{30 \; g/eq}}$ = 2.66 x $10^{-6}$ eq/L

**Alkalinity = (1.80 x $10^{-3}$) + (2.66 x $10^{-6}$) + $10^{-6.8}$ - $10^{-7.2}$ = 1.801 x $10^{-3}$ eq/L**

Alkalinity = 1.801 x $10^{-3}$ x 1000 x 50 = 90.1 mg/L as $CaCO_3$

Note: it is clear that the most effective form of alkalinity is bicarbonate, this is always true when the pH is 8.3 or less.

# Water Softening

**Example 3.3 ..cont'**

- Carbonate Hardness

  the portion of the hardness associated with carbonate or bicarbonate

  - Alkalinity = 90.1 mg/L as $CaCO_3$

    TH = 141 mg/L as $CaCO_3$

    CH = 90.2 mg/L as $CaCO_3$

  - Non-carbonate Hardness:

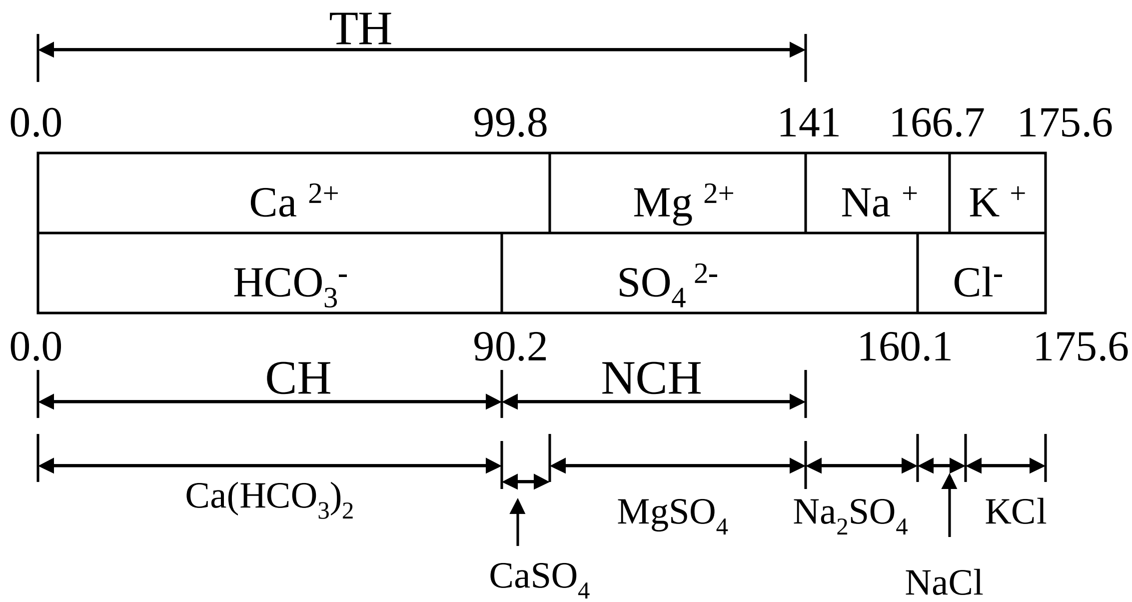
    NCH = TH - CH

    = 141 - 90.1= 50.9 mg/L as $CaCO_3$

# Water Softening

## Example 3.3 ..cont'

Construct the bar chart of the ions in term of mg/L $CaCO_3$




**Note:** the chemicals at the lower line of the bar graph is called the **hypothetical combination** of positive and negative ions in the water sample

# Water Softening

## 2. Softening definition:

a) Softening is the chemical processes in which hardness causing ions ( Ca $^{2+}$ , $Mg^{2+}$ ) are removed from water ether completely or partially.

b) Softening may be a chivied by chemical precipitation using the Lime- Soda Ash method or by ion exchange.

c) In the chemical precipitation method the objective is to produce $CaCO_3$ and $Mg(OH)_2$ :

$$Ca^{2+} + CO_3^{2-} \leftrightarrow 2CaCO_{3(s)} \downarrow$$

$$Mg^{2+} + 2OH^- \leftrightarrow Mg(OH)_{2(s)}$$

These two reactions are achieved by the addition of Lime [$Ca(OH)_2$] and Soda ash [ $Na_2CO_3$] as will be shown.

# Water Softening

f) A common water treatment goal is to provide a water with a hardness in the range of 75 to 120 mg/L as $CaCO_3$

g) To precipitate $CaCO_3$ and $Mg(OH)_2$ we need to raise the pH to 10.3 by the addition of Lime [$Ca(OH)_2$]. The addition of the OH- will convert $HCO_3^-$ to $CO_3^{2-}$

h) To precipitate $Mg(OH)_2$ we need to raise the pH to 11 by the addition of Soda ash [ $Na_2CO_3$]. This will add the $CO_3^{2-}$ ion needed to react with the remaining $Ca^{2+}$

i) Some of the added lime [$Ca(OH)_2$] is consumed to remove $CO_2$ which is necessary to raise the pH.

# Water Softening

## 3. Chemistry of Lime- Soda Ash Softening

### 3.1) softening reactions

- Neutralization of carbonic acid

  [To raise the pH we need first to neutralize any acid in the water]

  $CO_2 + Ca(OH)_2 \leftrightarrow CaCO_{3(s)} + H_2O$

- Precipitation of CH due to calcium:

  [To raise the pH to 10.3 all the $HCO_3^-$ is converted to $CO_3^{2-}$]

  $Ca^{2+} + 2HCO_3^- + Ca(OH)_2 \leftrightarrow 2CaCO_{3(s)} + 2H_2O$

- Precipitation of CH due to magnesium

  [To raise the pH to 11 add more lime]

$Mg^{2+} + 2HCO_3^- + Ca(OH)_2 \leftrightarrow Mg^{2+} + CO_3^{2-} + CaCO_{3(s)} + 2H_2O$

$Mg^{2+} + CO_3^{2-} + Ca(OH)_2 \leftrightarrow MgOH_{2(s)} + CaCO_{3(s)}$

# Water Softening

- Removal of NCH due to calcium

$$Ca^{2+} + SO_4^{-2} + Na_2CO_3 \leftrightarrow CaCO_{3(s)} + 2Na^{+} + SO_4^{-2}$$

$$Ca^{2+} + 2Cl^{-1} + Na_2CO_3 \leftrightarrow CaCO_{3(s)} + 2Na^{+} + 2Cl^{-1}$$

- Removal of NCH due to magnesium

$$Mg^{2+} + Ca(OH)_2 \leftrightarrow MgOH_{2(s)} + Ca^{2+}$$

$$Ca^{2+} + Na_2CO_3 \leftrightarrow CaCO_{3(s)} + 2Na^{+}$$

# Water Softening

## 3.2) Softening process limitations:

1. Lime-Soda softening cannot produce a water completely free of hardness because of the solubility of $CaCO_3$ and $Mg(OH)_2$, limitations of mixing and reaction time .
2. Thus , the minimum calcium hardness that can be achieved is 30 mg/L as $CaCO_3$ , the minimum Magnesium hardness that can be achieved is 10 mg/L as $CaCO_3$ , this gives a minimum hardness of 40 mg/L as $CaCO_3$.
3. However, normally the water is treated to give a hardness in the range of 75 to 120 mg/L as $CaCO_3$.
4. An Excess lime beyond the stoichiometric amount is usually added to remove $Mg^{2+}$ hardness . The minimum excess lime is usually 20 mg/L as $CaCO_3$ , maximum excess lime is 62.5 mg/L as $CaCO_3$ (1.25 meq/L).
5. $Mg^{2+}$ in excess of 40 mg/L as $CaCO_3$ is not desired as it forms scale in water heaters. $Mg^{2+}$ is expensive to remove, so we only remove $Mg^{2+}$ in excess of 40 mg/L as $CaCO_3$.

# Water Softening

## 3.3) Chemicals requirements:

According to the softening chemical reactions:

-Lime is added at the ratio of 1:1 for each carbonate hardness compound except for $Mg(HCO_3)$ the ratio is 2:1 [i.e. 2 lime for each 1 $Mg(HCO_3)$ ].

-Lime is also added at the ratio of 1:1 for each Magnesium NCH compound such as $MgSO_4$

-Soda ash is added at the ratio of 1:1 for each Magnesium or Calcium NCH compound such as $MgSO_4$ , and $CaSO_4$.

- $CO_2$ needed is 1:1 ratio with the excess lime added, and 1:1 ratio with $CaCO_3$ remaining after softening, 2:1 ratio with $Mg(OH)_2$ remaining after softening.

- The units of the chemicals are either in meq/L or mg/L $CaCO_3$
- Example 3.4 illustrates the chemical requirements calculations.

# Water Softening

## 4. Process variation in Lime Soda-Ahs softening:

There are three basic schemes for water softening:

- Excess lime treatment

-Selective Calcium removal

-Split treatment

# Water Softening

## 4.1) Excess lime treatment:

- Carbonate hardness associated with $Ca^{2+}$ can be effectively removed to the practical limit of $CaCO_3$ (30 mg/L as $CaCO_3$) by adding the stoichiometric addition of lime.
- Precipitation of hardness (CH or NCH) associated with $Mg^{2+}$ as $Mg(OH)_2$ needs in addition to the stoichiometric addition of lime to an excess lime of 62.5 mg/L as $CaCO_3$), without it $Mg(OH)_2$ will not precipitate. In fact this excess lime raise the pH to 11.
- Excess lime treatment reduces the total hardness to 40 mg/L as $CaCO_3$ ( i.e., 30 mg/L $CaCO_3$ and 10 mg/L $Mg(OH)_2$ as $CaCO_3$)
- The excess lime treatment is usually achieved in a two stage system as shown in the Figure 3.3

# Water Softening

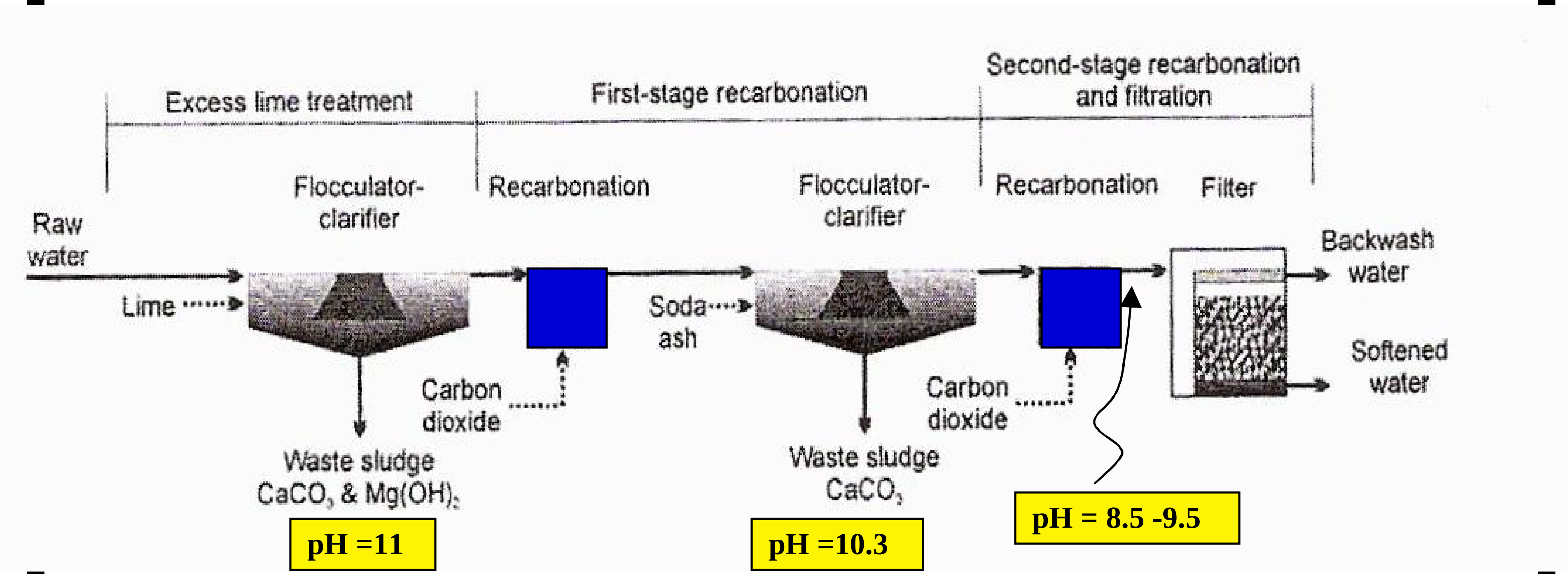



Fig. 3.3 **Schematic diagram of a two stage excess lime softening water treatment plant**

# Water Softening

- The system is composed of :
  - -Rapid mixer,
  - -Flocculator/sedimentation tank,
  - -recarbonation tank,
  - - Rapid mixer
  - -Second stage Flocculator/sedimentation tank
  - -second stage recarbonation tank
  - -Filtration tank
- In the first stage only lime is added to the system through a rapid mixer this will raise the pH to 11. $CaCO_3$ and $Mg(OH)_2$ will precipitate in this stage.
- Recarbonation is implemented to reduce the pH to 10.3 before interring the second stage. This reduction occurs due to the removal of the excess lime added in the first stage:

$$\underbrace{Ca(OH)_2}_{\text{Excess lime}} + CO_2 = CaCO_3 \downarrow + H_2O$$

# Water Softening

- In the second stage only Soda Ash is added to the system through a rapid mixer . $CaCO_3$ will precipitate in this stage from the excess lime and from the NCH reaction .

•Recarbonation is implemented after the second stage Flocculator /sedimentation to reduce the pH in the range of 8.5-9.5 to stabilize the water by converting some of the $Ca\ CO_3$ and $Mg\ (OH)_2$ residual to bicarbonate :

$$Ca\ CO_3 + CO_2 + H_2O = Ca\ (HCO_3)_2$$
$$Mg\ (OH)_2 + 2CO_2 = Mg\ (HCO_3)_2$$

•Recarbonation is a chivied in a tank in which carbon dioxide is injected either in liquid form or in the gaseous form generated in the tank using a special burner as Shown in Figure 3.4.

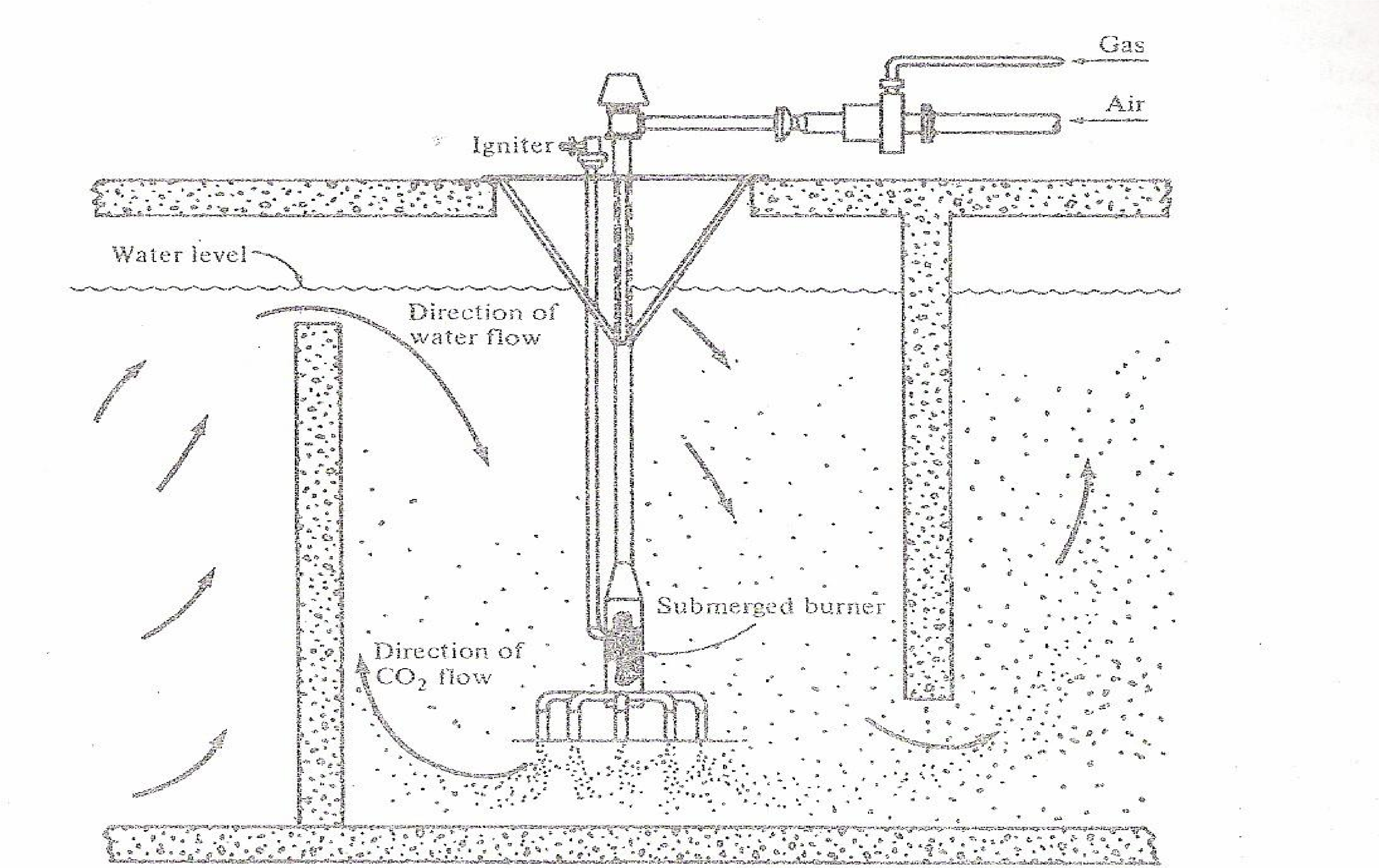



Fig. 3.4 Submerged burner for recarbonation

# Water Softening

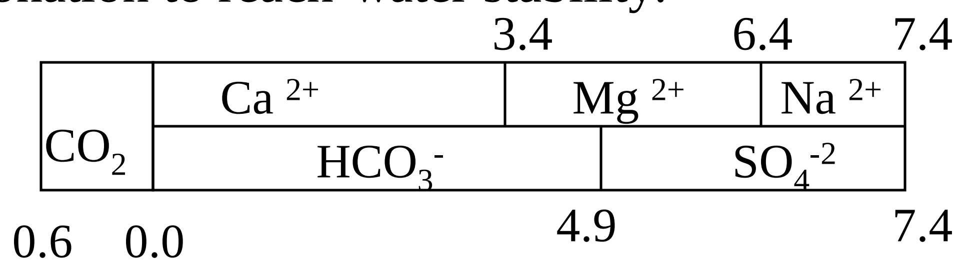
- The first stage removes the following:
  - CH hardness associated with $Ca^{2+}$
  - CH and NCH associated with $Mg^{2+}$
  - Recarbonation reduces pH from 11 to 10.3
- The Second stage removes the following:

-NCH hardness associated with $Ca^{2+}$ that is originally existing in water
-NCH hardness associated with $Ca^{2+}$ that was created from the first stage.
-Recarbonation reduces pH from 10.3 to the range 8.5-9.5

# Water Softening

## Example: 3.4

A water with the ionic characteristics shown below is to be softened to the minimum possible hardness by the two stage lime-soda-ash excess lime process. Calculate the required chemical quantities in meq/L. Draw a bar diagram of the finished water. Assume that 0.6 meq/L $CaCO_3$ and 0.2 meq/L $Mg(OH)_2$ will be in the effluent of the second stage before recarbonation. Assume also that 0.2 meq/L $Mg(OH)_2$ and 0.2 meq/L of the 0.6 $CaCO_3$ will be converted to $HCO_3^-$ by second stage recarbonation to reach water stability.




<u>Solution:</u>

Lime = 0.6+3.4+ 2(4.9-3.4)+ (6.4-4.9)+ excess lime
= 8.5 +1.25 = 9.75 meq/L

Soda Ash = 6.4-4.9 = 1.5 meq/L ( to remove NCH, $MgSO_4^{2-}$)

# Water Softening

Example: 3.4 Cont'

$CO_2$ :

$1^{st}$ stage recarbonation = 1.25 meq/ L [to remove the excess lime]

$2^{nd}$ stage recarbonation = 0.2 meq/L [to convert 0.2meq/L of $CaCO_3$ to $Ca(HCO_3)$ ]

+ (0.20 x 2) meq/L [to convert all $Mg(OH)_2$ to $Mg(HCO_3)$]= 0.60 meq/L]

Total $CO_2$ needed = 1.25+0.6 = 1.85 meq/L

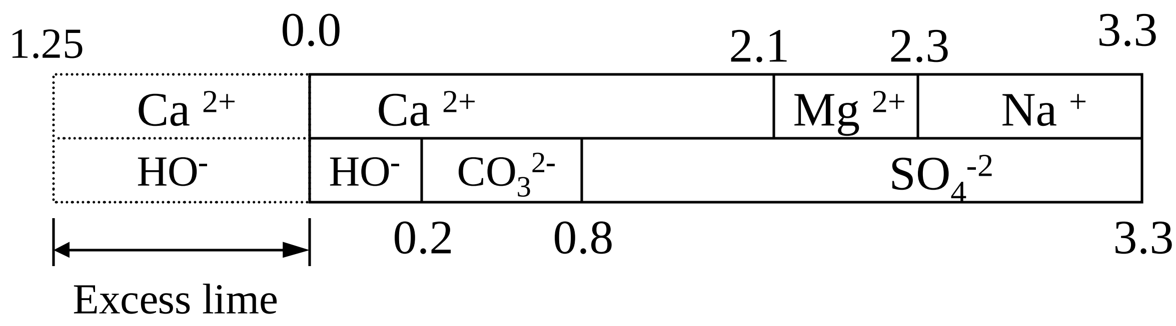
$Na^+$ :

- The addition of soda ash adds to the water an equal amount of $Na^+$.
- Since we added 1.5 meq/L soda ash, this will add 1.5 meq/L $Na^+$
- The original concentration existing in the raw water is 1.0 meq/L .

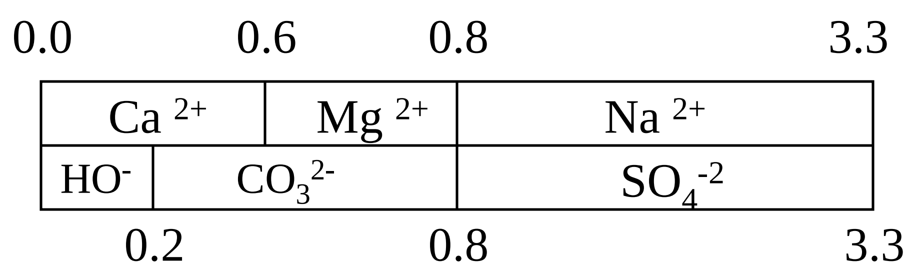
Total $Na^+$ = 1 + 1.5 = 2.5 meq/L $Na^+$.

# Water Softening

Example: 3.4 Cont'




Bar graph of the water before recarbonation and before adding Soda -Ash




Bar graph of the water after adding Soda –Ash and 1st stage recarbonation

# Water Softening

Example: 3.4 Cont’

| | 0.6 | 0.8 | 3.3 |
|---|---|---|---|
| $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | |
| $CO_3^{2-}$ | $HCO_3^{-}$ | $SO_4^{-2}$ | |
| 0.0 | 0.4 | 0.8 | 3.3 |

Bar graph of the finished water after and 2nd stage recarbonation

The remaining hardness:

Calcium hardness = 0.6 meq/L = 30 mg/L as $CaCO_3$

Calcium hardness = 0.2 meq/L = 10 mg/L as $CaCO_3$

TH remaining = 0.8 meq/L = 10 mg/L as $CaCO_3$

# Water Softening

## 4.2) Selective Calcium removal:

-Magnesium hardness is expensive to remove.

-Only Magnesium hardness in excess of 40 mg/L as $CaCO_3$ (0.8 meq/l) needs to be removed.

- For waters having an $Mg^{2+}$ hardness less or equal to 40 mg/L $CaCO_3$, only $Ca^{2+}$ hardness needs to be removed.

- to remove only $Ca^{2+}$, we add lime needed to remove Ca 2+, and do not add excess lime. In this way no $Mg^{2+}$ removal occurs.

-Soda Ash may be needed if NCH associated with $Ca^{2+}$ is to be removed.

-That's way this treatment is called selective.

-This treatment is achieved in a single stage system as that shown in Figure 3.5

# Water Softening

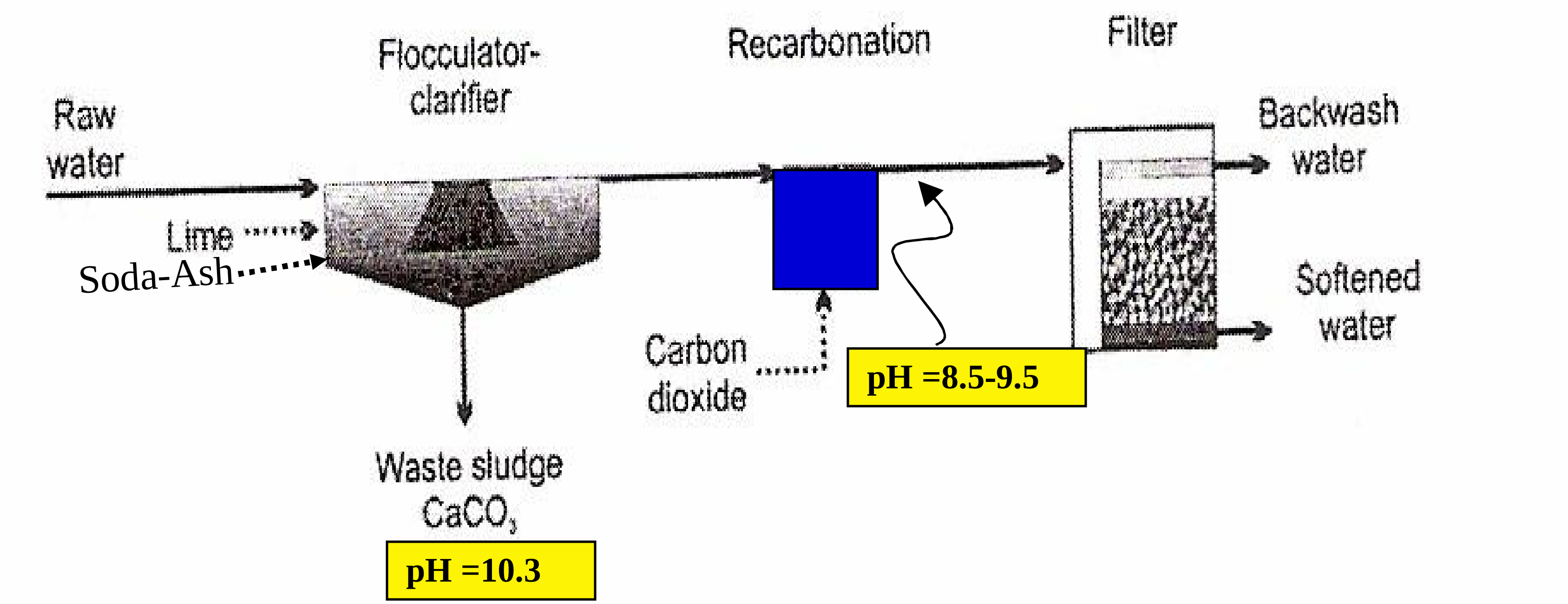



Fig. 3.5 **Schematic diagram of a single stage softening water treatment plant**

# Water Softening

## Example: 3.5

A water with the ionic characteristics shown below is to be softened by selective calcium process. Calculate the required chemical quantities in meq/L. Draw a bar diagram of the finished water.

0.4 0.0 3.5 4.3 4.6

| | | | |
|---|---|---|---|
| $CO_2$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{2+}$ |
| | $HCO_3^-$ | $SO_4^{-2}$ | $Cl^{-1}$ |

0.4 0.0 2.3 4.3 4.6

Solution:

Since $Mg^{2+}$ is 0.8 meq/L we can apply the selective calcium treatment.

Lime = 0.4 + 2.3 = 2.7 meq/L [to remove $CO_2$ and $Ca(HCO_3)$ only]
= 2.7 x 28 = 76 mg/L CaO

Soda Ash = 3.5 - 2.3 = 1.2 meq/L [ to remove NCH, $CaSO_4$]
= 1.2 x 53 = 64 mg/L $Na_2CO_3$

# Water Softening

Example: 3.5 Cont'

$CO_2$ :

For stability reasons it is desired to convert 0.3 out of the 0.6 meq/L $CaCO_3$ to $Ca(HCO_3)_2$ by recarbonation.

Recarbonation = 0.3 meq/ L $CO_2$ [to convert 0.2meq/L of $CaCO_3$ to $Ca(HCO_3)$ ]

= 0.3 x 22 = 6.6 mg/L $CO_2$

$Na^+$ :

- The addition of soda ash adds to the water an equal amount of $Na^+$.
- Since we added 1.2 meq/L soda ash, this will add 1.2 meq/L $Na^+$
- The original concentration existing in the raw water is 0.3 meq/L .

Total $Na^+$ = 0.3 + 1.2 = 1.5 meq/L $Na^+$

= 1.5 x 23 = 34.5 mg/L $Na^+$

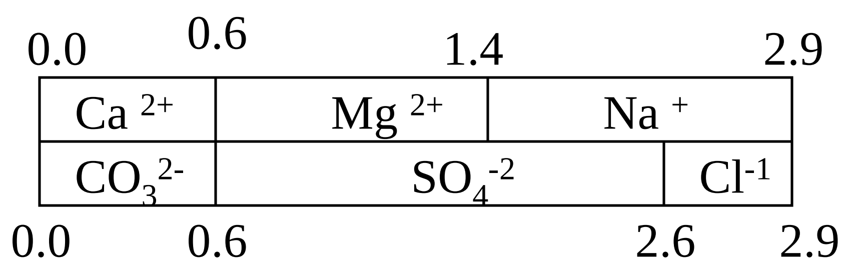
Final hardness = all the original $Mg^{2+}$ + 0.6 meq/L calcium hardness

= 0.8 meq/L $Mg^{2+}$ + 0.6 meq/L $Ca^{2+}$ = 1.4 meq/L

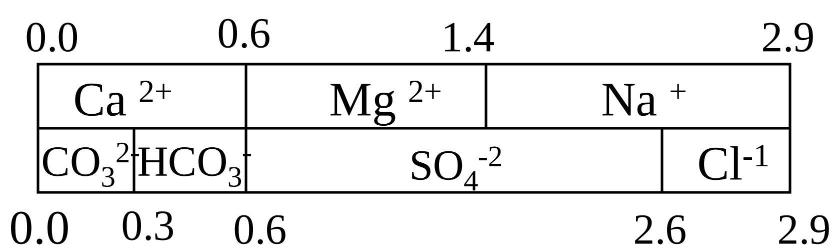
= 1.4 X 50 = 70 mg/L $CaCO_3$

# Water Softening

Example: 3.5 Cont'




Bar graph of the water after softening and before recarbonation




Bar graph of the finished water after recarbonation

# Water Softening

## 4.3) Split Treatment:

- Split treatment consist of treating  portion of the raw water by excess lime treatment and Then neutralizing the excess lime by the bicarbonate naturally existing in the untreated bypass flow (Figure 3.6).
- The first stage is operated to soften the water to the practical limits of 10 mg $Mg^{+2}$/L as $CaCO_3$ , and 30 mg $Ca^{2+}$ /L as $CaCO_3$.
- Magnesium concentration in the bypass will be the same as in the raw water.
- The finished water should have a final of 40 mg $Mg^{+2}$/L as $CaCO_3$ as desired by domestic water users and industries.
- Some advantages of Split Treatment:
  * Reduces the chemical dosage of lime and $CO_2$.
  * No need for first stage recarbonation
  * Reduce the capital cost of the first stage since only a portion of the water is treated and consequently the tanks are smaller.
  * Allows us to leave a $Mg^{2+}$ concentrations above the practical value of 10 10 mg $Mg^{+2}$/L as $CaCO_3$ usually we are forced to achieve in the conventional excess lime treatment.

# Water Softening

-The Fraction Bypassed is calculated as :

$$\boxed{X = \frac{Mg_f - Mg_i}{Mg_r - Mg_i}}$$

Where, $Mg_f$ = final magnesium concentration, mg/L $CaCO_3$
$Mg_i$ = magnesium concentration from the first stage, mg/L $CaCO_3$
$Mg_r$ = raw water magnesium concentration, mg/L $CaCO_3$

# Water Softening

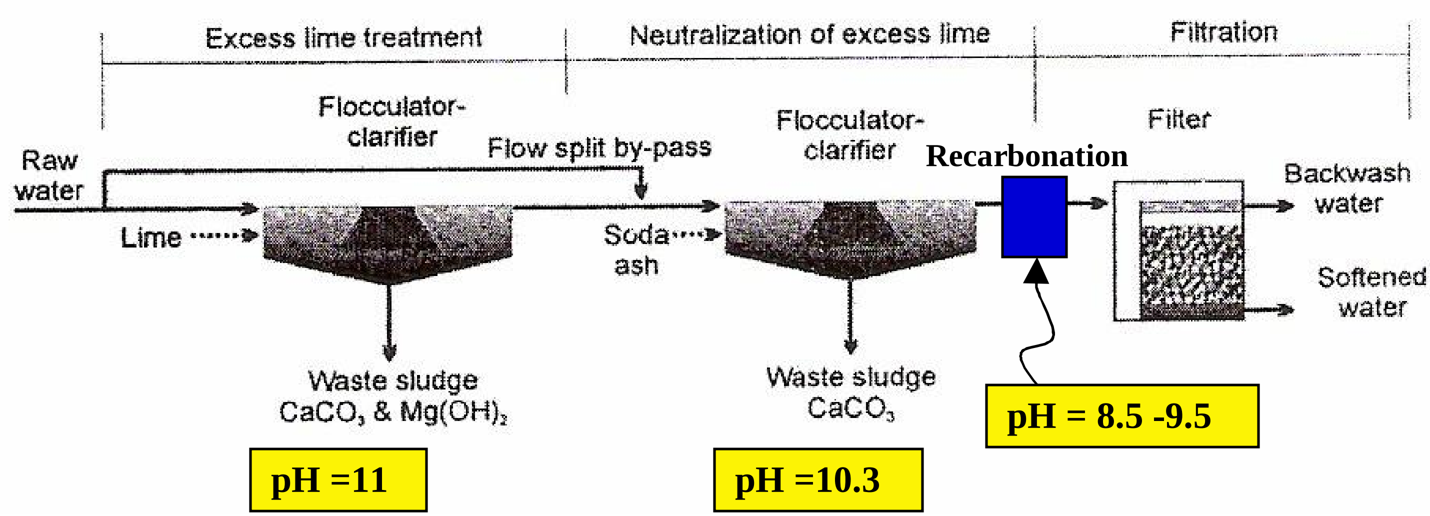
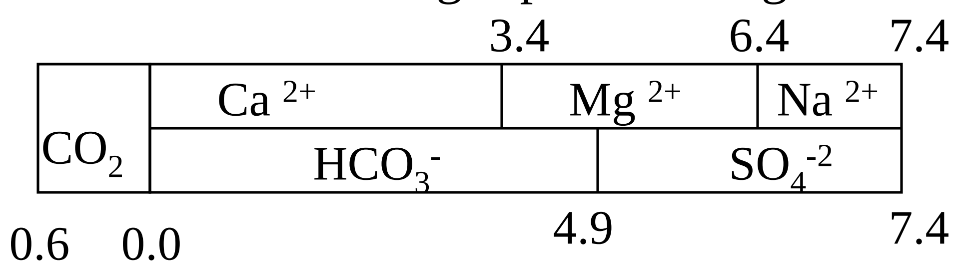



Fig. 3.6 **Schematic diagram of a split system softening water treatment plant**

# Water Softening

## Example: 3.6

For the water in example 3.4 use a split treatment to soften it. Calculate the required chemical quantities in meq/L. Draw a bar diagram of the finished water. Assume that the maximum permissible Magnesium hardness of 40 mg/L $CaCO_3$ and Calcium hardness in the range of 40-60 mg/L $CaCO_3$ . The expected magnesium hardness from the first stage split is 10 mg/L $CaCO_3$ .




<u>Solution:</u>

$$\boxed{X = \frac{Mg_f - Mg_i}{Mg_r - Mg_i}} \longrightarrow \boxed{X = \frac{40-10}{3(50)-10} = 0.214}$$

$$\boxed{1 - X = 1 - 0.214 = 0.786}$$

# Water Softening

Example: 3.6 Cont'

Solution:

Chemicals to be added

A ) Lime = 0.786 [(0.6 + 3.4+ 2(4.9-3.4) + (6.4-4.9)]

= 6.681 meq/L [needed for the first stage treatment]

Lime = 0.214 [ 0.6 + 3.4] = 0.856 meq/L [needed for removing the $Ca^{2+}$ hardness and $CO_2$ from the bypass flow. However, this amount will be added to the first stage, and will act as an excess lime.]

Excess lime concentration in the first stage = (0.856/ 0.786) = 1.09 < 1.25 meq/L so additional amount is needed

= Y/0.786 = 1.25 $\longrightarrow$ Y = 0.983 meq/L

= 0.214 [ 0.6 + 3.4+ Z] = 0.983 $\longrightarrow$ Z = 0.593 meq/L

Corrected lime for the bypass = 0.214[ 0.6+ 3.4 + 0.593]= 0.983 meq/L

Excess lime concentration in the first stage = (0.983/ 0.786) = 1.25 meq/L (OK).

B) Soda Ash = See the lower Bar graph in slide 48 , we need to remove $CaSO_4$

= 1.3-0.60 = 0.70 meq/L

Another method to calculate the needed Soda Ah:

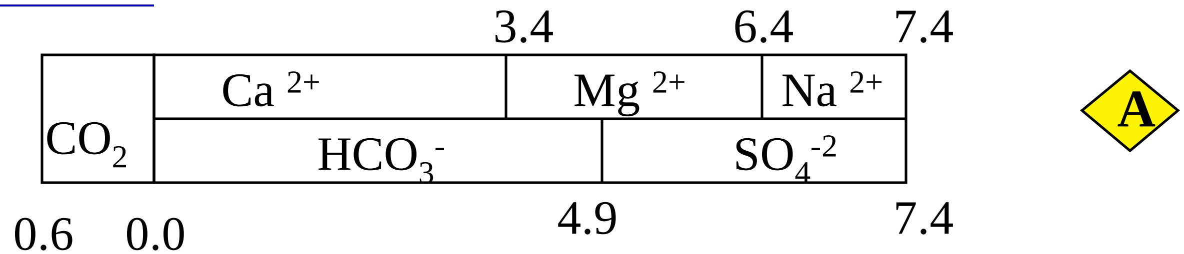
Soda ash =(Raw water $Mg^{2+}$ concentration - 0.80) meq/L $Mg^{2+}$ NCH + meq/L $Ca^{2+}$ NCH

= 1.50 - 0.80 + 0.0

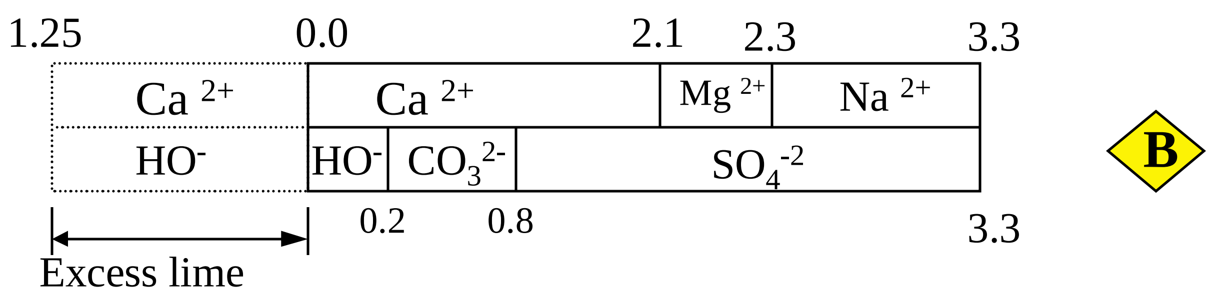
= 0.70 meq/L

# Water Softening

Example: 3.6 Cont'




Bar graph of the water in the Bypass line (Raw water)

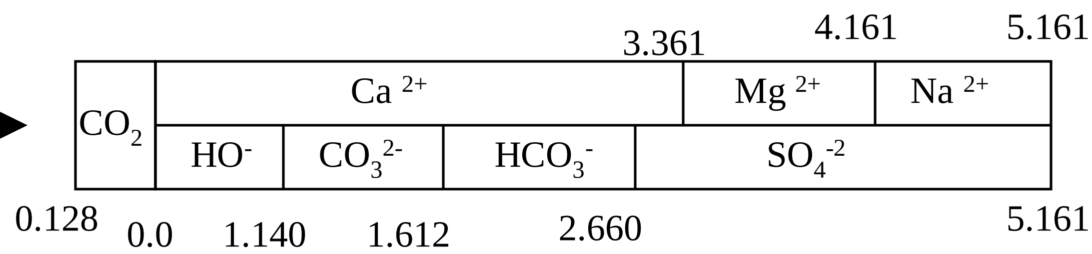



Bar graph of the water after the first stage split softening before blending and before adding Soda Ash

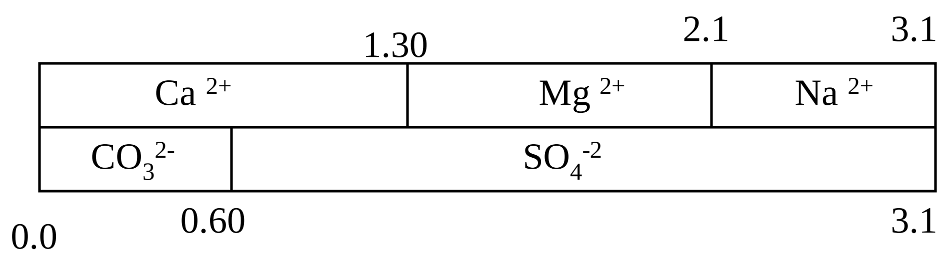
# Water Softening

## Example: 3.6 Cont'

**0.214 A + 0.786 B** →




Bar graph of the water after blending and before reaction between the excess lime and before adding Soda Ash




Bar graph of the water after blending and reaction between the excess lime and before adding Soda Ash

# Water Softening

Example: 3.6 Cont’

0.60 1.40 3.1

| $Ca^{2+}$ | $Mg^{2+}$ | $Na^{2+}$ |
|---|---|---|
| $CO_3^{2-}$ | $SO_4^{-2}$ | |

0.0 0.60 3.1

Bar graph of the water after adding Soda Ash and before second stage carbonation

0.60 1.40 3.1

| $Ca^{2+}$ | | $Mg^{2+}$ | $Na^{2+}$ |
|---|---|---|---|
| $CO_3^{2-}$ | $HCO_3^-$ | $SO_4^{-2}$ | |

0.0 0.30 0.60 3.1

Bar graph of the finished water

**Note :**

Remaining hardness = 0.60 $Ca^{2+}$ hardness + 0.8 $Mg^{2+}$ hardness = 1.40 meq/L

= 0.60X 50 mg $Ca^{2+}$ /L $CaCO_3$ + 0.8 $Mg^{2+}$ mg/L $CaCO_3$

= 30 mg $Ca^{2+}$ /L $CaCO_3$ + 40 mg $Mg^{2+}$ /L $CaCO_3$

Remaining Hardness = 70 mg /L $CaCO_3$

# Water Softening

## 5. Coagulation and Softening

- The softening precipitates [i.e. $CaCO_3$ and $Mg(OH)_2$] may be more efficiently removed by adding a coagulant such as Alum.
- On the other hand, if both coagulation and softening are to be applied ,(such as in hard turbid surface water), the coagulation process is more efficient due to the greater quantity of precipitate formed due to softening.
- That's why coagulation and lime soda-Ash softening have similar infrastructure (i.e. rapid mixer, Flocculator, sedimentation tank).