Benefits of Soft Water Makeup for Cooling Tower Operation

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ABSTRACT: Soft water is generally considered unacceptable for use as cooling tower makeup. This study indicates, however, than in many applications, soft water is a better source of cooling tower makeup than untreated, hard water. The use of soft water allows the tower to run at higher cycles of concentration without the need for supplemental acid or scale inhibitor additives. A higher cycle of concentration offers the advantage of reducing the makeup water requirements and minimizing wastewater discharge. The higher alkalinity and pH environment produced by the soft water reduces the corrosion of system metals and helps limit the growth of microorganisms commonly found in cooling water systems including Legionella, the causative agent for Legionnaire's disease. This paper documents and defines the specific applications where soft water makeup offers distinct advantages over the use of untreated, hard water.

INTRODUCTION

The conventional wisdom among cooling tower operating engineers and water treatment service providers is that hard water is best for use as tower makeup because it's "less corrosive" than soft water.

Experience working with cooling towers operating on soft water has shown that in many applications soft water is a better source of cooling tower makeup than untreated, hard water. Some of the benefits of using soft water for cooling tower makeup include:

- Eliminates mineral scale deposits on heat transfer services
- Passivates and reduces corrosion on steel and other metals
- Limits the growth of bacteria
- Conserves water
- Reduces chemical consumption

WHAT IS SOFT WATER?

The options for cooling tower makeup sources include plant wells, municipal supplies, recycled process, and, increasingly, treated municipal wastewater. These water supplies vary in the nature and concentration of dissolved and suspended impurities. This includes mineral salts of calcium and magnesium. The combined concentration of calcium and magnesium is referred to as total hardness. By far, it's the calcium hardness that is primarily responsible for scale deposits in water-cooled heat transfer equipment.

Water softening is employed to achieve partial or complete removal of calcium and magnesium hardness. This can be accomplished by many classical methods including lime softening, which removes a percentage of the hardness or by ion exchange, which reduces the hardness to zero.

Other softening processes remove essentially all dissolved solids resulting in water that is of demineralized or deionized quality. While this softens the water by removing the calcium and magnesium hardness, it also dealkalizes the water by removing all carbonate and bicarbonate alkalinity. These water treatment methods include ion exchange demineralization, reverse osmosis and distillation (such as steam condensate). These sources of high-purity water are frequently blended with raw, hard water to produce a tower makeup of any desired quality by adjusting the percentage of each component in the blend.

For the purposes of this discussion, we will examine the benefits of using softened cooling tower makeup produced by a traditional ion exchange softener. Although other softening options are available, this method is most common in power plant operation particularly if excess soft water is available from the boiler pretreatment system or plant process.

SOFT WATER MAKEUP ELIMINATES MINERAL SCALE DEPOSITS

Calcium and magnesium salts are the primary cause of mineral scale deposits on heat transfer surfaces. Calcium reacts with carbonate and bicarbonate alkalinity to form calcium carbonate ($CaCO_3$) scale. Calcium may also react to form calcium phosphate and calcium sulfate deposits. This typically occurs at the point of highest heat transfer such as in a mechanical chiller condenser or process heat exchanger. Calcium carbonate can also form in the bulk cooling water as it flows through the tower. This off-white sludge tends to accumulate in the tower basin and on the tower fill, but can also foul heat transfer equipment.

Calcium hardness, total alkalinity, pH and temperature determine the solubility of calcium carbonate in cooling water service. Traditional cooling water treatment programs control these variables by adjusting the tower bleed to limit the concentration ratio of these mineral salts to below the solubility of calcium carbonate. The concentration ratio is commonly called the cycles of concentration and is determined by calculating the ratio of impurity in the cooling water to that in the makeup. This can be easily estimated by determining the ratio of the cooling water specific conductance (micromhos/cm) to the makeup water specific conductance. Alternatively, cycles are defined by the ratio of makeup water volume to bleed volume.

Various indices, such as the Langelier (LSI) and Ryznar (RSI), are used to estimate the solubility limit of calcium carbonate. With the Langelier Index (LSI), the $pH_{solubility}$ is calculated from the calcium hardness, total alkalinity, total dissolved solids, and temperature. This value is subtracted from the actual cooling water pH (pH_{actual}) to determine the LSI. The Ryznar method utilizes the same variables to determine the $pH_{solubility}$, but the calculation for RSI is $(2*pH_{solubility}) - pH_{actual}$. For traditional water treatment programs, the cooling tower concentration ratio is controlled by the tower bleed to limit the LSI to a maximum of +2.5, which corresponds to an RSI value of 4.0.

As a general rule of thumb, the calcium hardness is maintained within the range of 350 to 400 ppm as calcium carbonate. For a high hardness makeup supply containing 90 to 100 ppm calcium, for example, the tower is limited to operating within a range of 3 to 4 cycles of concentration. Further increases in cycles require pH adjustment by acid neutralization of makeup water alkalinity.

Softening the tower makeup to remove calcium hardness eliminates the solubility limitation imposed by calcium carbonate and permits operation of the tower at much higher cycles without mineral scale formation. Theoretically, over 10 cycles of concentration are permissible with soft water makeup, but from a practical view 6 to 9 cycles are more common because of limitations caused by uncontrollable water losses from windage and system leaks that add to the tower bleed.

The use of soft water results in heat transfer surfaces that are free of mineral scale deposits. Photo No. 1 shows the ID section of a copper condenser tube removed from a centrifugal chiller operated for over 5 years on soft water makeup. The roots of the grooves in the enhanced tube are clearly visible and the metal surface is "bare metal" clean with no evidence of surface deposition.

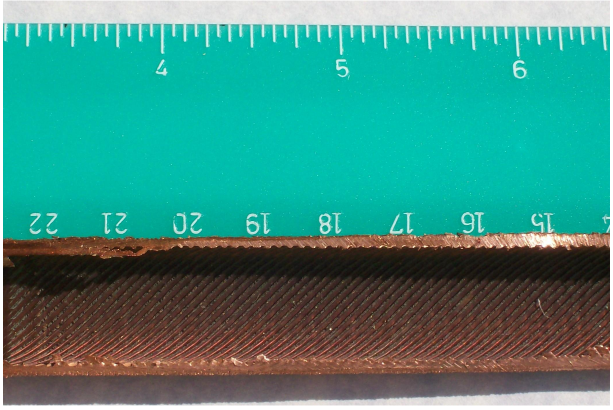

Photo 1: Condenser tube after 5 years of service

Maintaining clean metal surfaces in a mechanical chiller reduces the relative horsepower per ton of refrigeration capacity, which saves energy and prolongs the life of the plant equipment.

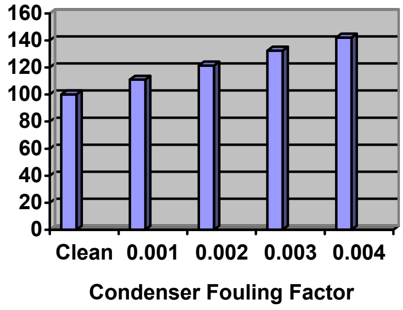

Chart 1: Effect of Scale on Compressor Horsepower[1]

For these reasons, plant operators strive to maintain clean condenser tube surfaces for maximum heat transfer efficiency.

SOFT WATER RENDERS STEEL PASSIVE AND REDUCES CORROSION ON OTHER METALS

The argument is often given that soft water is more corrosive than hard water and, therefore, shouldn't be used for cooling tower makeup. This claim is based on the theory that a very thin layer of calcium carbonate acts as a barrier to corrosion and thereby protects the underlying metal from general and pitting attack. In fact, some chemical treatment methods rely on calcium to perform as a necessary component of the corrosion inhibitor program. This approach generally stipulates a minimum of 20 to 50 ppm calcium hardness in the cooling water. While true that a thin, almost invisible eggshell layer of calcium carbonate is an effective corrosion inhibitor, even very thin surface films retard heat transfer and result in lower efficiency and higher energy consumption.

Traditionally, achieving higher cycles of concentration on high hardness, high alkalinity makeup requires acid neutralization of the bicarbonate alkalinity. In practice, acid injection is difficult to control and frequently results in upsets caused by accidental over or underfeed conditions. Overfeed depresses the pH below 6 and results in a very corrosive condition, whereas acid underfeed allows the formation of calcium carbonate scale. The use of acid to maximize cycles and limit the deposition of calcium salts on heat transfer surfaces is difficult to control and frequently results in unintended upsets leading to very corrosive, low-pH excursions.

Soft water makeup eliminates the restrictions on cycles imposed by calcium hardness and removes the need to use acid for pH control. The cooling tower can be safely operated at maximum cycles of concentration. At high cycles of concentration the natural bicarbonate alkalinity in the makeup is allowed to concentrate in the cooling tower resulting in an alkaline pH in the 9.2 to 9.6 range.

Table 1 indicates the analysis of a high-hardness, high-alkalinity, makeup water from a well water source used in this study.

Parameter	Test Result
Total hardness	318 mg/l
Calcium hardness	212 mg/l
Magnesium hardness	106 mg/l
Sodium	6.3 mg/l
P alkalinity	0 mg/l
M alkalinity	290 mg/l
Carbon dioxide, CO_2	50 mg/l
Specific conductance	631 micromhos/cm
pH	7.06

Table 1: Raw water makeup quality

In this case, the M alkalinity is present as bicarbonate alkalinity in equilibrium with free carbon dioxide. Operating the tower at 2 cycles of concentration without pH control produces an LSI of +2.31, which is in the middle of the +2.0 to +2.5 control range. Further increases in cycles require the use of acid to neutralize the M alkalinity and depress the cooling water pH. Table 2 indicates the cooling water quality targets for operating the tower at 3 cycles of concentration with sulfuric acid neutralization of the cooling water alkalinity. This produces a pH within the 7.2 to 7.6 range.

Parameter	Cooling Water @ 3 cycles with sulfuric acid for pH control
Total hardness	954 mg/l
Calcium hardness	636 mg/l
Magnesium hardness	318 mg/l
Sodium	18.9 mg/l
P alkalinity	0 mg/l
M alkalinity	75 mg/l
Carbon dioxide, CO_2	6 mg/l
Specific conductance	1893 micromhos/cm
pH	7.4

Table 2: Water quality at 3 cycles with acid

These operating conditions yield an LSI value within the +0.1 to +0.2 range, which is near-neutral to slightly scaling. Further increases in cycles are possible by adjustment of the acid feed to suppress and control the pH sufficiently to avoid exceeding the solubility limit imposed by calcium carbonate. Supplemental chemical scale inhibitors are also used to enhance calcium solubility. Success with this treatment approach requires precise control of the acid and chemical injection to avoid under or over feed conditions, which can result in either a very scaling or corrosive condition, respectively.

Softening the makeup provides an alternative approach to pH and alkalinity control with acid. By removing the calcium hardness, the natural bicarbonate alkalinity is allowed to concentrate in the tower to produce a high-pH, alkaline environment. Table 3 indicates the water quality targets when operating the cooling tower at 6.5 cycles of concentration with soft water makeup.

Parameter	**Cooling Water @ 6.5 cycles with soft water makeup**
Total hardness	0 to 10 mg/l
Calcium hardness	0 to 10 mg/l
Magnesium hardness	0 to 10 mg/l
Sodium	988 mg/l
P alkalinity	440 mg/l
M alkalinity	1980 mg/l
Carbon dioxide, CO_2	0 mg/l
Specific conductance	4100 micromhos/cm
pH	9.2 to 9.6

Table 3: Tower at 6.5 cycles on soft water makeup

With soft water, the total (M) alkalinity is 1980 mg/l with a pH of 9.3 as compared to the acid controlled tower that has a pH of 7.4 and a total alkalinity of 75 mg/l in equilibrium with 6 ppm free CO_2 (CO_2 is present as carbonic acid). At high pH with soft water, the alkalinity is present as carbonate (880 ppm) and bicarbonate (1100 ppm). This buffers and keeps the pH well-above the oxidizing point of steel, which is within the pH range of 8.2 to 8.3. Also, the corrosion rate on copper is minimized at pH values approaching 8.5 or greater[2]. In very general terms, the impact of pH on the corrosion rate of steel, copper, and galvanized steel is minimized within the range of pH 8.5 to 9.5. The higher carbonate and bicarbonate alkalinity neutralizes all acidity and renders steel surfaces passive.

Photo 2: Corrosion coupons removed from soft water tower; light cleaning

SOFT WATER MAKEUP LIMITS THE GROWTH OF PATHOGENIC BACTERIA

Cooling towers are an ideal habitat for the growth of algae and bacteria including pathogenic organisms such as Legionella pneumophila. Table 4 indicates the most common type of organisms found in cooling tower systems.

Bacteria and algae grow best within a fairly narrow pH range. Pathogenic organisms (those that cause disease) live within a pH range that closely matches that of the host such as pH 7.3 to 7.5 in humans. A review of Table 4 suggests that, when taken as a whole, bacteria tend to survive best within a pH range of 5.0 to 8.0 while algae prefer a pH environment of 5.5 to 8.9. A few exceptions are noted such as iron bacteria and Nitrobacter, which can be found at pH's as high as 9.5 – 10. Overall, however, bacteria and algae amplify within a fairly neutral pH range with the population dying out beyond either extreme of their ideal growth habitat.

Referring back to the example of the cooling tower operating on soft water makeup versus acid-pH control on hard water makeup, the natural carbonate alkalinity of the soft water concentrates in the cooling tower to produce a pH between 9.2 and 9.6. This is above the maximum pH tolerated by most of the common bacteria and algae found in cooling water systems including Legionella p. By contrast, the acid-pH controlled treatment program puts the pH at a more-neutral 7.2 to 7.6, which is squarely in the middle of the ideal growth environment for the organisms listed. In this case, the acid-pH controlled program creates an environment that is ideally suited for the growth of pathogenic organisms such as Legionella pneumophila. The high pH environment of the soft water program, however, serves as a bacteriastat toward these same strains of bacteria and algae.

Type	Example	pH Range	Problems
Aerobic capsulated bacteria	Arobacter aerogenes	4.0 to 8.0	Slime forming bacteria
Aerobic capsulated bacteria	Flavobacterium	7.5	Slime forming bacteria
Aerobic capsulated bacteria	Pseudomonas aeroginosa	5.6 to 8.0	
Aerobic spore-forming bacteria	Bacillus mycoides	5.0 to 8.0	Add to slime problem
Aerobic sulfur bacteria	Thiobacillus thiooxidans	0.6 to 6.0	Oxidize sulfur to sulfuric acid
Legionella bacteria	Legionella pneumophila	Natural 5.5 to 8.1 Tap Water 5.5 to 9.2	Causative agent for Legionnaires disease
Anaerobic sulfate-reducing bacteria	Desulfovibrio desulfuricans	4.0 to 8.0	Produces H_2S gas
Iron bacteria	Crenothrix	7.4 to 9.5	Forms ferric hydroxide in sheath-like coating
Green algae	Chlorella	5.5 to 8.9	Common green algae
Green algae	Ulothrix	5.5 to 8.9	Common green algae
Blue-green algae	Oscillatoria	6.0 to 8.9	Common blue-green algae

Table 4: Common bacteria and algae found in cooling tower environments [3]

The impact of alkalinity and pH on the growth of Legionella pneumophila was investigated by Dr. Stanley J. States, et al through the City of Pittsburgh Water Department and the Graduate School of Public Health at the University of Pittsburgh in a May 1987 study on the amplification of Legionella in cooling tower systems[4]. This study concluded that the "results of the current investigation suggest that elevated pH and alkalinity would bring environmental conditions out of the tolerance range of Legionella species and could be useful in controlling multiplication in cooling systems." [4]

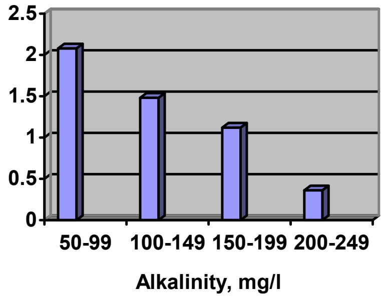

Chart 2: Relationships between Legionella multiplication and alkalinity [4]

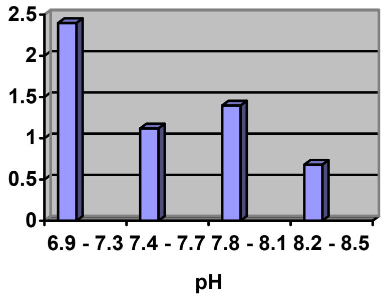

Chart 3: Relationship between Legionella multiplication and pH [4]

As indicated in the data obtained from this study, both alkalinity and pH have a significant impact of the multiplication of Legionella in cooling water systems. This data indicates that maintaining cooling tower alkalinity above 250 mg/l and pH above 8.5 will suppress the growth of L. pneumophila. In the case of cooling towers operating with soft water makeup, alkalinities and pH values in excess of those identified in this study are possible. This suggests that even greater inhibition over the growth of bacteria and algae in the cooling tower environment is achievable at these higher alkalinity and pH values.

Notwithstanding the benefits of an alkaline, high-pH environment for controlling bacteria populations, best practice suggests that a biocide be administered to control the growth of bacteria and algae in the tower. An oxidizing biocide such as chlorine, bromine, chlorine dioxide or ozone is generally recommended as this is endorsed by OSHA[5] , ASHRAE[6] , CTI [7], CDC[8] and AWT[9].

Liquid sodium hypochlorite is an effective, low cost biocide for use in cooling tower applications. The claim is frequently made, however, that bromine is better than chlorine in high-pH conditions because it reacts "faster" than chlorine. This refers to the more favorable equilibrium distribution of hypobromous acid versus hypochlorous acid at equivalent pH values. The acid form of the halogen is more toxic (i.e. it reacts faster) than the corresponding sodium salt.

The speed of reaction argument has merit if one is concerned with adding the biocide at Point A in a linear system and then measuring the bacteria population at Point B downstream from the point of injection such as in the case of a municipal water distribution system where the bacteria population must be under control between the point of chlorination and the first tap. In this scenario, the required contact time increases with increasing pH and is expressed as a T-value measured in minutes. In an open recirculating cooling tower, however, where the water is continuously chlorinated, the contact time between the chlorine and the organism is infinite. The high pH of the cooling water tends to stabilize the chlorine and thereby helps to foster and maintain a continuous residual. And, as mentioned previously, because pH values above 9.0 do not support amplification of the bacteria population, the chlorine demand is not as great as in low-pH conditions. Under these conditions liquid chlorine provides very good control over bacteria and algae populations. Nevertheless, using the same argument, the other oxidizing biocides will produce results similar to that of chlorine. The choice between the various alternative halogens is best determined by economic factors and personal preference.

SOFT WATER MAKEUP CONSERVES WATER AND REDUCES COST

The purpose of a cooling tower is to conserve water. Cooling towers fulfill this purpose by recycling water back to the point of heat exchange by rejecting waste heat to the atmosphere via the evaporative cooling process.

Cooling tower bleed is used to control the cycles of concentration. One way to calculate the cycles is to meter the makeup and bleed. If this is done, the ratio of makeup (MU) to bleed (BD) is a good indication of cycles in a system that has minimal windage and leak losses. Water lost by evaporation (E) from the tower is the other major component of water consumption.

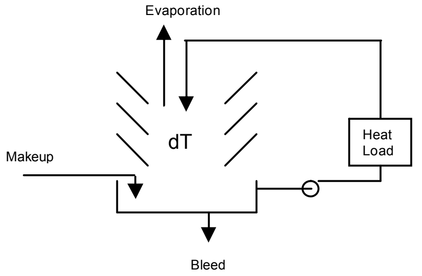

Figure 1: Typical cooling tower system schematic

These operating variables are related as indicated below:

Evaporation (E) = 0.001 X Recirc. X dT ^{o}F X 0.75

Makeup (MU) = Evaporation (E) + Bleed (B)

Cycles (C) = Makeup (MU) / Bleed (B)

From these relationships, we see that decreasing the bleed rate increases the cycles of concentration and reduces the makeup demand, i.e. increasing the cycles of concentration reduces water consumption.

Calcium hardness limits the cycles of concentration because of the limited solubility of calcium carbonate under high alkalinity and pH conditions. Softening the makeup removes this limitation and allows the tower to be operated at maximum cycles.

Referring back to our example of a tower operating on hard water versus soft water, the LSI calculation indicates that this system is limited to 2 cycles of concentration based on the solubility of calcium carbonate. Figure 2 illustrates the water demand for such a tower that services a 400 T chiller load, 360 days per year.

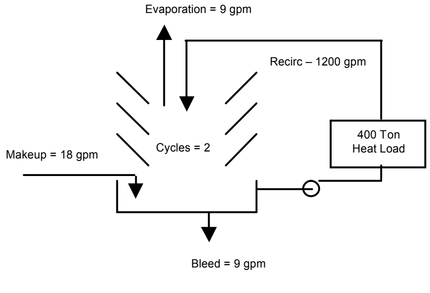

Figure 2 Tower with hard water makeup

The makeup demand is 9,331,200 gallons per year with a wastewater flow (bleed) of 4,665,600 gallons per year. An additional 4,665,600 gallons is lost due to evaporation. The makeup water cost is $1.75 per Kgal and wastewater disposal is $2.25 per Kgal. Total water and wastewater cost for this cooling tower is $26,828 per year.

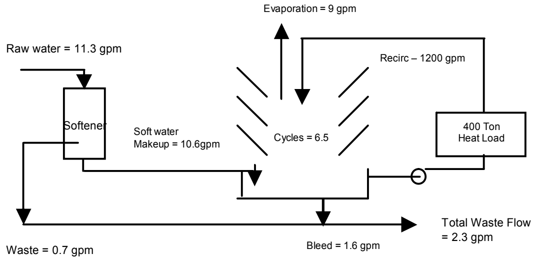

Figure 3: Tower with soft water makeup

Now let's consider the impact on water consumption and wastewater disposal by softening the makeup. In this example, the calcium hardness is removed by ion exchange softening, which allows the tower to operate at a minimum of 6.5 cycles of concentration. The raw water consumption is 5,857,920 gallons per year. Wastewater disposal is equal to the tower bleed plus the wastewater produced by the regeneration of the softener. Softeners typically recover 93.6% of the raw, hard, feedwater as product, i.e. on average 6.4% of the feedwater is sent to drain during the regeneration cycle. In this example, total wastewater production is 1,192,320 gallons per year. Since the heat load remains the same, 4,665,600 gallons is lost due to evaporation. The raw water cost is $1.75 per Kgal and wastewater disposal is $2.25 per Kgal. The total water and wastewater cost for operating the tower on soft water is $12,934 per year.

Since salt is used to regenerate the softener, this cost must be added to the water and wastewater cost. The softener is regenerated with 6 lbs of salt per cubic foot of resin to produce a total exchange capacity of 22,500 grains per cubic foot. The raw water hardness is 18.6 grains per gallon. The cost of salt is $66 per ton. Working through the calculations, we arrive at a salt cost of $0.164 per Kgal of soft water. Total annual salt cost for cooling tower makeup is $900 per year.

To summarize, total cost for water and waste disposal on hard water is $26,828 per year. Total cost of water, waste disposal and salt on soft water is $13,834 per year. Total cost savings per year is $13,000.

A similar calculation can be performed using sulfuric or hydrochloric acid to achieve higher cycles of concentration using hard water makeup. However, the acid controlled tower has a lower pH and alkalinity, which makes the water more corrosive and tends to enhance the conditions for bacteria and algae growth as compared to cooling towers operated on soft water makeup.

SOFT WATER MAKEUP REDUCES CHEMICAL CONSUMPTION AND COST

Hard water makeup requires the addition of chemical scale inhibitors and mineral acid to maintain the solubility of calcium carbonate at higher cycles of concentration. Chemical inhibitors are also required to protect the system from corrosion. This is particularly evident where acid addition is used to adjust and control the cooling water pH. Softening the tower makeup to remove calcium and magnesium hardness eliminates the need for supplemental chemical scale inhibitors and reduces the corrosion potential of the cooling water by maintaining higher carbonate and bicarbonate alkalinity.

Common chemical scale inhibitors include organophosphonates such as Hydroxyl ethylidene (1,1 – diphosphonic acid) (HEDP)and 2-Phosphonobutane – 1,2,4-tricarboxylic acid (PBTC). HEDP and PBTC are maintained in the cooling water at sub-stoichiometric dosages to increase the solubility of calcium carbonate at Langelier Saturation Index levels of up to +2.0 to +2.5. Softening the makeup to remove calcium and magnesium hardness eliminates the requirements for these chemical additives.

Corrosion inhibitors are commonly used in cooling water chemistry to protect steel, copper, brass and galvanized steel from corrosion. These inhibitors include polyphosphate, zinc, molybdate and/or azoles such as tolytriazole (TT). With soft water makeup, the elevated alkalinity and pH of the cooling water acts as a passivating agent on steel and copper. To be clear, the carbonate and bicarbonate alkalinity do not passivate the metal, which by definition implies a permanent condition, but rather the more alkaline, higher pH environment makes the metal more passive to oxidizing corrosion reactions. This same principle is used in the preparation of steel surfaces by blasting with sodium carbonate to render the metal free of oxidation and passivate the base metal prior to applying a protective coating.

In this study, a low level of tolytriazole (1 to 3 ppm) was used as a supplemental corrosion inhibitor for copper and 4 to 6 ppm of molybdate (as Mo^{+6}) was used as a tracer to monitor and control the dosage of the inhibitor product.

The use of soft water makeup does not entirely eliminate the need for chemical additives. The requirement for a microbicide, such as the oxidizing agents discussed previously, still exists. And, depending on the chemical characteristics of the makeup, a chemical additive may be required for supplemental corrosion protection. In other cases, polymer dispersants may be required to minimize fouling. Each system is different and requires an assessment by a qualified consultant.

The main advantage of soft water makeup is that the tower operates at maximum cycles of concentration. This reduces the tower bleed rate and thereby reduces the chemical requirements. Referring to the previous example of the tower servicing 400 tons of heat load, the bleed volume at 2 cycles is 4,665,600 gallons per year. At 6.5 cycles, the bleed volume is reduced to 829,400 gallons (1,192,320 total wastewater produced if you include the regeneration rinse water produced by the softener).

In this study, a commercial cooling water inhibitor was dosed at a rate sufficient to maintain 150 ppm of product in the cooling water. This is equivalent to 1.25 pounds of product per 1000 gallons of bleed. At 2 cycles, the chemical demand is 5,832 pounds per year. At 6.5 cycles, the chemical demand is reduced to 1,036 pounds per year. This is a reduction in chemical usage of 4,796 pounds per year or 82%. Calculated at the rate of $2.35 per pound, the annual cost savings for the chemical inhibitor is $11,270 per year.

As noted previously, salt is required to regenerate the water softener used to produce the tower makeup. Salt is relatively inexpensive at $66 per ton ($0.033 per pound) as compared to chemical scale inhibitors. It takes 13.6 tons of salt to meet the makeup demand for the cooling tower when operated at 6.5 cycles of concentration. The total cost for salt is about $900 per year.

The other option is to operate the tower on hard water makeup with acid injection for pH and alkalinity control. One (1) part of acid is required to neutralize one (1) part of M alkalinity in the makeup. In this case, the makeup alkalinity requires neutralization to 15 ppm, which requires 275 ppm of sulfuric acid (H_2SO_4 as 100%). This is equivalent to 2.3 pounds of acid per 1000 gallons of makeup. The total sulfuric acid (100% basis) demand is 6.7 tons per year. At $120 per ton, the estimated annual cost for sulfuric acid is $800, which is comparable to the cost of salt used to regenerate the softener.

The use of soft water makeup will increase the sodium chloride loading on the plant waste stream and contribute to the total dissolved solids discharged from the plant. Likewise, sulfuric acid will contribute to the sulfate content of the plant effluent and increase the solids loading in the waste stream. This requires a check on local discharge limitations before proceeding with a retrofit of the current cooling water system.

SUMMARY AND CONCLUSIONS

The use of soft water makeup in cooling tower operation has several advantages over hard water makeup. These include performance, environmental and economic benefits.

Performance

- Eliminates calcium and magnesium scale deposits for "bare metal" clean heat transfer surfaces
- Reduces corrosion on steel, copper, brass and galvanized steel by allowing the maintenance of a high-pH, high alkalinity environment that renders steel and other metals more passive to corrosion
- Controls the growth of pathogenic organisms by maintaining the pH above the amplification range (pH greater than 9.2)

Environmental

- Conserves water by reducing makeup (37% water reduction in this study)
- Reduces wastewater production (74% wastewater reduction in this study)
- Exposure to harmful pathogens is reduced because of the high pH environment of the cooling water (pH greater than 9.2)

Economic

- Reduces overall operating costs

Budget Item	Hard water	Soft water	Annual Savings
Water	$26,828	$12,934	$13,894
Chemical	$13,705	$2,434	$11,271
Salt	$0	$900	-$900

Table 6: Cost savings with soft water makeup

The total annual cost savings in terms of water, waste and chemicals for the tower evaluated in this study serving a 400 Ton load is $24,265. This represents an overall operating cost reduction of 59.9%.

The results of this study support the use of soft water makeup for cooling tower operation to eliminate scale deposition on heat transfer surfaces, control corrosion on steel and other metals, limit the growth of bacteria, conserve water, and reduce chemical consumption. This helps protect the natural environment, saves energy, extends the useful life of plant equipment and creates wealth for the owners.

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