Chemicals required for various hardness constituents

Key Points:

1. Substances such as NaCl, Na_2SO_4, $NaNO_3$, KCl, K_2SO_4, KNO_3, SiO_2, Fe_2O_3, etc. do not consume any L & S and should therefore be excluded from the calculation of L & S requirements.
2. All substances must be converted into their respective $CaCO_3$ equivalents.
3. Ca-hardness is precipitated as $CaCO_3$, while Mg-hardness is precipitated as $Mg(OH)_2$.

Chemicals requirement for Temporary hardness constituents:

A. $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$ -------- needs 1 mole of L (1L)

B. (i) $Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow \mathbf{Ca(HCO_3)_2} + Mg(OH)_2$ ----- 1L
(ii) $\mathbf{Ca(HCO_3)_2} + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$ ----- 1L
Or by combining eq. (i) and (ii) we get
$Mg(HCO_3)_2 + 2Ca(OH)_2 \rightarrow 2CaCO_3 + Mg(OH)_2 + 2H_2O$ --- 2L

1L + 1L = 2 L

✓ *1 mole of $Ca(HCO_3)_2$ needs 1 mole of Lime whereas 1 mole of $Mg(HCO_3)_2$ needs 2 moles of Lime.*

Chemicals requirement for Permanent hardness constituents:

A. ***Calcium permanent hardness*** *(*$CaCl_2$, $Ca(NO_3)_2$, $CaSO_4$)

(i) $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$ ------- needs 1 mole of Soda (1S)

(ii) $Ca(NO_3)_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaNO_3$ ----- needs 1 mole of Soda (1S)

(iii) $CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$ ----- needs 1 mole of Soda (1S)

✓ ***** *All Calcium permanent hardness constituents* [$CaCl_2$, $CaSO_4$, $Ca(NO_3)_2$] *need only 1- mole of Soda (1S)*

B. ***Magnesium permanent hardness*** *(*$MgCl_2$, $Mg(NO_3)_2$, $MgSO_4$)

(i) $MgCl_2 + Ca(OH)_2 + \rightarrow Mg(OH)_2 + CaCl_2$ ------- needs 1 mole of Lime (1L) *but releasing 1 mole of CaCl2. For its removal we need 1 mole of Soda*
$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$ ------- needs 1 mole of Soda (1S)

✓ **So, 1 mole of *Magnesium permanent hardness needs 1 mole of lime and 1 mole of Soda* (1L + 1S).**

***Chemicals requirement for coagulants* ($FeSO_4$, $Al_2(SO_4)_3$):**

(i) $FeSO_4 + Ca(OH)_2 + \rightarrow Fe(OH)_2 + CaSO_4$ ------- needs 1 mole of Lime (1L) *but releasing 1 mole of* $CaSO_4$. *Its removal needed 1 mole of Soda*
$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$ ------- needs 1 mole of Soda (1S)

✓ ***So,*** $FeSO_4$ ***needs 1 mole of lime and 1 mole of Soda* (1L + 1S).**

(ii) $Al_2(SO_4)_3 + 3Ca(OH)_2 + \rightarrow 2Al(OH)_3 + 3CaSO_4$ – 3 moles of Lime (3L)
$3CaSO_4 + 3Na_2CO_3 \rightarrow 3CaCO_3 + 3Na_2SO_4$ ------- needs 3 mole of Soda (3S)

✓ ***So,*** $Al_2(SO_4)_3$ ***needs 3 mole of lime and 3 mole of Soda* (3L + 3S).**

Q.1 Give reason that 1 mole of *$Ca(HCO_3)_2$ needs 1 mole of Lime whereas 1 mole of $Mg(HCO_3)_2$ needs 2 moles of Lime. (write chemical reactions)*

Ans.

A. $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$ -------- needs 1 mole of L (1L)

B. (i) $Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow \mathbf{Ca(HCO_3)_2} + Mg(OH)_2$ ----- 1L

(ii) $\mathbf{Ca(HCO_3)_2} + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$ ----- 1L

} 1L + 1L = 2 L

Q. 2. Give reason that *Calcium permanent hardness constituents need only 1- mole of Soda (1S).*

Ans.

(i) $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2\ NaCl$ ------- needs 1 mole of Soda (1S)

(ii) $Ca(NO_3)_2 + Na_2CO_3 \rightarrow CaCO_3 + 2\ NaNO_3$ ----- needs 1 mole of Soda (1S)

(iii) $CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$ ----- needs 1 mole of Soda (1S)

Q.3. Give reason that 1 mole of *Magnesium permanent hardness needs 1 mole of lime and 1 mole of Soda* (1L + 1S).

Ans. (i) $MgCl_2 + Ca(OH)_2 + \rightarrow Mg(OH)_2 + CaCl_2$ ------- needs 1 mole of Lime (1L) *but releasing 1 mole of $CaCl_2$. For removal of $CaCl_2$ we need 1 mole of Soda as per the following reaction*

$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2\ NaCl$ ------- needs 1 mole of Soda (1S)

Q.4. Give reason that lime is not consumed by $CaCl_2$ or any calcium-permanent hadness constituents.

Ans. $CaCl_2 + Ca(OH)_2 \rightarrow CaCl_2 + Ca(OH)_2$

See the above reaction, there is no change in reactant and product side. It means there is no reaction between these two constituents.

Solved Numerical

Note:

(A) Lime required for softening of 1L of hard water (mg) = 74/100 (Lime consuming substances as $CaCO_3$ eq.) x Vol. of water x (100/% purity of lime)

(B) Soda required for softening of 1L of hard water (mg) = 106/100 (Soda consuming substances as $CaCO_3$ eq.) x Vol. of water x (100/% purity of soda)

Solved numerical on Lime-soda Process

Example-1 A sample of water on analysis has been found to contain 100 mg/L of $KHCO_3$ and 200 mg/L of K_2SO_4. Calculate the amount of lime and soda required for softening of 10,000 litres of hard water. (At. mass: K = 39, Ca = 40, H =1, C = 12, O =16, S = 32 g/mol)

Ans. The amount of lime and soda required = 0, as both are non hardness constituents.

Example-2 A sample of water on analysis has been found to contain 100 mg/L of $Mg(HCO_3)_2$ and 200 mg/L of K_2SO_4. Calculate the amount of lime and soda required for softening of 10,000 litres of hard water. (At. mass: Na = 23, Mg= 24, H =1, C = 12, O =16, K=39 g/mol, S = 32 g/mol)

Solution: Na_2SO_4 does not consume chemicals like lime and soda.

N.B: if purity of lime and soda is not mention then take % purity = 100

$Mg(HCO_3)_2$ as $CaCO_3$ eq. = 100 x (100/146) = 68.493 mg/L

$Mg(HCO_3)_2$ require only 2L (**no soda requirement**, that is soda amount = 0)

So, lime required for softening of 10,000 L of hard water = 74/100($Ca(HCO_3)_2$ $CaCO_3$ eq.) x V x (100/% purity of lime)

= (74/100) x **2 x 68.493** x 10,000 L x 100/100 (here purity of lime 100%)

= 1013696.4 mg = 1.013 Kg (Ans.)

Example-3 A sample of water on analysis has been found to contain 150 mg/L of $Ca(HCO_3)_2$ and 100 mg/L of Na_2SO_4. Calculate the amount of lime and soda required for softening of 15,000 litres of hard water after boiling the water for 20 min. (At. mass: Na = 23, Ca = 40, H =1, C = 12, O =16, S = 32 g/mol)

Solution: As boiling removes $Ca(HCO_3)_2$, lime and soda required will be zero.

Example-4 Calculate the amount of lime and soda required for softening of 100 L of hard water having 95 mg/L of $MgCl_2$.

Solution: $MgCl_2$ needs 1L + 1S.

$CaCl_2$ as $CaCO_3$ eq. = 95 x (100/95) = 100 mg/L

(A) Lime required = 74/100($MgCl_2$ as $CaCO_3$ eq.) x Vol. of water x (100/% purity of lime) = (74/100) x 100 x 100 x (100/100)= 7400 mg

(B) Soda required = 106/100($MgCl_2$ as as $CaCO_3$ eq.) x Vol. of water x (100/% purity of soda) = (106/100) x 100 x 100 x (100/100)= 10600 mg

Example-6 Calculate the amount of lime required for softening of 100 L of hard water having 250 mg/L of $CaCl_2$ and 220 mg/L of KCl

Ans. KCl is a non hardness mass.

$CaCl_2$ do not consume any lime. So, lime required = 0

Example-7 A sample of water on analysis has been found to contain 150 mg/L of $Ca(HCO_3)_2$, 100 mg/L of $Mg(HCO_3)_2$ and 100 mg/L og KCl. Calculate the amount of soda required for softening of 15,000 litres of hard water.

Ans. Soda required = 0

Example-8 A sample of water on analysis has been found to contain 150 mg/L of $Ca(HCO_3)_2$ and 100 mg/L of $CaSO_4$. Calculate the amount of lime and soda required for softening of 15,000 litres of hard water after boiling the water for 20 min. (At. mass: Ca = 40, H =1, C = 12, O =16, S = 32 g/mol)

Solution: Boiling will remove the $Ca(HCO_3)_2$. So only $CaSO_4$ will be remain in the hard water after boiling.

$CaSO_4$ consumes only soda (Mol .mass = 136 g)

$CaSO_4$ as $CaCO_3$ eq. = 100 x (100/136) = 73.529 mg/L

Soda required = 106/100 ($CaSO_4$ as $CaCO_3$ eq.) x V x (100/%purity of soda)

= 106/100 x 73.529 x 15,000 x 100/100 (purity of soda is 100%)

= 1169111.1 mg = 1.169 Kg (take 1 mg = 10^{-6} Kg).

Here, lime required = 0

Example-9 A sample of water on analysis has been found to contain 150 mg/L of $Ca(HCO_3)_2$ and 200 mg/L of $Ca(NO_3)_2$. Calculate the amount of lime required for softening of 15,000 litres of hard water after boiling the water for 20 min. (At. mass: Ca = 40, H =1, C = 12, O =16, N = 14 g/mol)

Solution: Lime required = 0

Example-10 Calculate the amount of Lime and soda needed for the softening of 10 litres of hard water having 146 mg/l of $Mg(HCO_3)_2$.

Solution: We know that $Mg(HCO_3)_2$ consumes 2 moles of lime and no soda.

$Mg(HCO_3)_2$ as $CaCO_3$ eq. = 146 x 100/146 = 100 mg/L or ppm

(i) **Lime reqd.** = 74/100 (2 x $Mg(HCO_3)_2$ as $CaCO_3$ eq.) x Vol. of hard water x (100/% purity)
= (74/100) x 100 mg/L x 10 L x (100/100) = 1480 mg

(ii) **Soda Reqd.** = 0 mg.

Example-11 **Calculate the amount of Lime and soda needed for the softening of 50,000 litres of hard water having $Mg(HCO_3)_2$ = 144 ppm, $Ca(HCO_3)_2$ = 25 ppm, $MgCl_2$ = 95 ppm, $CaCl_2$ = 111 ppm, Fe_2O_3 = 25 ppm, and Na_2SO_4 = 15 ppm. Also find the cost of chemicals for softening. (Given that cost of lime = Rs.10 per Kg and cost of soda = Rs. 100 per Kg)**

Solution:

As Fe_2O_3 and Na_2SO_4 are non-hardness constituents, they do not consume Lime (L) and Soda (S)

Constituents	Strength (ppm or mg/L)	Mol. Mass	Chemical Need	$CaCO_3$ eq. (mg/L)
$Mg(HCO_3)_2$	144	146	2L	144 x (100/146) =98.63
$Ca(HCO_3)_2$	25	162	1L	25 x (100/162) =15.43
$MgCl_2$	95	95	L + S	95 x (100/95) =100
$CaCl_2$	111	111	S	111 x (100/111) =100

**n-factor = 2 for all the salts

Remember that Lime is reqd. by $Mg(HCO_3)_2$, $Ca(HCO_3)_2$, and $MgCl_2$

(i) **Lime reqd.** = 74/100 [(2 x $Mg(HCO_3)_2$ + $Ca(HCO_3)_2$ + $MgCl_2$); all as $CaCO_3$ eq.] x Vol. of hard water x (100/% purity)
= (74/100) x [2 x 98.63 + 15.43 + 100] mg/L x 50,000 L x (100/100)
= 11569530 mg = 11569530 x 10^{-6} Kg = 11.5695 Kg

Soda is reqd. by only $CaCl_2$ and $MgCl_2$

Cost of lime = 11.5695 x 10 = Rs. 115.695

(ii) **Soda reqd.** = 106/100 [($CaCl_2$ + $MgCl_2$); all as $CaCO_3$ eq.] x Vol. of hard water x (100/% purity)
= (106/100) x [100 + 100] mg/L x 50,000 L x (100/100)
= 10600000 mg = 10600000 x 10^{-6} Kg = 10.6 Kg
Cost of soda = 10.6 x 100 = Rs. 1060
Total cost of chemicals for softening of 50,000L of hard water = 115.695 = 1060 = Rs. 1175.695

Example-12 **20,000 L of hard water to be softens by a chemist using a lime-soda softener. The budget allocated for the said purpose is Rs.500. Do you think the allocated amount is sufficient to get the job done? The sample contains $Mg(HCO_3)_2$ = 73 ppm, $Ca(HCO_3)_2$ = 81 ppm, $MgCl_2$ = 95 ppm, $CaSO_4$ = 68 ppm, and Na_2SO_4 = 30 ppm. The purity of lime is 95% and that of soda is 90%. The costs per 1 Kg of lime and soda are Rs. 100 and Rs. 100, respectively**.

Solution: As Na_2SO_4 is a non-hardness constituent, it does not consume Lime (L) and Soda (S)

Constituents	Strength (ppm or mg/L)	Mol. Mass	Chemical Need	$CaCO_3$ eq. (mg/L)
$Mg(HCO_3)_2$	73	146	2L	73 x (100/146) =50
$Ca(HCO_3)_2$	81	162	1L	81 x (100/162) =50
$MgCl_2$	95	95	L + S	95 x (100/95) =100
$CaSO_4$	68	136	S	68 x (100/136) =50

Lime is reqd. by $Mg(HCO_3)_2$, $Ca(HCO_3)_2$, and $MgCl_2$

(i) **Lime reqd.** = 74/100 [(2 x $Mg(HCO_3)_2$ + $Ca(HCO_3)_2$ + $MgCl_2$); all as $CaCO_3$ eq.] x Vol. of hard water x (100/% purity)
= (74/100) x [2 x 50 + 50 + 100] mg/L x 20,000 L x (100/95)
= 3894736.842 mg = 3894736.842 x 10^{-6} Kg = 3.894 Kg
(1 mg = 10^{-6} Kg)

Cost of lime = 3.894 x 100 = Rs. 389.4

Soda is reqd. by only $MgCl_2$ and $CaSO_4$

(i) **Soda reqd.** = 106/100 [($CaSO_4$ + $MgCl_2$); all as $CaCO_3$ eq.] x Vol. of hard water x (100/% purity)
= (106/100) x [50 + 100] mg/L x 50,000 L x (100/90)
= 3533333.333 mg = 3533333.333 x 10^{-6} Kg = 3.533 Kg

Cost of soda = 3.533 x 100 = Rs. 353.3

Now, total cost of chemicals = Rs. 389.4 + Rs. 353.3 = **Rs. 742.7**

No, the allocated amount is not sufficient to get the job done.