Lecture 9 - Lime-soda ash softening, Part 2

For waters with non-carbonate hardness, single-stage softening is insufficient. Leftover hardness is removed by addition of soda ash (Na_2CO_3)

8. $Ca^{2+} + SO_4^{2-} + Na_2CO_3 \rightarrow CaCO_3\downarrow + 2Na^+ + SO_4^{2-}$

9. $Ca^{2+} + 2Cl^- + Na_2CO_3 \rightarrow CaCO_3\downarrow + 2Na^+ + 2Cl^-$

Practical limits of lime-soda ash softening are dictated by solubility of precipitates: $CaCO_3$ & $Mg(OH)_2$

Ca: 30 mg/L as $CaCO_3$
Mg: 10 mg/L as $CaCO_3$
Total hardness: 40 mg/L as $CaCO_3$

In practice, residual hardness = 50 to 80 mg/L

This water has high pH and needs to be recarbonated

Lime-soda ash treatment is usually treated by "two-stage softening" also called "excess-lime treatment" and "split recarbonation treatment"

See Lecture 8, page 10

Split treatment is similar, except only part of water is treated with lime. Other part by-passes lime treatment and gets soda-ash treatment along with lime-treated water
The CO_2 in untreated water neutralizes high pH in lime-treated water and recarb. is not needed

Water split is computed such that enough Mg is removed in lime-treated water to meet target Mg level in combined finished water

Computing chemical doses for lime soda ash softening - Example 11.4 from Viessman and Hammer, pg. 445 - pg 3 and 4

CO_2 = 8.8 mg/L as CO_2
Ca^{++} = 70 mg/L
Mg^{++} = 9.7 mg/L
Na^{+} = 6.9 mg/L

Alk = 115 mg/L as $CaCO_3$
SO_4^{2-} = 96 mg/L
Cl^{-} = 10.6 mg/L

Easiest method is to construct a table that converts all concentrations to equivalent concentrations, and then to equivalents of $CaCO_3$
Also use chart from VH Fig 11.8, pg 446

	conc (mg/L)	MW (gm/mole)	equiv (eq/molecule)	eq wt (gm/mole-eq)	meq/L	mg/L as $CaCO_3$
CO_2	8.8	44.0	2	22.0	0.4	20.0
Ca^{2+}	70	40.0	2	20.0	3.5	175.
Mg^{2+}	9.7	24.4	2	12.2	0.80	39.8
Na^{+}	6.9	23.0	1	23.0	0.30	15.0
					4.6	229.8
Alk	115	100	2	50.0	2.3	115.0
SO_4^{2-}	96	96.0	2	48.0	2.0	100.0
Cl^{-}	10.6	35.5	1	35.5	0.30	14.9
					4.6	229.9

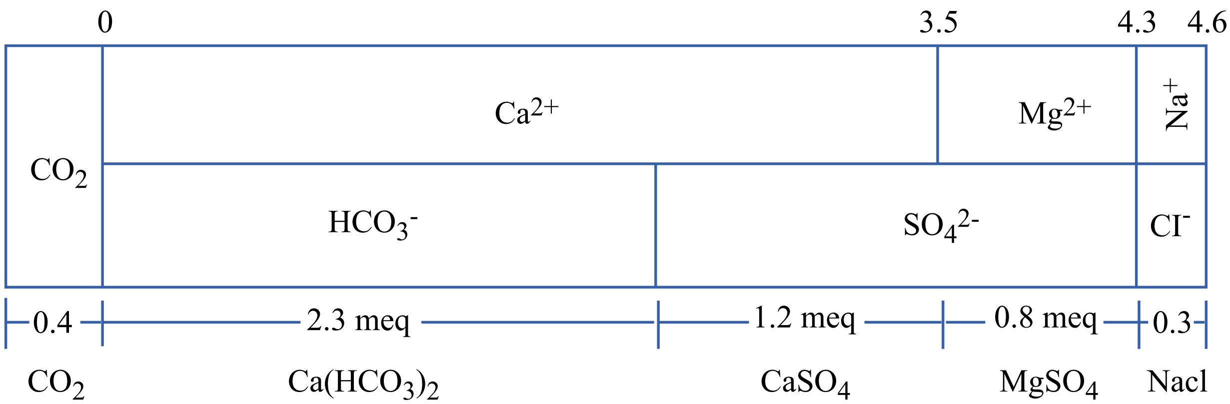
Total hardness = $Ca^{2+} + Mg^{2+}$ = 175 + 39.8 = 214.8 mg/L as $CaCO_3$

Carbonate hardness = [Alk] = 115 mg/L as $CaCO_3$

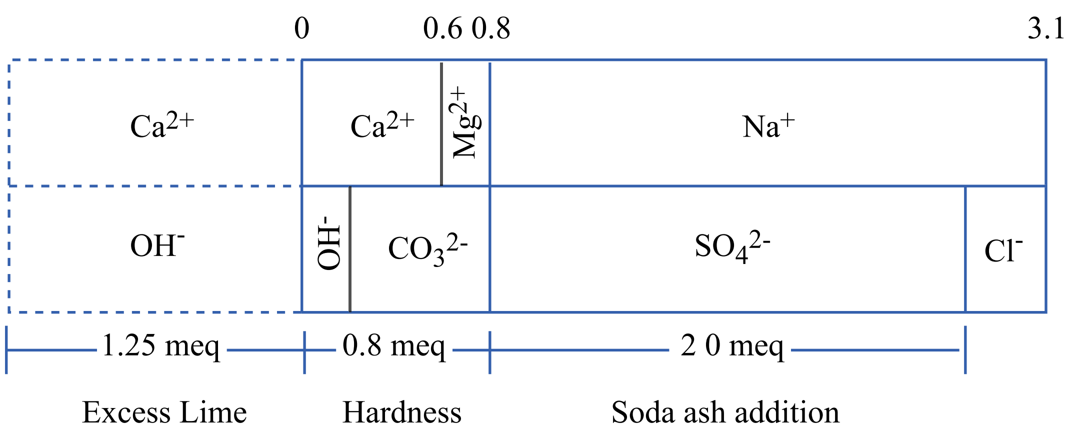
Noncarbonate hardness = TH - CH = 99.8 mg/L as $CaCO_3$

Mg noncarbonate hardness = 39.8 mg/L as $CaCO_3$

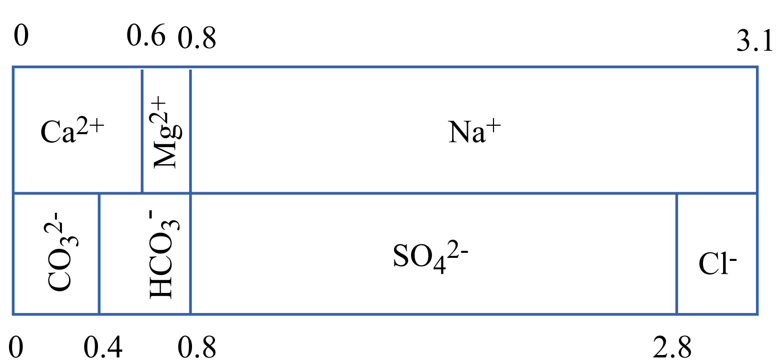
Milliequivalent Bar Graph for Example 11.4



(A) Bar graph & hypothetical chemical combinations in the raw water



(B) Bar graph of the water after lime & soda ash additions & settling but before recarbonation.

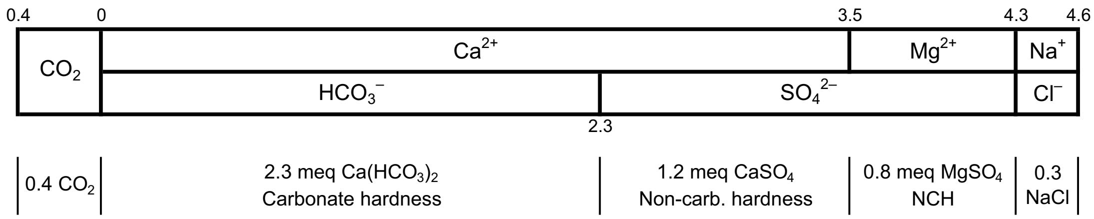


(C) Bar Graph of the water after two-stage recarbonation & final filtration

Figure by MIT OCW.

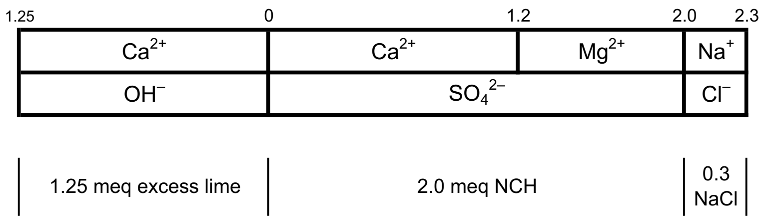
Adapted from: Viessman, W., Jr., and M. J. Hammer. *Water Supply and Pollution Control*. 7th ed. Upper Saddle River, NJ: Pearson Education, Inc., 2005, p. 446.

Before treatment:



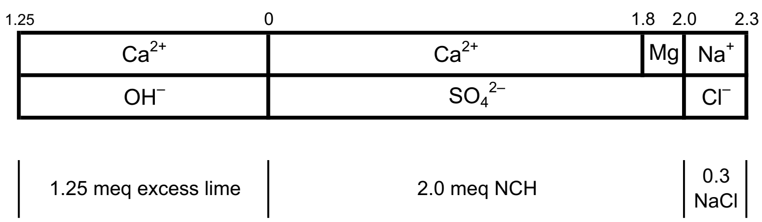
After treatment with lime $Ca(OH)_2$ and intermediate reaction to remove carbonate hardness:

(chemical equations 1, 2, & 3)



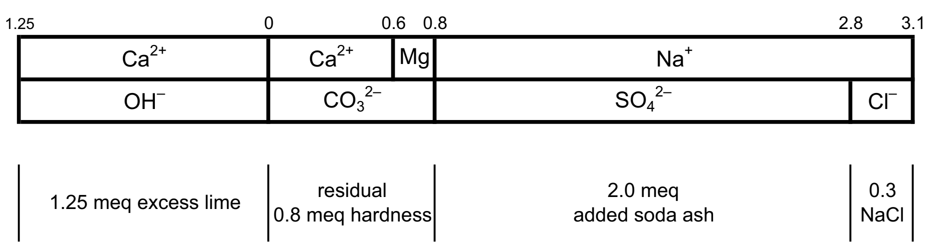
After treatment with lime and intermediate reaction to remove noncarbonate Mg hardness:

(chemical equations 4 & 5)



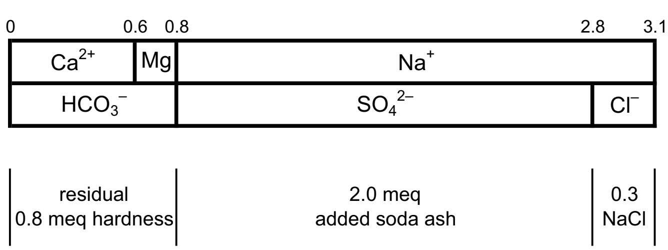
After treatment with soda ash Na_2CO_3:

(chemical equations 8 & 9)



After recarbonation:

(chemical equations 6 & 7)



Lime required

For CO_2 — 20.0 mg/L as $CaCO_3$
For carbonate hardness — 115.0
For Mg noncarbonate hardness — 39.8

174.8 mg/L as $CaCO_3$
(3.5 meq)

Convert from $CaCO_3$ to CaO

$$\frac{CaO}{CaCO_3} = \frac{40+16}{40+12+3\times16} = \frac{56}{100} = \frac{28}{50}$$

174.8 mg/L as $CaCO_3$ = 97.9 mg/L as CaO

Include excess lime of 35 mg/L

Req'd lime = 133 mg/L

Soda Ash for noncarbonate hardness

NCH = 99.8 mg/L as $CaCO_3$ (2.0 meq)

(recall that Mg NCH was treated with lime but simply swaps Ca for Mg, so still needs treatment with soda ash)

Reqd Soda Ash — 99.8 mg/L as $CaCO_3$

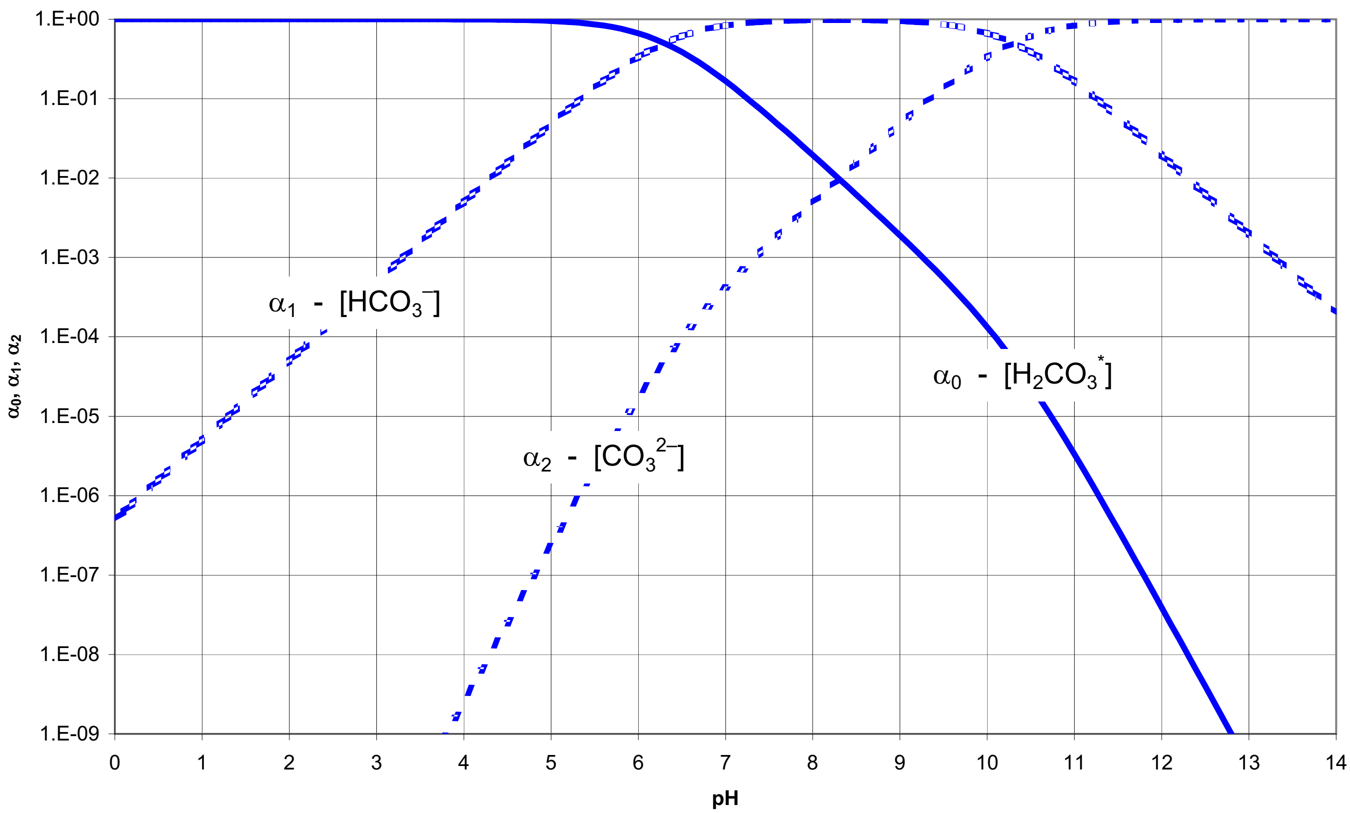
Convert to Na_2CO_3:

$$\frac{Na_2CO_3}{CaCO_3} = \frac{2\times23+12+3\times16}{40+12+3\times16} = 1.06$$

Reqd soda ash = 1.06 × 99.8 = 106 mg/L

Note that pg 14 shows HCO_3^- but will actually be an equilibrium between CO_2, HCO_3^-, CO_3^{2-} depending on pH per pg 6

Carbonate system equilibrium



Summary of chemical dosage calculations required for lime & lime-soda ash softening*

PROCESS	REQUIRED CHEMICAL DOSAGE CALCULATIONS
Single-Stage Lime: For waters with high calcium, low magnesium, & carbonate hardness	**Lime addition for softening:** CaO = {carbonic acid concentration} + { calcium carbonate hardness} **Soda ash addition for softening:** Na_2CO_3 = none **Carbon dioxide for pH adjustment after softening:** CO_2 = {estimated carbonate alkalinity of softened water} = {source water alkalinity} − {source water calcium hardness} + {estimated residual calcium hardness of softened water}
Excess Lime: For waters with high calcium, high magnesium, and carbonate hardness; process may be one or two stages	**Lime addition for softening:** CaO = {carbonic acid concentration} + {total alkalinity} + {magnesium hardness} + {excess lime dose} **Soda ash addition for softening:** Na_2CO_3 = none **Carbon dioxide for pH adjustment after softening:** CO_2 = {source water alkalinity} − {source water total hardness} − {excess lime dose} + {estimated residual calcium hardness of softened water} + 2 {excess lime dose} + {estimated residual magnesium hardness of softened water}
Single-Stage Lime Soda Ash: For water with high calcium, low magnesium, & carbonate and noncarbonte hardness	**Lime addition for softening:** CaO = {carbonic acid concentration} + { calcium carbonate hardness} **Soda ash addition for softening:** Na_2CO_3 = {calcium noncarbonate hardness} and /or {magnesium noncarbonate hardness} **Carbon dioxide for pH adjustment after softening:** CO_2 = {source water alkalinity} + {soda ash dose} − {source water calcium hardness} + {estimated residual calcium hardness of softened water}
Excess Lime - Soda Ash: For waters with high calcium, high magnesium, and carbonate and noncarbonate hardness; process may be one or two stages	**Lime addition for softening:** CaO = {carbonic acid concentration} + {calcium carbonate concentration} + 2 {magnesium carbonate hardness} + {magnesium noncarbonate hardness} + {excess lime requirement} **Soda ash addition for softening:** Na_2CO_3 = {calcium noncarbonate hardness} + {magnesium noncarbonate hardness} **Carbon dioxide for pH adjustment after softening:** CO_2, first stage = {estimated hydroxide alkalinity of softened water} = {excess lime dose} + {estimated residual magnesium hardness of softened water} CO_2, second stage = {estimated hydroxide alkalinity of softened water} = {source water alkalinity} + {soda ash dose} − {source water total hardness} + {estimated residual hardness of softened water}

* All quantities are expressed as mg/L as $CaCO_3$

Figure by MIT OCW.

Adapted from: MWH, J. C. Crittenden, R. R. Trussell, D. W. Hand, K. J. Howe, and G. Tchobanoglous. *Water Treatment: Principles and Design*. 2nd ed. Hoboken, NJ: John Wiley & Sons, 2005, pp. 1610-1611.