Designing Ion Exchange Systems

Part I: Reading a Water Analysis

By C.F. Michaud

One's success in any profession draws heavily on his or her understanding of the basic rules and technologies of their industry.

A water testing lab will report the ionic content of water as milligrams of ion per liter of water. This is abbreviated as mg/l. Since there are 1000 mg per gram and one liter of water weighs 1000 grams, 1 mg/l is equal to 1 part per million (ppm). Be certain that you do not misinterpret the greek letter μ (mu) as in "μg" as an "m" in "mg." μ means micro which in one millionth. Therefore, 1μg/l is one part per billion (ppb), not 1 ppm. Misreading an analysis can easily lead to designing a system 1000 times too big or too small.

Since a reverse osmosis (RO) unit rejects a percentage of each ion present, it is not necessary to convert the water analysis to calculate the ionic content of the permeate stream (product stream). The result is simply a new water analysis in mg/l or ppm. However, if ion exchange is involved, it is necessary to convert the water analysis to ppm as calcium carbonate ($CaCO_3$) to properly size the system.

Although 1 mg/l of calcium is equal in weight to 1 mg/l of sodium or hydrogen, it is not equal in terms of the number of ions it contains. Years ago, a gentleman by the name of Avagadro discovered that all elements exhibit an ion content in reverse proportion to their molecular weight (M.W.). To put it another way, for a given number of ions, the weight of each element is in direct proportion to its M.W. Since calcium has a M.W. of 40 and sodium is 23, the ratio of sodium to calcium ions at equal ppm levels is 40/23 = 1.74. In other words, one gram of sodium contains 74% more ions than one gram of calcium. One gram of hydrogen (M.W.=1) has 40 times more ions than calcium and 23 times as many as sodium.

Calcium, however, is written in its ionic form as Ca^{++}. It is, therefore, considered divalent. Aluminum (Al^{+++}) is trivalent and sodium (Na^{+}) and hydrogen (H^{+}) are monovalent. Therefore, an ion exchange resin would have to give up two ions of Na^{+} for each ion of Ca^{++} picked up in a softener. A demineralizer would give up one H^{+} for each Na^{+} and two for each Ca^{++}. Since Ca^{++} can occupy the sites occupied by two Na^{+} ions, we give Ca^{++} an equivalent weight of 20 (40/2 = 20). Therefore, the weight ratio of sodium needed to replace calcium in a softener is 23/20 = 1.15. This means that raw water containing 100 ppm of calcium ion would contain 115 ppm of sodium ion after softening.

Toss in magnesium (M.W. = 12) and iron (M.W. = 56) and one soon sees that to attempt to equate the resulting ionic composition of water treated by ion exchange would become an accounting nightmare. Parts per million of different ions are not additive or subtractive. For instance:

Table I

Cations			Anions		
Ion	**Symbol**	**Factor**	**Ion**	**Symbol**	**Factor**
Aluminum	Al^{+++}	5.56	Bicarbonate	HCO_3^{-}	0.82
Calcium	Ca^{++}	2.50	Carbonate	CO_3^{--}	0.83
Copper	Cu^{++}	1.57	Chloride	Cl^{-}	1.41
Hydrogen	H^{+}	50.00	Hydroxide	OH^{-}	2.94
Iron	Fe^{++}	1.79	Nitrate	NO_3^{-}	0.81
Magnesium	Mg^{++}	4.10	Silicate	H_3SiO_4	0.83
Manganese	Mn^{++}	1.82	Sulfate	SO_4^{--}	1.04
Potassium	K^{+}	1.28	Sulfite	SO_3^{--}	1.25
Sodium	Na^{+}	2.18	Sulfide	S^{--}	3.13

A resin's rating is dependent upon water composition, flow rate and desired quality as well as amount and type of regenerant used. It will, therefore, differ for each system.

In part II and III of this series, a handy monograph will be provided, and we will go into detail on resin systems ratings and hydraulic design. We'll also take a look at resin selection for various end use requirements. In addition, some insight will be given to designing a DI system to give a neutral regenerant waste effluent. ❑

About the Author

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Table II

Ion	ppm	Factor	ppm as $CaCO_3$
Ca^{++}	63.2	(2.50)	158
Mg^{++}	13.4	(4.10)	55
K^{+}	2.0	(1.28)	2.5
Na^{+}	100.9	(2.18)	220
Fe^{++}	.6	(1.79)	1.0
Total Cation	180.1 mg/l		437 ppm / 17.1 = 25.6 grains
HCO_3^{-}	241.5	(0.82)	198
SO_4^{--}	59.6	(1.04)	62
NO_3^{-}	8.6	(0.81)	7
Cl^{-}	120.6	(1.41)	170
Subtotal Anion	430.30 mg/l		437
Silica	42.2	(0.83)	35
Total Anion	472.5 mg/l		472 ppm / 17.1 = 27.6 grains
TDS	652.6 mg/l		