Distribution System Corrosion Control for Desalinated Seawater

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Prepared by:

McGuire Environmental Consultants, Inc.

3471 Via Lido
Suite 207
Newport Beach, CA 92663

Introduction

The potable water produced at the seawater desalination plant will be distributed through the existing water distribution system and blended with other existing water sources. The purpose of this paper is to determine the desalination plant water quality and corrosion control measures, which will render the desalinated water compatible with the other existing potable water sources in terms of corrosion effect on the water distribution system. The base for establishing water quality compatibility are year 2001 water quality data for the Municipal Water District of Southern California's Diemer and Skinner Water Filtration Plants and the projected water quality to be produced by the seawater desalination plant.

Product Water Quality Parameters Related to Distribution System Corrosion

The key water quality parameters related to distribution system corrosion are:

- pH
- Alkalinity
- Hardness
- Total Dissolved Solids
- Temperature

pH

The potable water pH is a measure of the concentration of hydrogen ions present in the water. Since the hydrogen ions are one of the major substances that accepts the electrons given up by a metal when it corrodes, pH is a very important factor in corrosion control. Water of low pH is associated with corrosion problems for all metals in the distribution system. At pH values below 5, the water is rendered unstable and both iron and copper corrode rapidly. The water corrosivity decreases with pH increase.

The potable water pH range recommended in the Safe Drinking Water Act is 6.5 to 8.5. The pH of the potable water produced at the Diemer and Skinner plants is 8 to 8.1. The desalinated plant product water will have pH of 8.0 to 8.5, which matches the other water sources. Since the permeate produced by the reverse osmosis (RO) system has a relatively low pH (5 to 5.5), this water will be conditioned with lime, which will allow product water pH increase to the target range of 8.0 to 8.5.

Alkalinity

Alkalinity is a measure of water's ability to neutralize acids. In potable water, alkalinity is mostly composed on carbonates (CO3) and bicarbonates (HCO3). Alkalinity relates to water's ability to form a protective carbonate coating on the distribution system pipes, which diminishes pipe material corrosion rate. However, very high alkalinity may result in excessive calcium precipitation and pipeline scaling, especially if water's calcium concentration is relatively high.

Potable water alkalinity is not limited by the water quality regulations. Water alkalinity of the Diemer and Skinner plants is in a range of 100 to 115 mg/L. After lime addition, the product water from the desalination plant will have alkalinity of 40 mg/L or higher. This alkalinity will

be adequate to provide protective carbonate coating without causing calcium scaling on the pipelines.

Hardness

Hardness is determined as the total concentration of calcium and magnesium ions in the water, reported as calcium carbonate. The degree of hardness is usually determined as shown on Table 1 [1].

Table 1
Degree of Water Hardness

Hardness (as CaCO3), mg/L	Definition
0 - 50	Soft
50 -150	Moderately Hard
150-300	Hard
>300	Very Hard

The potable water hardness is not regulated by the Safe Drinking Water Act. However, hard water usually consumes more soaps and detergents and tends to create deposits on piping and home appliances.

The potable water currently produced at both the Diemer and Skinner plants can be classified as hard and ranges between 219 to 255 mg/l and 232 to 248 mg/L, respectively. The permeate from the RO system will have very little hardness. This hardness will be increased by lime addition. The finished water from the seawater desalination plant will be moderately hard. Hard waters are less corrosive than soft waters if sufficient calcium ions and alkalinity are present to form a protective calcium carbonate lining on the pipe walls. However, high water hardness is not beneficial for corrosion control because it may create excessive carbonate deposits on the pipes. The moderately hard potable water from the desalination plant will have hardness above 50 mg/L, which will be adequate to provide comparable corrosion control effect.

Total Dissolved Solids

Product water total dissolved solids (TDS) concentration is directly related to ion concentration in the water. The higher TDS/ion content results in increased water conductivity, which in turn increases water's ability to conduct a corrosive current, hence enhances corrosivity.

The product water from the seawater desalination plant will have TDS concentration of 350 to 400 mg/L, which is 10 to 20 % lower than that of the water produced at the Diemer and Skinner plants. This lower TDS concentration will have a positive effect on distribution system piping in terms of corrosivity.

Temperature

Temperature effects on corrosion are complex and depend on the water chemistry and type of the pipeline materials. In general, the rate of all chemical reactions, including corrosion increases with increased temperature. However, the rate of increase is impacted by the other water quality factors discussed above and may be negligible for water of given quality.

On the other hand, temperature significantly affects the dissolving of calcium carbonate. Less calcium carbonate dissolves at higher temperatures, which means that calcium carbonate tends to come out of solution (precipitate) and form protective lining more rapidly at higher temperatures [(2)]. The protective coating resulting from the precipitation can reduce corrosion.

The product water temperature of the Diemer and Skinner plants is expected to be several degrees Celsius lower than that of the seawater desalination plant. However, this difference is not anticipated to have a significant effect on distribution system corrosivity.

Corrosivity and Stability Index

As discussed above, the distribution system corrosion is impacted by many water quality parameters with overlapping effect. Currently, a number of indexes are used to quantify the overall water stability and corrosivity. The most commonly applied index is the Langelier Saturation Index.

The Langlier Saturation Index, or LSI (Equation 1), which describes in terms of pH values how close the water quality matrix is to saturation with respect to carbonate solids:

$$LSI = pH - pH_s \qquad (1)$$

where

LSI = Langlier Saturation Index (pH units)
pH = actual pH of system
pH_s = pH of system when saturated with a carbonate solid (typically calcite)

and results in the number of pH units above or below saturation (or the point where the carbonate solid is theoretically predicted to precipitate).

Use of the LSI is premised on observations that slightly positive LSI values result in fewer corrosion problems through the formation of a protective scale that slows down the corrosion process and solidifies existing corrosion scales. The optimal range for the LSI value is between 0 and 0.5, with higher LSI values resulting in excessive scaling, loss of flow and pressure, and operational issues regarding equipment fouling and binding.

A simple method of calculation for the LSI simply involves calcium concentrations, the bicarbonate system pK_a values, and the solubility constant for calcium carbonate (values given are for 25 °C and a TDS of 400 mg/L):

$$pH_s = pK_{a,2} - pK_s + p[Ca^{2+}] + p[HCO_3^-] - \log\gamma_{Ca^{2+}} - \log\gamma_{HCO_3^-} \qquad (2)$$

where

$pK_{a,2}$ =negative log of second pK_a of carbonate system = 10.33
pK_s = negative log of calcite solubility constant = 8.48
$p[Ca^{2+}]$ =negative log of free or uncomplexed molar calcium concentration
$p[HCO_3^-]$ = negative log of molar bicarbonate concentration
γ_{Ca2+} = activity coefficient for calcium
γ_{HCO3-}= activity coefficient for bicarbonate

Standard Methods for the Examination of Water and Wastewater can be consulted to obtain corrections for proper activity coefficients and equilibrium constants as a function of temperature, pH and ionic strength, where a combined value for the activity coefficient correction is given ($5\ pf_m = 5 \times 0.044 = -\log\gamma_{Ca2+} - \log\gamma_{HCO3-}$).

The LSI is widely used index because it allows incorporating most of the key water quality parameters that have impact on distribution system corrosion into one quantitative measure:

- Total Alkalinity
- Calcium Hardness
- TDS
- pH
- Temperature

The average LSI for the Diemer and Skinner Plants is 0.36 and 0.41, respectively. Both indexes are in the optimum range of 0.0 to 0.5. The desalination plant product water will have LSI index in the optimum range, as well.

RO Water Conditioning for Corrosion Control

Permeate from the desalination system will have low alkalinity and pH and will be conditioned by lime and carbon dioxide addition to produce stable and non-corrosive product water. The alkalinity addition that is required for desalinated seawater is the primary process variable that can be used to control corrosion, and will also affect pH values due to the interrelationship between CO_2, alkalinity, and pH. The goal of alkalinity addition is to provide buffering capacity against changes in pH and induce the formation (precipitation) of passivating or stabilizing carbonate and hydroxide scales (most likely calcite or calcium carbonate), without exacerbating other aspects of corrosion.

The finished water will approximate the same pH and chlorine residual concentration as the potable water from the existing other sources (Diemer/Skinner water treatment plants) delivering water to the same distribution system, thereby minimizing the pH-related dissolution and scale release and upsets of the biological community in the system. Potable water from the desalinated plant with a pH value of 8 to 8.5 will also balance the various risks of cement dissolution and lead, copper, and iron corrosion. Finally, the finished water from the desalination plant will

maintain a positive LSI in a range of 0 to 0.5 and continue to provide the benefits of this time-tested practice.

Lime will be delivered on site in a form of dry powder or pellets, stored in silos and used to prepare liquid lime solution. This liquid lime solution will be fed continuously to the plant reverse osmosis (RO) system permeate line and mixed with the RO permeate in a designated contact vessel. Lime solution will be injected into the permeate lines just ahead of the lime contact vessel. The turbulent mixing during upward and downward movement of the water in the vessel chambers will provide complete mixing. The lime contact vessel will be located upstream of the plant on-site storage tank, which will provide an additional lime contact time.

Carbon dioxide will be delivered to the desalination plant in liquid compressed form and distributed as a gas in the on-side product water storage tank via distribution and diffuser system installed on the bottom of the storage tank. Calculations were performed using the RTW Model [3] and using the water quality for RO permeate listed in Table 2.

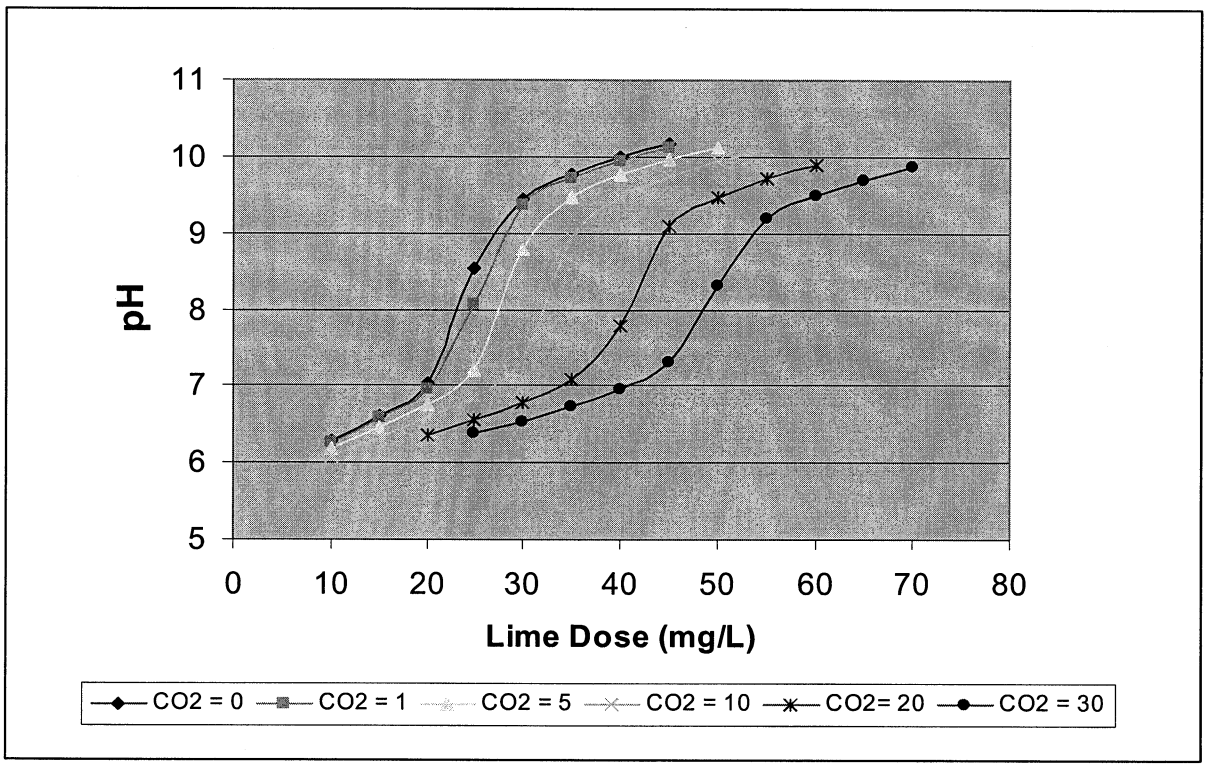

Figure 1. Chemical addition requirements for typical RO product waters. The figure demonstrates that at least 20 – 25 mg/L of lime is required to reach pH 8.0 – 8.5, while adding additional lime to reach alkalinities representative of Southern California surface waters requires the addition of substantial amounts of carbon dioxide.

A LSI close to zero and a pH of 8.5 can be achieved by adding approximately 25 mg/L of lime (Figure 2) without carbon dioxide addition Because lime is a weak base, the addition of more lime to increase alkalinity and the LSI will require the addition of carbon dioxide the maintain target pH values without destroying alkalinity.

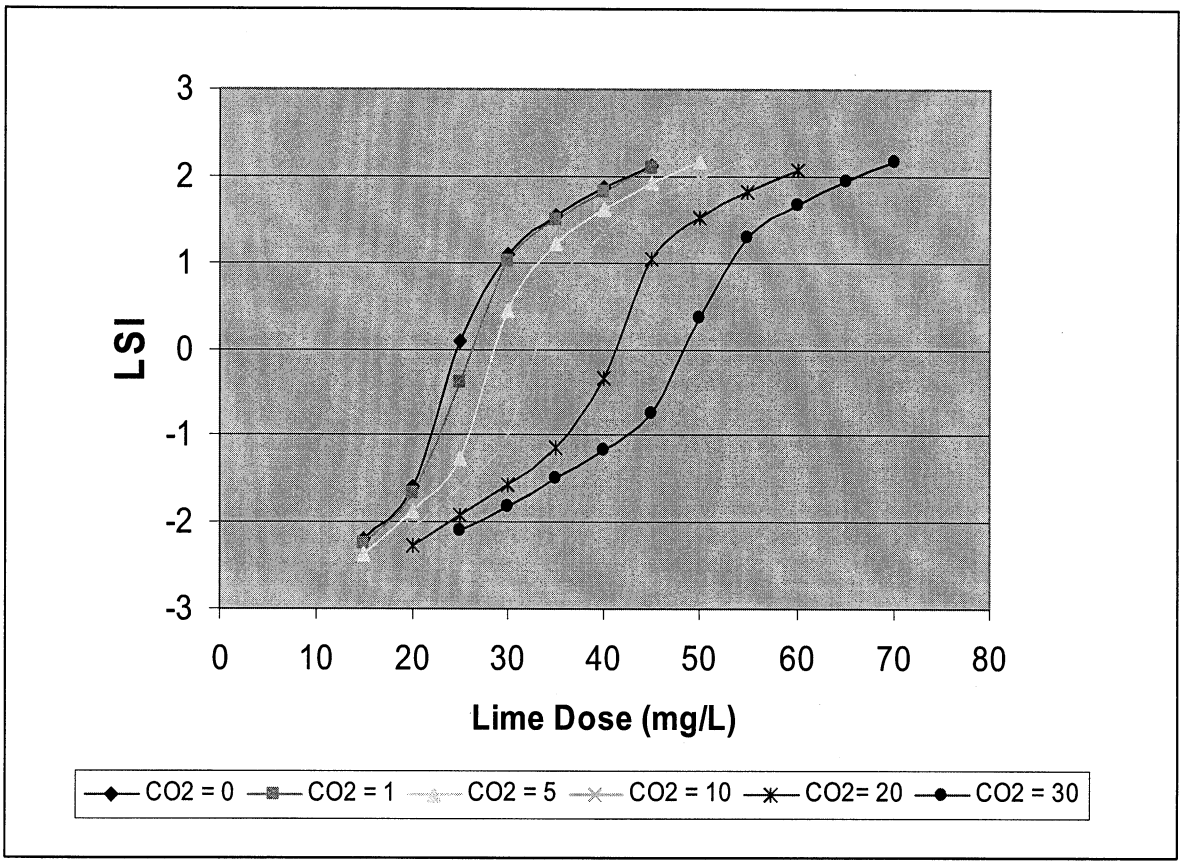

Figure 2. LSI values for a range of lime and carbon dioxide doses. Target LSI values are achieved at nearly the same concentrations of lime addition as target pH values. Both the LSI and pH change very rapidly in the optimum chemical dose range (note the relatively steep slopes of the curves near zero LSI values).

Table 2 shows the key water quality parameters for the Diemer and Skinner Water Filtration Plants and the water quality of the desalination plant at various lime and carbon dioxide dosages. As previously noted, the minimum lime dosage (w/o addition of carbon dioxide) needed to achieve product water of comparable pH and similar LSI is 25 mg/L. At this dosage, the desalination water LSI will be at the lower end of the optimum range (0.11-0.14). The amount of lime and carbon dioxide needed to slightly exceed the water quality of the existing water sources in terms of LSI and reach the upper end of the LSI range of 0.5, is – lime dosage of 50 mg/L and carbon dioxide dosage of 30 mg/L (Table 2). The alkalinity under this maximum dosage is 76 mg/L, which is an indication of moderately hard water.

Based on the results summarized in Table 2, the desalination plant product water conditioning system will be designed to deliver:

- Lime Dosage of 25 to 50 mg/L (avg. of 30 mg/L)
- Carbon Dioxide Dosage of 0 to 30 mg/L (avg. of 6 mg/L)

The desalination plant product water will have:

- pH of 8 to 8.5
- LSI of 0.0 to 0.5
- Alkalinity of 40 mg/L or higher

Parameter or Index	units	Diemer Effluent	Skinner Effluent	RO Permeate			
Lime Addition (@ 27 °C)	mg/L	none	none	none	24.9	30	50
Lime Addition (@ 20 °C)		none	none	none	27.2	32.3	52.3
CO_2 Addition	mg/L	none	none	none	0	6	29.5
ALK	mg/L as $CaCO_3$	113	116	5	39	56	73
HCO_3	mg/L	138	141	6	48	56	89
HCO_3	mM	2.26	2.31	0.10	0.79	0.92	1.46
Cl	mg/L	79	81	180	180	180	180
Cl	mM	2.23	2.28	5.07	5.07	5.07	5.07
SO_4	mg/L	177	176	5	5	5	5
SO_4	mM	1.84	1.83	0.05	0.05	0.05	0.05
Ca	mg/L	56	58	5	18	21.00	32.00
Ca	mM	1.40	1.45	0.13	0.45	0.53	0.80
pH		8.02	8.06	5.5	8.5	8.5	8.5
pHs		7.57	7.54	9.98	8.52	8.39	8.00
LSI (calculated)		0.45	0.52	-4.48	-0.02	0.11	0.50
LSI (RTW)	@ 27 °C	-	-	-4.43	0.02	0.14	0.50
LSI (RTW)	@ 20 °C	0.36	0.41	-4.53	0.01	0.12	0.46

Table 2. Water quality and Langlier Saturation Index values for finished water from the MWDSC Diemer WTP, desalinated seawater using reverse osmosis, and several permutations of stabilized RO permeate. Positive LSI values and target pH values are achieved for RO product water with lime doses greater than approximately 25 mg/L.

The finished product water from the desalinated plant will have comparable and compatible quality to the water quality of the other sources of water delivered to the same distribution system.

The effect of temperature on the CO_2/alkalinity/pH system and the increased solubility of carbonates at lower temperatures is illustrated by evaluating the lime addition requirements at 20 °C and 27 °C, where slightly more lime is required at the lower temperature to achieve similar LSI values. The results presented in Table 2 indicate that the effect of the slightly higher temperature of the desalinated water on the corrosivity is readily compensated with a minimal increase in lime and carbon dioxide dosages and is accounted in the distribution system corrosion control assessment.

Conclusions

The product water from the seawater desalination plant will be suitable for delivery through the existing water distribution system and will be comparable and compatible to the other water sources currently delivering water to the same system. Prior to delivery to the water distribution system the desalinated water will be conditioned using lime and carbon dioxide to achieve the following corrosion control driven water quality goals:

- PH of 8 to 8.5
- LSI of 0.0 to 0.5
- Alkalinity of 40 mg/L or higher

These water quality goals will be achieved by the addition of the following chemicals:

- Lime at dosage of 25 to 50 mg/L (avg. of 30 mg/L)
- Carbon dioxide at dosage of 0 to 30 mg/L (avg. of 6 mg/L)

The proposed on-site mixing and contact facilities will provide adequate conditioning of the finished product water prior to introduction to the distribution system.

References:

1. AWWA Research Foundation, Water Quality Impacts from Blending Multiple Water Types, 2001.
2. AWWA Corrosion Control for Operators, 1986.
3. The Rothberg, Tamburini, and Windsor Model for Corrosion Control and Process Chemistry, Version 2.0, AWWA, 1994