Water Treatment Specification Manual

Frank Rosa

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Preface

The objective of this book is to provide consulting firms, professional engineers, mechanical contractors and direct clients with the means for solving water treatment problems, while at the same time using minimal chemistry to illustrate its points.

Up till now, design engineers wanting sets of specs and drawings for projects requiring water treatment had to utilize sets already existing, altering them to meet the new conditions. The engineers may have also contacted water treatment firms to supply specifications for the proposed projects, which guidelines in all probability were very specific and tended to limit the engineers to the use of particular programs and at times unique chemical feed equipment unavailable elsewhere. But with the help of this book design engineers can now specify nonproprietary water treatment programs for clients and feel confident, if the specs are met, that the clients will be pleased. The drawings used to illustrate the manual, based on extensive field experience, try to eliminate those water treatment call-back problems that can sour engineer-client relationships.

For mechanical contractors, this work will help trace water treatment problems on troublesome jobs — that is, will help answer questions such as "Why are the heat pump coils plugging?" or "Why is a particular water treatment feed system not suitable for this project?"

Plant managers or physical plant directors for educational facilities can use this work to solve boiler flooding problems, upgrade chemical feed equipment, or publish a set of specs for comparative bidding on water treatment projects for the facility.

This manual can be effectively used in schools that teach HVAC courses since it is devoid of chemical terms which tend to confuse the HVAC and mechanical engineering student. Students in the HVAC field understand plumbing, pressures, thermodynamics, and associated HVAC terms. However, it is unlikely they will know the differences between phosphonic and phosphoric acids or will even care to know them. The HVAC student is interested in why a problem occurs, *not* in chemical terms but in terms that can be related to. For example, on finding a condenser loaded with lime, will HVAC technicians want to hear that the unit scaled up because the solubility limits of the carbonates of calcium and magnesium were exceeded, and this, compounded by high alkalinity, caused the carbonate salts to layer on the heat exchange surfaces of the condenser? Or will they want to know that the unit plugged because of insufficient bleed-off?

The reader will note that this work is devoid of references to specific products manufactured by water treatment firms. It was felt that their inclusion would take away rather than contribute to the value of the book. The engineers consulted during its writing felt there were enough puff works available without adding another.

The author is indebted to the following for assistance and inspiration:

Mr. Michael H. Johnson, plumbing designer for a major northeastern architectural firm, for his help in making the author's drawings suitable for publication.

The late Messrs. T. T. Peck, C. F. Schweizer, and W. J. Covney for the fine examples they set.

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To Master Efrain J. Rosa for spotting numbering errors in the drawings.

Frank Rosa

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ONE

Water Treatment Justification

This chapter provides guidelines that will enable the reader to choose a heat rejector based on sound principles. When does one opt for an air-cooled condenser vs. a water-cooled unit? Which chemical feed system is best? Although many factors must be taken into consideration in choosing a particular heat rejector, the reader or design engineer should not overlook a prime parameter — the quality of the water supply! Let us analyze the water quality for each system under consideration and strive to use the information gleaned here in the decision-making process.

OPEN RECIRCULATING WATER SYSTEMS

The primary factor in choosing a water-cooled vs. an air-cooled condenser should be the quality of the water supply. However, design engineers are often confused by the term "quality" as it is applied to recirculating water systems. As used here, this term describes the ramifications of using the water for a particular purpose. For example, a water supply may be of excellent quality for drinking purposes but be of very poor quality for process use. In open recirculating water systems, one is concerned with those parameters which will impede heat transfer and thus affect heat-rejecting efficiency. The parameters of concern are *hardness*, which must not exceed 1200 parts per million (ppm) as calcium carbonate; *alkalinity*, which must not exceed 500 ppm as calcium carbonate; and *silica*, which must not exceed 150 ppm. These are the maximum parameter limits, and to exceed them invites problems. This is not to say that one will not experience problems as long as one does not exceed the maximums. Rather, as a primary analytical tool, one should take these parameters into consideration. Since the author does not intend to burden the reader with many chemical terms or formulas, the reader is urged to review other works on the subject.[1,8,9] However, the author does not feel that knowledge of chemistry is essential to the design engineer, just as a knowledge of mechanical engineering is not needed to operate an automobile. One need only understand that certain parameters are not to be exceeded to design successful water treatment facilities.

Let us now analyze some water supplies and examine their use in open recirculating water systems.

CASE 16300

Parameter	Values	
	City	Softened
pH	7.7	7.8
Alkalinity, ppm as $CaCO_3$	215.0	225.0
Total hardness, ppm as $CaCO_3$	705.0	0.0
Silica, ppm as SiO_2	7.0	7.0
Chloride, ppm as NaCl	18.0	78.0*
Total dissolved solids (TDS) by conductance, ppm	607.0	819.0

* The apparent discrepancy in the value of salt, sodium chloride (NaCl), in the city supply is not an analytical error. The author brought this to the attention of the water softener mechanic and was informed that since the softener was delivering soft water, it was functioning satisfactorily. Rebuilding the valves had no effect on the results, nor was the seller of any help. The author acknowledges that something was wrong, but the owners expressed no concern.

It is evident that the limiting factor in the use of the city water is the hardness, or 1200/705 = 1.7 cycles. Should the concentration of the water in the recirculating system become more than 1.7 times that of city water, then scale, or lime, on the heat-exchanger surfaces will be a certainty! Alkalinity (500/215 = 2.3), though high, and silica (150/7 = 21.4) do not enter as factors unless their maximums are exceeded.

Let us now consider the ramifications of operating a centrifugal machine of 100-ton cooling capacity with a minimal chemical feed and bleed-off system; see Fig. 1. To achieve a scale-free operation for the condenser, we must provide a bleed-off rate in excess of the maximum system load (see Fig. 42). Thus, a continuous bleed-off rate of 4.5 gallons per minute (gal/min) must be maintained. We cannot assume a bleed-off rate of 2.2 gal/min, a 50 percent load, adequate with this supply; we must provide for bleed at the maximum anticipated load! At a continuous bleed of 4.5 gal/min, we drain 6480 gal of water as bleed and evaporate, at an actual 100 percent load, 4320 gal for a total daily consumption of 10,800 gal of water!

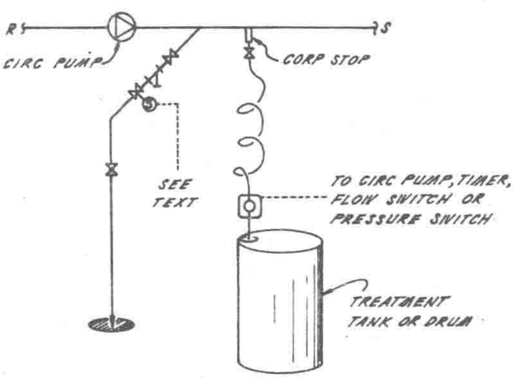

FIGURE 1 Simple chemical feed system.

If soft water were used as make-up water and provisions were made for alkalinity reduction and acid feed, one could reduce water consumption by operating at higher cycles, or so one could be led to believe. Referring to Langelier's saturation index (often abbreviated as LSI, or simply SI) in Fig. 2, let us look at two approaches — 10 cycles with no bleed-off and 7 cycles with a bleed-off of 0.5 gal/min.

10 Cycles of Concentration

Let us add to the known facts that we have a mechanical draft cooling tower with 0.2 percent windage drift and a recirculation rate of 300 gal/min for the 100-ton system. At 10 cycles we would require a bleed-off rate of 0.33 gal/min to maintain the stated concentration of solids in the system. However, since the cooling tower has a built-in bleed-off rate of 0.6 gal/min (the 0.2 percent windage drift), bleed is not required, or so our calculations would lead us to believe. However, let us play it safe and maintain a 0.33-gal/min bleed rate and look at the tower water at 10 cycles:

pH	Being kept at 7.2 to 7.4
Alkalinity	Being kept at 40 to 45 ppm as $CaCO_3$
Hardness	Softener keeping it at 1.0 ppm so we concentrate to 10.0 ppm
Silica	Climbs to 70 ppm
Chlorides	Climbs to 180 or 780 ppm*
TDS	Climbs to 8190 ppm
Sulfates as Na_2SO_4	3122 ppm due to acid use
Langelier's saturation index	$-1.60 I_s$ at 7.4 pH at 140°F (60°C) skin temperature

From the above, clearly at 10 cycles we would wind up with a very corrosive water, $-1.60 I_s$, containing sufficient chlorides and sulfates to challenge any corrosion inhibitor. Furthermore, the use of bio-degradable organic corrosion-inhibitor systems along with the sulfates could lead to problems with bacterial slime or the growth of acid-producing bacterial species. We could hope to control them with algaecides, but would soon be plagued with a strain resistant to the conventional attack and then chlorine, at 50 to 100 ppm, would have to be used.

7 Cycles of Concentration

At this 7 cycles of concentration we would require a bleed-off rate of 0.5 gal/min to maintain conditions as stated. The water, at this level, will appear as follows:

pH	Being kept at 7.2 to 7.4
Alkalinity	Being kept at 40 to 45 ppm as $CaCO_3$

* Theoretically, the chlorides should be 180 ppm, but they will be 780 ppm as long as the water softener maintains a 78-ppm constant feed.

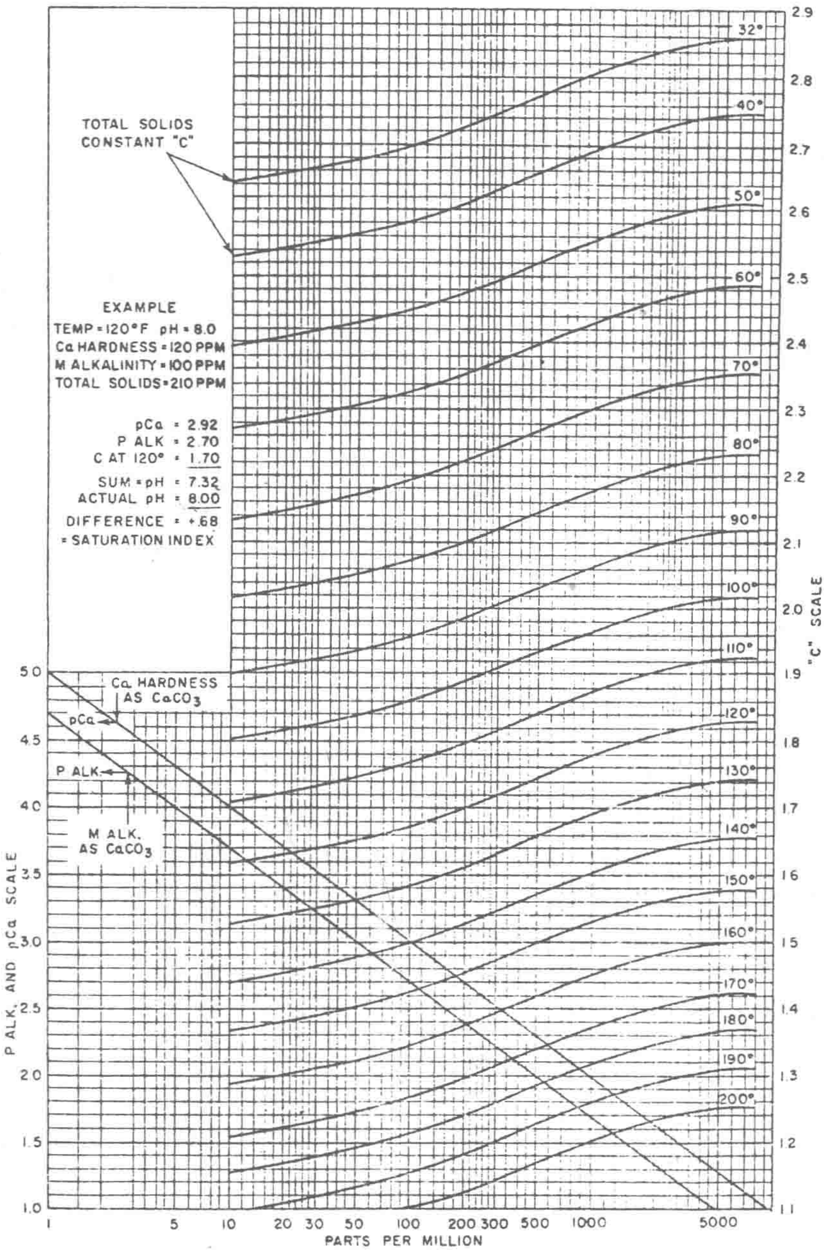

FIGURE 2 Langelier's saturation index I_s. (From Sheppard T. Powell, *Water Conditioning for Industry*, McGraw-Hill Book Company, New York, 1954. Used courtesy McGraw-Hill Book Company.)

Hardness	Concentrates to 7.0 ppm
Silica	Climbs to 49 ppm
Chlorides	126 or 546 ppm as NaCl
TDS	5733 ppm
Sulfates	2172 ppm as Na_2SO_4
LSI	$-1.31 I_s$ at 7.4 pH at 140°F (60°C) skin temperature

Even at 7 cycles, clearly there is not too much hope for using this supply as the cooling tower feed. The difference between 10 and 7 cycles is not significant enough to even consider using a water softener. Even as a stop-gap measure, using a water softener would be throwing good money after bad. We would require a softener with a capacity of 200,000 grains per day (gr/day), which would consume about 60 pounds (lb) of salt every time it went into regeneration!

What, then, are the alternatives with this supply? On a contemplated job, the choice should be easy—specify an air-cooled condenser! For an existing job, consider going to a once-through water-cooled system if the switch to an air-cooled condenser is too expensive. With a once-through cooling system, we could consider a threshold-type chemical feed program with, perhaps, a little acid as insurance against scale formation. Figure 3 shows a suggested installation similar to one the author designed for a plant utilizing water on a once-through basis. The baffled mixing tank is constructed in the field out of 12-inch (in) pipe. Note that this is not an installation for a modulated system. When water is required for cooling purposes it should flow at full pipe capacity, and should cease flowing when water for cooling is no longer required.

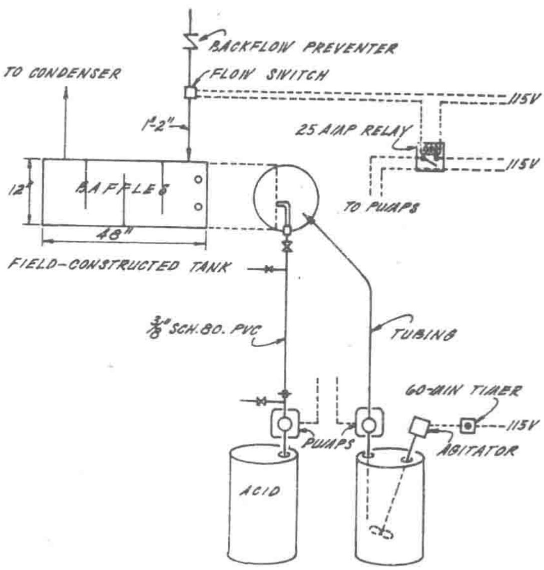

FIGURE 3 Chemical feed for once-through cooling water.

So much for the impossible situation. Now let us consider an acceptable water supply.

CASE 28585

Parameter	Values City	Values Softened
pH	7.0	7.0
Alkalinity, ppm as $CaCO_3$	90.0	95.0
Total hardness, ppm as $CaCO_3$	125.0	0.0
Silica, ppm as SiO_2	3.0	3.0
Chlorides, ppm as NaCl	17.0	17.0
TDS by conductance, ppm	185.0	132.0

Here the limiting factor is the alkalinity (500/90 = 5.6 cycles) with hardness close behind (1200/125 = 9.6) and silica not even a factor. This supply is satisfactory for an open recirculating water system, but it does pose somewhat of an equipment selection problem for the design engineer at the planning stage. Even though this supply is satisfactory, it will pose a problem because of the alkalinity. Although operation at 5.6 cycles appears to be indicated without acid, prudence dictates otherwise, for a 4.0-cycle maximum without acid would provide a small safety margin. With acid use we could reduce water consumption and operate at 7 cycles with little fear of scale formation.

Let us consider the following, which should assist in the choice of feeding equipment. Use $1 per pound for the scale and corrosion inhibitor, which will be fed at 100 ppm, and $0.08 per pound for 60° Baumé sulfuric acid. The tonnage will be the same as previously — 100-ton centrifugal machine at 100 percent load at 24 h/day at 182 days:

Parameter		
Cycles	4.0	7.0
Bleed-off, gal/min	1.00	0.50
Total bleed, gal/day	1440	724
Treatment (scale/corrosion inhibitor), lb	1.2	0.6
Sulfuric acid, lb	0	2.6
Daily cost	$1.20	$0.81
×182 days	$218.40	$147.42
+Water at $0.90 per 1000 gal	$236.04	$118.59
Total	$454.44	$266.01

As can be seen, there is a slight benefit in the use of acid for alkalinity control — a 48 percent savings in treatment cost and a reduction in water use of 716 gal/day. Is it cost-effective to sell the client on an acid feed system, given the above figures? The author would be hard-pressed to do so, considering the added cost of the acid feed pump and tank, about $600. However, as insurance against scale formation [a layer of scale the thickness of a dollar bill (0.060 in) increases energy consumption by 53 percent[10]], the use of acid is advised with this supply. The following should help to clarify the point:

100-ton centrifugal machine × 1.0 kW/ton × 24 h
× 182 days × $0.04 per kWh = $17,472.00
Scale layer of 0.06 in = $26,732.00
Net waste = $ 9,260.00

The above is not a complete case history. It is only meant to show that other factors need to be taken into consideration when you attempt to justify specific chemical feed equipment. On the surface, case 28585 does not show a definite need for acid. But as insurance, the added one-time cost is insignificant compared with the potential added energy costs resulting from scale formation on the heat exchanger.

The following case involves such an excellent supply that it can almost be used without bleed-off.

CASE 47348

Parameter	*Value*	*Cycles*
pH	7.0	
Alkalinity, ppm as $CaCO_3$	30.0	500/30 = 16.7
Total hardness, ppm as $CaCO_3$	42.0	1200/42 = 28.6
Silica, ppm as SiO_2	2.7	150/2.7 = 55.6
Chlorides, ppm as NaCl	2.9	
TDS (by conductance), ppm	55.0	

This is an excellent supply for an open recirculating water system. A calculation of the limiting factors reveals that we can operate a spray pond or an atmospheric tower with little, if any, bleed-off at 15 cycles. The following tabulation shows the requirements for each type of heat rejector:

100-ton Refrigeration at 100 Percent Load

	Heat rejector			
	Spray pond	*Atmospheric tower*	*Mechanical draft tower*	*Evaporative condenser*
% Windage drift	1.0	0.3	0.1	0.05
Windage drift, gal/min	1.0	0.3	0.1	0.05
Bleed-off,* 15 cycles	0.2	0.2	0.2	0.2
25 cycles	0.13	0.13	0.13	0.13

* The bleed-off, calculated from $B = E/C - 1$, where C = cycles and E = evaporation, is taken as 3 percent of tonnage in gallons per minute. The use of $E_{gal/min}$ = tonnage × heat-rejection factor × 24/(1050 Btu/lb) will provide a much more accurate figure.

The mechanical draft tower and evaporative condenser, owing to their minimal windage drift, would require additional water loss, bleed-off, to maintain 15 cycles. With a little acid to neutralize alkalinity, we could conceivably operate at 25 cycles. At this range the only heat rejector that would require bleed-off would be the evaporative condenser, since its windage drift is only 0.05 gal/min.

How important is this ability to read an analysis? Let us take the following case and analyze our options:

Known: A 3000-ton refrigeration load with a mechanical draft tower operating a 100 percent load at 24 h/day. Use 0.03 gal/(min·ton) as an evaporation factor.

Limit: The authorities will not allow more than 1000 gal/day to be dumped from the system.

Options:

	Cycles 10	15	25
Wind drift, gal/min	3.0	3.0	3.0
Bleed-off, gal/min	10.0	6.43	3.75
Net loss, gal/min	7.0	3.43	0.75
Net loss, gal/day	10,080	4939	1080
Cost/day*			
Scale/corrosion inhibitor	12.00	8.00	4.75
Acid	0	0	3.17

* Inhibitor is fed at 100 ppm at $1.00 per pound with acid at $0.08 per pound.

A casual inspection of the water analysis, case 47348, would lead us to believe that acid is not required. However, when confronted with the 1000-gal/day maximum waste limitation, do we inform the client that the project is not feasible? An in-depth analysis would reveal that by going to 25 cycles and using an easily maintained sand filtration system, a water-meter-activated chemical and acid feed system with a tower capable of a slightly higher windage drift, we could satisfy the limiting criteria.

So far we have covered an impossible supply, an acceptable supply, and an excellent supply, all of which had one thing in common—*consistency!* Let us now examine and address the problem of the variable supply, the scourge of water treatment firms and thorn in the side of design engineers.

Figure 4 lists analytical results of a central New York municipal water supply covering the 1981 to 1983 air conditioning season. How can one propose to treat this water in an effective manner if one is not aware of the nature of the supply? If one were to accept the results of a springtime analysis as representative of the supply, for example, one dated April 20, 1982 one would be hard-pressed to explain to the operators why the heat

FIGURE 4 Analytical results of domestic water, city of Ithaca, NY, 1981, 1982, 1983

Date 1981	*5/11*	*5/18*	*5/26*	*6/1*	*6/9*	*6/15*	*6/16*	*6/22*	*6/29*	*7/6*	*7/13*	*8/17*
pH	7.5	7.5	7.6	7.3	7.2	7.5	7.4	7.1	7.4	7.4	7.0	7.2
M alkalinity, ppm as $CaCO_3$	75	85	80	90	85	90	105	100	115	125	100	110
Hardness, ppm as $CaCO_3$	98	104	104	114	112	114	128	120	140	136	124	130
Silica, ppm as SiO_2	4.0	4.0	3.2	4.0	3.4	3.0	5.0	4.4	6.0	6.0	5.3	7.0
Sodium chloride, ppm	41	35	35	35	29	32	38	35	52	46	35	41
TDS by meter, ppm	154	154	159	121	148	150	149	154	174	180	167	169

Date 1982	*4/20*	*5/7*	*5/13*	*5/14*	*5/19*	*5/24*	*6/2*	*9/22*	*9/28*	*10/5*	*10/13*
pH	7.4	7.4	7.7	7.3	7.4	7.2	7.6	7.4	7.6	7.6	(6.8)
M alkalinity, ppm as $CaCO_3$	60	95	100	80	95	110	115	130	140	130	135
Hardness, ppm as $CaCO_3$	90	102	120	112	130	142	142	170	152	184	188
Silica, ppm as SiO_2	5.0	3.8	5.0	. . .	4.2	(25)	4.0	5.0	5.0	5.0	4.0
Sodium chloride, ppm	35	35	29	41	35	41	35	47	41	35	41
TDS by meter, ppm	113	139	173	132	145	187	196	197	203	185	202

Date 1983	*5/2*	*5/9*	*5/20*	*5/30*	*6/10*	*6/21*	*6/30*	*7/6*	*7/11*	*7/29*	*8/12*
pH	(8.4)	(8.3)	7.4	7.1	7.4	7.7	7.8	7.6	7.8	7.5	7.2
M alkalinity, ppm as $CaCO_3$	55	70	70	90	105	110	110	115	115	125	125
Hardness, ppm as $CaCO_3$	70	100	120	108	275	144	130	140	135	154	148
Silica, ppm as SiO_2	4.0	(40.0)	14.	4.1	3.1	2.0	4.0	5.0	4.6	5.0	4.9
Sodium chloride, ppm	17	23	23	35	29	41	29	41	41	26	47
TDS by meter, ppm	103	124	134	167	162	164	178	197	179	191	185

NOTE: Figures in parentheses indicate possible analytical error. All figures are for the city of Ithaca, NY.

rejector or exchanger was loaded with lime at season's end. If one had based one's recommendations on a summer analysis, say, one dated August 17, 1981, and supplied an acid-based treatment, then the pH would have taken a nose dive during the spring months. Figure 74 is a graphical representation of the alkalinity during the period of observation, and it illustrates the difficulties involved in setting up a proper water treatment program. Thus the reason for stressing that when a set of water treatment specifications is put together, the onus of responsibility should fall on the water treatment firm. The hardness was not graphed because it does not have as significant an impact as does the change in alkalinity.

How would we attack the problem of a variable water supply? First, and foremost, we obtain a history of the water. Hopefully the local water authorities can supply it; if not, then a few calls to others using the supply can produce analyses provided by their water treatment firms. For this particular supply (Fig. 4), the author would insist on nothing less than a water-meter-activated chemical feed system, a pH controller/recorder for acid feed, and the maintenance of the concentration at 6 cycles, not higher! With small systems under 100 tons, to operate at higher than 3.0 cycles with a simple chemical feed/bleed system (Fig. 1) is to risk scale formation and an inefficient operation.

At what tonnage does one insist on a pH controller? The design engineer must make this decision based on payback, cost of treatment chemicals, and cost and availability of the water supply. Figure 5 provides some guideline data. In each case, the difference between using acid and not using acid is 68 percent. However, with a cost factor of $1000 for an acid pump and a pH controller, the payback is 6 years for the 200-ton unit and 4 years for the 300-ton unit. The reader should, at this time, study the contents of pages 6 and 7 as they relate to costs vs. scale, for the numbers can be misleading. To decide, based on a 5-year payback, not to use acid could be a mistake. Once a unit develops scale, it can cost anywhere between $600 and $1000 to remove. This does not take into consideration three factors:

1. Increased energy costs
2. Damage to fan or air-moving components of system[11]
3. Stripping of the galvanizing if an improper acid is used for descaling a galvanized tower or evaporative condenser

There are many facets to water treatment for open recirculating water systems. It involves more than a couple of drums of chemical, more than feeding equipment, more than a choice of water treatment firm. And it is folly to concentrate on one aspect of the system and overlook the impact of the whole.