

# **Cooling Water Management**

## **Basic Principles and Technology**

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## I. INTRODUCTION

Evaporative cooling towers are very popular as they provide the most cost effective cooling technology for commercial air conditioning and industrial processes. However, drought conditions and increasing water usage have combined to decrease the availability and increase the cost of the good quality, low hardness water preferred for cooling tower makeup use. At the same time, stricter environmental restrictions on effluent discharge have resulted in increased fees for disposal of cooling tower blowdown to the sewers. The addition of these concerns to the existing requirements for control of scale, corrosion, deposition, and biological fouling has increased the difficulty and costs associated with operating a cooling tower water system.

In spite of these concerns, treatment and control of cooling tower water is commonly neglected, which is then responsible for substantial problems due to downtime, equipment damage, loss of process control, high water use, environmental violations, safety hazards, and increased energy usage. Neglect of cooling water results from two major facts: first, the user often does not appreciate that cooling water is a vital part of the facility operation or production process; and second, that misinformation, fraudulent products, and marketing hype are common when cooling water treatment is the issue under discussion due to the proprietary nature of the water management business.

This paper is intended to provide the cooling water user with a basic knowledge of cooling water management so that problems resulting from corrosion, scale, deposition, and biological fouling can be avoided. Reduction of operating costs from increased efficiency in use of energy and control of both makeup water and sewerage use will be discussed as well as health and safety hazards, environmental problems, zero blowdown operation, USGBC LEED certification, supplier selection, and non-chemical devices. Except where specific proprietary processes are unique or patent protected, we will utilize generic descriptions. Expressed opinions are based on active participation in the cooling water management field since 1973.

### **Evaporative Cooling Tower**

A cooling tower is simply a device for rejection of unwanted heat into the atmosphere. The fact that water is a low cost, convenient, and highly effective heat transfer medium, and that evaporation of a pound of water requires about 1000 btu, makes the evaporative cooling tower the most effective means for this heat transfer. Water evaporation within the cooling tower accounts for the majority of the heat rejected, typically **75 to 80% of the heat is removed from the cooling water by evaporation (E)**. The rest of the heat is removed by transfer to the substantial air flow passing through the cooling tower.



“Water is not missed  
‘till the well runs dry,”  
*Benjamin Franklin*

For example, a 1000 ton rated cooling tower is designed to have a heat rejection of 12 million btu/hr, 12,000 btu/hr/ton. At 80% heat rejection by evaporation, this unit will evaporate 26.55 gpd/ton, or 26,550 gpd. Evaporation of water in the cooling tower concentrates the dissolved salts found in almost all water sources, which increases the potential for scale, corrosion, and biological fouling.

In addition to the concentration of salts from evaporation, a 1000 ton unit operates at a design air flow rate of 271,000 cfm through the unit. Since a cooling tower is also a very effective "air scrubber," passage of such large amounts of air through the device results in the addition of significant amounts of airborne dust and debris to the cooling water.

**Blowdown (BD)**, or intentional removal of water from the cooling tower, is required to prevent over concentration of salts and insoluble airborne debris and results in potential environmental problems, increased water use, and wastewater disposal costs. The number of times that the replacement water, **makeup**, (**MU**) is increased in concentration is commonly referred to as **cycles (C)**, which is calculated by dividing the dissolved solids level (commonly measured as conductivity) in the cooling water by that of the makeup water.

While generally not important unless a cooling tower is to be operated at zero blowdown, **windage (W)** is a small loss of cooling water into the air stream passing through a cooling tower. Windage is a direct function of the design of the cooling tower and water **recirculation rate (R)** through the unit. Typically, windage will be between 0.01 and 0.05% of the cooling water recirculation rate.

In many areas of the country scale formation due to poor makeup water quality prevents any cycling, while other areas are severely limited as to the maximum obtainable. Chemical treatment of the cooling water is thus required in many areas to permit cycling operation, to reduce water usage, of an evaporative cooling tower without formation of scale.



Typical Cooling Tower Installation for Air Conditioning

Scale, in addition to causing physical blockage of piping, equipment, and the cooling tower, also increases the energy use of the chillers used in comfort cooling. For example, the thermal conductivity of copper is 2674 btu/[hr(ft<sup>2</sup>)(F/in)], while the common cooling water scale calcium carbonate has a thermal conductivity of just 6.4 btu/[hr(ft<sup>2</sup>)(F/in)]. The energy cost penalty for even a small amount of scale can be significant.

For example, a calcium carbonate scale of just 1.5 mil thickness is estimated to decrease thermal efficiency by 12.5 %, which on a 1000 ton chiller would increase annual power costs by about \$72,000/yr at current power costs and typical HVAC service loads.

Described as the "universal solvent," water corrodes all materials of construction at different rates. Steel, being the lowest cost construction material for cooling systems, is very common and is readily corroded by most cooling waters. Other materials, such as copper, brass, and galvanized steel, are also corroded, though at generally lower rates. To obtain a useful life from a cooling system, corrosion inhibitors are generally used to control the corrosion rates to an acceptable level.

The cooling water environment (warm with high dissolved solids and debris loading) is an excellent medium for growth of microorganisms that may cause many severe problems. Not only is there an increased risk of Legionnaires' Disease, but biofilms also plug water passages and piping, help to accelerate corrosion, and reduce heat exchanger efficiency. The affect of biofilms on the power cost of chiller operation is often not appreciated. Looking at the thermal conductivity of biofilm, typically 0.2 btu/[hr(ft<sup>2</sup>)(F/in)], it is substantially less conductive than the common calcium carbonate scale. Therefore, while a system may be scale free, any biofilm present will still cause excessive energy use. To prevent these problems, toxic chemicals referred to as "biocides" are added to cooling towers to control the growth of unwanted microorganisms in the cooling water.

### **Water Management Program Requirements**

Our discussion of cooling water management will begin with an objective statement of what is expected from the cooling tower water system. In most facilities, this system must provide reliable equipment cooling with maximum heat transfer efficiency. The following are the four basic requirements for a successful program:

- **Obtain maximum energy efficiency and equipment life by minimizing problems due to corrosion, scale, deposition, and biological growth**
- **Permit feasible implementation and control with a minimum input of labor and money**
- **Be cost effective considering the total water system capital and operating costs**
- **Cause minimal problems as to health, safety, and the environment**

## II. WATER CHEMISTRY CONTROL

Based on many hundreds of surveys, we find that operational control of cooling water treatment programs is often neglected and that it is the single most common cause of water management program failure. The best possible combination of corrosion, scale, and deposition control chemicals, with effective biocides, is completely worthless if not consistently and correctly applied to the cooling water. It is a continual source of amazement that firms will spend tens of millions of dollars on their facilities, and then use the lowest cost (low bid!!) control equipment on their cooling systems, bearing in mind that with control equipment, as most other items, you get exactly what you pay for!

### Cycles

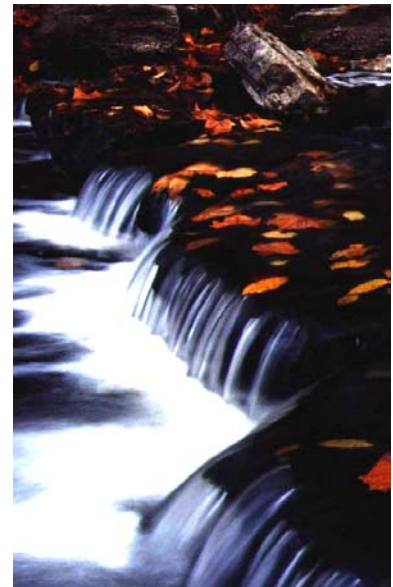
Cooling water chemistry control begins with the cooling water cycles (**C**), or the number of times that the dissolved salts in the fresh makeup water (**MU**) are concentrated by evaporation (**E**) from the cooling system. This parameter is commonly obtained by measuring the conductivity of the cooling water (**CW**) and dividing it by the measured conductivity of the makeup water. Cycles can also be calculated using other parameters, such as chlorides and dissolved solids, which are common to both the makeup and cooling water and are not expected to be effected in any great degree by chemical additions, or precipitations. Another simple calculation of cycles, if the appropriate water meters are in place, is to simply divide the amount of makeup by the amount of blowdown.

Control of cycles is critical in systems using hard makeup water as no chemical treatment program can prevent scale when excessive levels of dissolved salts are present in the cooling water. Cycles are controlled by discharging, or blowing down, concentrated water from the system and replacing it with fresh water. Referred to as blowdown (**BD**), this wasted water keeps the concentration of dissolved solids in the cooling system at levels where no precipitation will take place.

### Why Cycle?

A common question is, "Why use chemical treatments to operate at additional cycles when often no scale will form when operating at lower cycles." The best answer is that operation at increased cycles substantially lowers both the makeup and blowdown requirements, cutting the cost of fresh water and sewage disposal. With corrosive waters, increasing the cycles so that the water is rendered less corrosive is an inexpensive means to improve control of corrosion. Another point is that operation at increased cycles permits use of effective corrosion inhibitors that may be too costly to employ at the higher blowdown rates resultant from low cycle operation.

Often the quality of the makeup water is so bad that a scale inhibitor must be employed just to use the water. In such cases cycling reduces the cost of the scale inhibitor use to an economic level. We find that operation of cooling towers between 3 to 6 cycles is the most economical range.



Environmental requirements, insufficient amounts of fresh makeup water, and the USGBC LEED program are additional forces driving cooling tower operation to higher cycles. For example, sewer tap fees for a new plant of \$100,000 were reduced to \$10,000 simply by increasing cooling tower cycles from 3 to 6, cutting the blowdown amount in half. Environmental agencies are also taking a much closer look at facility water use. One recent NPDES permit issued in Arizona contained a condition that the permittee operate at 17 cycles in order to reduce its fresh water usage and blowdown. The USGBC LEED program awards certification points for reduction of water use, elimination of hazardous chemical usage, reduction in wastewater discharged, and use of innovative technology. All of these factors must now be considered in design of a cooling water management program where the user desires LEED certification.

### **The Economics of Cycles**

'Maximum economic cycles' is the cycles value where the total operating cost for the entire program is lowest. This value is determined based on the cost of water, sewerage, blowdown, and chemical treatment for each specific application. One unique set of operational parameters consisting of cycles, inhibitor chemistry, inhibitor dosage, makeup, and blowdown can be found for each makeup water/facility combination which gives the lowest total operating cost.

Generally maximum economic cycles are controlled by the calcium carbonate saturation index (**SI**) of the cycled makeup water. Using an analysis of the makeup water, it is modeled over a typical range of 2 to 10 cycles and the resultant SI values determined. The cycles values matching to SI values of 1.0, 2.0, and 3.0 are utilized as breakpoints in determination of the cost of the chemistry required to prevent scale at those cycles. The costs for makeup water, blowdown disposal, and the inhibitor chemistry required are then calculated at these determined values and compared to determine the maximum economic cycles. The SI calculations can be accomplished totally by hand calculator as follows, or by specific computer programs such as WaterCycle.

### **Saturation Index by Hand Calculator**

- 1).  $P1 = \log_{10}(\text{calcium} * 2.5 * \text{total alkalinity})$
- 2).  $P2 = (\text{maximum system water temp, F} * 0.00912) + P1$
- 3).  $P3 = ((\log_{10}(\text{conductivity} * 0.8) * 0.1) + 12.27$
- 4).  $\text{pH saturation} = P3 - P2$
- 5).  $\text{SI} = \text{pH of cycled water} - \text{pH saturation}$

The pH of the cycled water can also be estimated by first converting the pH to a "real" number by using the inverse log function,  $10^{\text{pH}}$ . Then multiply this "real" number by the number of cycles desired, converting back to a pH value by taking the log of this number. Most cooling systems are operated with SI values between 0.5 and 3.5.

The calculation of maximum economic cycles is not always possible due to insufficient information. In the majority of cases, we have found that using a chemistry which will permit 3 to 6 cycles operation will result in a total operating program cost close to the absolute minimum cost.

## Methods for Controlling Cycles

There are two good methods for control of cooling system cycles: makeup proportional blowdown and conductivity based blowdown.

**Makeup proportional blowdown control** is really quite simple, the amount of makeup added to the cooling tower is metered and a signal is generated by the water meter which activates a timer. This timer then controls operation of a flow controlled blowdown valve to discharge a proportional amount of blowdown from the cooling system. For example, if 1000 gallons of makeup was added to a system operating at 5 cycles, the timer would operate a 10 gpm flow controlled blowdown valve a total of 20 minutes to discharge the 200 gallons required to maintain 5 cycles in the cooling tower.

**Conductivity based blowdown control** is based on measuring the conductivity (which is proportional to the level of dissolved salts) of the cooling water. When the conductivity reaches a predetermined control level, an automatic valve is activated and high dissolved salt content water is drained from the cooling water system. Replacing this blowdown with new makeup water lowers the conductivity of the cooling water, deactivating the automatic valve.

Comparing the two methods, we find that proportional blowdown control is less costly to install and maintain, while conductivity blowdown control can compensate for leaks (smaller ones!) in the cooling system and somewhat for changing makeup water quality.



Conductivity based blowdown control does have one significant problem that is often not considered when using a hard makeup water. When scale forms in a cooling system, calcium and alkalinity are both removed from the cooling water as calcium carbonate, lowering the conductivity of the cooling water. The conductivity blowdown controller sees this as a lowered cycles value and thus does not blowdown to maintain a “true” cycles value, resulting in over cycling and generation of additional scale, which then further lowers the conductivity, increasing true cycles even more. This is a "Catch 22" type situation where some initial scale formation results in a cycle effect leading to more and more scale formation in the cooling system. This problem is more common than realized and must be considered when deciding upon which cycle control method to use.

Cycled cooling water often contains various items; dead bugs, leaves, and pine cones; which when lodged in blowdown valves disable the valve, either open or closed, resulting in loss of cycle control. Good engineering practice is to install a Y, or small basket, strainer upstream of the blowdown valve to prevent this problem.

## Chemical Feed Control

Many methods have been used over the years to control the addition of chemical inhibitor products to cooling systems. Common methods have included manual batch feed, timer controlled feed, constant feed, controlled rate dissolving feeders, simultaneous blowdown and chemical injection (bleed - feed), makeup water proportional feed, and active on-line tracer monitoring.

Of these various methods, only active on-line tracer monitoring provides “real” control of the actual inhibitor level in the cooling system and even this method can be defeated if product actives precipitate, leaving the tracer still present in cooling water. The next best method, and hopefully the minimum standard for inhibitor feed control, is makeup proportional control. While makeup proportional feed is far superior to such control methods as bleed-feed, it can still be defeated by failure to maintain set cycles in the cooling system, which would result in lowered inhibitor levels.

The recent commercialization of a colorant tracer control technology, BlueTrace™, has resulted in subsequent development of an economical on-line active control feed system, BlueTrak™, which makes active on-line tracer control of chemical inhibitor feed possible at a price many facilities can now afford.



BlueTrak I On-Line Tracer Chemical Controller

Proportional chemical feed systems are quite simple. They are based upon metering the amount of makeup (or blowdown) water flow and activating a chemical metering pump via a timer to add an amount of inhibitor proportional to the amount of makeup (or blowdown). With makeup water generally being higher quality than blowdown, it is preferred to meter the makeup in order to reduce meter maintenance problems. Note should be made that makeup proportional controls



Proportional Chemical Pump Feed System

are well suited for feed of inhibitors directly from the product shipping container, eliminating handling of sometimes hazardous chemicals. Please note that the same proportional control system used for blowdown control can also be used for chemical feed control by simply adding a second timer to the controller, making a very economical and simple control system.

The re-introduction of **solid treatment products** to the cooling water market as a method of feed control also deserves some comment. The use of solid products was common prior to about 1965, when reliable chemical feed pumps were introduced. With a reliable means to feed liquid treatment chemical products, the use of solid treatment products virtually disappeared by the mid 1970's.

What has happened here? Lack of knowledge and marketing hype. The sellers of solid products claim that they are providing more actives per pound, making their programs appear less costly. They also claim that their products are safer from the environmental, health, and safety points of view. However, the facts are quite the contrary:

- Many liquid products contain equal, or higher amounts, of active ingredients
- The \$/lb of active ingredient is usually far higher with a solid product
- Active ingredient selection is limited by the gel process used to make a solid product
- Many liquid products are also non-hazardous and safe to handle

**However, the biggest problem with use of solid products is a matter of control.** The dissolving and feed mechanism is costly, complex, and beset with reliability problems. This translates immediately into a chemical feed control problem. A simple chemical pump controlled by a makeup water meter is very reliable and much less costly to purchase, install, and maintain.

### **Calculation of Operating Parameters**

Calculation of the various operating parameters for a cooling system is very important as to initial sizing of such things as water meters and blowdown valves, as well as subsequent monitoring of cooling system performance. The following equations are the most accurate for obtaining values for system evaporation (**E**), blowdown (**BD**), windage (**W**), cycles (**C**) and makeup (**MU**).

Evaporation can be calculated by:

$$\mathbf{E \text{ in gpd} = \frac{\text{heat load btu/hr (Q) x 24 hr/day x (0.75 to 0.80)}}{1040 \text{ btu/lb} * 8.345 \text{ lb/gal}}}$$

If the cooling tower size is known, heat load can be determined using the Q factor of 12,000 btu/hr per ton of industrial cooling tower capacity, 15,000 btu/hr for HVAC applications. The evaporation constant will vary from 0.75 to 0.80 dependent upon the humidity of the location where the cooling tower is located. Use 0.75 for humid areas, 0.80 for arid areas.

a quick fairly accurate shortcut is **E in gpd = tons x 26.55 gpd**

Heat load (Q) in btu/hr is determined by the following equation if the cooling tower recirculation rate (R) in gpm and  $\Delta T$  across the cooling tower are known.

$$\mathbf{Q \text{ btu/hr} = R \text{ x } 60 \text{ min/hr} \text{ x } 8.345 \text{ lb/gal} \text{ x } \Delta F}$$

Blowdown is calculated using the evaporation determined from the heat load on the cooling system with the following equation.

$$\text{BD in gpd} = E / C - 1$$

While maximum cycles will be set based upon the determined lowest total operating cost for the water treatment program as already discussed, operating cycles are calculated by:

$$C = \frac{\text{CW conductivity}}{\text{MU conductivity}} \quad \text{or} \quad \frac{\text{MU}}{\text{BD}}$$

Windage is commonly calculated using the following equation.

$$\text{W in gpd} = R \times 1440 \text{ min/day} \times (0.001 \text{ to } 0.005)$$

Please note that the windage factor varies from 0.001 to 0.005 depending on the model and type of cooling tower in use. Quality units by BAC, Evapco, ProChemTech, and Marley are designed at a windage factor of 0.001, while most other units can be calculated at 0.002. In typical systems windage can be ignored for calculation purposes, it is a major factor only in high cycles and zero discharge systems where windage becomes a significant portion of, or the only, system blowdown.

Makeup is simply the sum of evaporation, blowdown, and windage, and can be checked using mass balance techniques.

$$\text{MU} = E + \text{BD} + W$$

The measured cycles and makeup of a cooling system can be used to determine the thermal load on a system by using the above equations. Comparison of measured parameters against calculated values should be done on a routine basis to ensure that cooling systems are operating within design limits.

### Biocide Control



The critical point concerning control of biocide feed is to remember that the dose makes the poison: in other words, there is a dosage (toxic threshold) below which a biocide will not work. The critical dosage point and time required for effective microbiological control varies substantially depending on the biocide used. In addition to the critical dosage and time factor, one must also be aware that microorganisms are very fast to adjust to toxins in their environment.

Constant use of just a single biocide, excepting oxidizers, will result in establishment of a resistant flora in the cooling system being treated. This, of course, will result in biological fouling of the cooling water system. The typical solution for this problem is routine alternation of two, or more, biocides.

Acknowledging these facts, the best method for addition of a biocide is on a slug (intermittent) dosage basis using the system volume to establish initial dosage. Slug dosage can be accomplished either manually or automatically using weekly timers and pumps (or other delivery devices such as tablet dissolvers or electrolytic bromine generators). Excellent results can be obtained by either addition method, though health and safety considerations in the handling of toxic biocides are increasing the use of automatic feed systems and on-site oxidizing biocide generation. We note that several makeup water proportional timers are now available which incorporate weekly timers, making such units a complete low cost, reliable chemistry control system.

### **Operator Attention**

While automatic systems for control of cycles, chemical feed, and biocide addition improve the probability for success of any cooling water treatment program, a certain level of attention by facility operations personnel is required. Replacement of empty chemical drums and finding / repair of water leaks can only be done by an operator. A daily check and logging of the conductivity and makeup meter readings is recommended as well as a visual and operational check of the chemical feed pumps and drums.

Chemical tests of the cooling water should be made and logged at least once a week by the operator to ensure that proper levels of treatment chemicals are being maintained in the cooling water. Larger plants may benefit from an increased amount of testing due to the potential costs of upsets.

A technical representative of the treatment chemical supplier should visit the plant on a routine basis to check operation of the automatic systems, undertake his own chemical and biological tests (using his own reagents!) of the cooling water, review cooling tower system operation, and assist the plant operator with resolution of any problems. We have found that such service is usually better if the treatment chemical supplier has also supplied the chemical controls and any pretreatment equipment used on the cooling water system.

While a lot of marketing attention is being expended upon the telemetry and/or WEB computer based controls now available in the market, someone still has to go to the system to prime the chemical pumps, change-out the empty drum, or track down the leak. Trained operators and experienced service personnel are vital to obtaining good cooling water system operation and always will be.

### III. CORROSION

Water, while an excellent transporter of heat and quite inexpensive, is also an excellent polar solvent which will dissolve in more, or less, time just about all known materials. Given this fact, the chemistry of all cooling water treatment programs must begin by addressing corrosion, which is basically an electrochemical oxidation process which results in destruction of the metals from which most cooling systems are constructed.

Uncontrolled corrosion is often responsible for physical equipment failure and the plugging of cooling water passages from deposition of corrosion products.



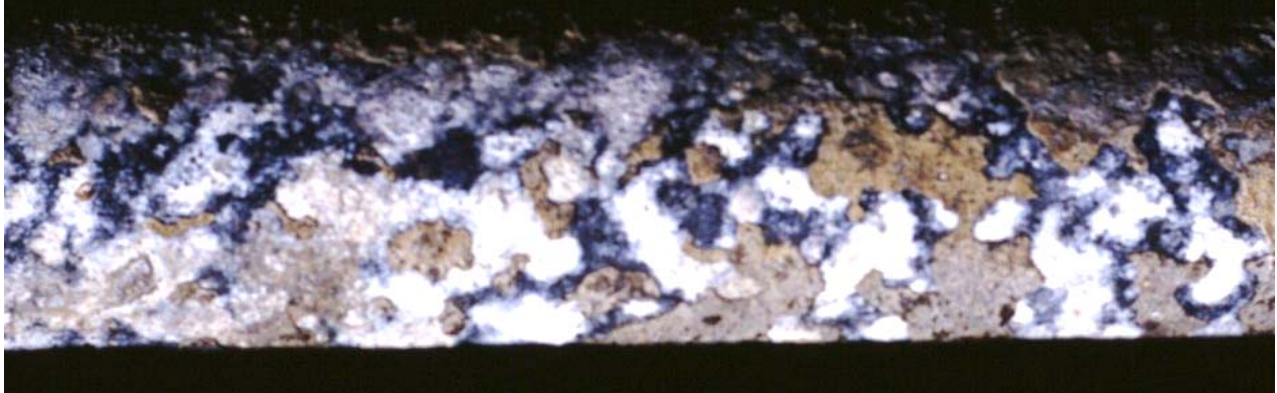
More subtle effects, often not linked to corrosion, are loss of production speed and/or control and decreased energy efficiency from deposition of corrosion products on heat transfer surfaces where the deposit acts as an insulator to decrease thermal conductivity.

#### Factors

Many factors affect the expected uncontrolled corrosion rates in a given cooling water system. The presence of dissolved gases, chloride and sulfate levels, pH, alkalinity, scaling tendency, and protective ions such as calcium, magnesium, phosphate nitrate, and silicate must all be taken into consideration along with such engineering factors as water temperatures, presence of galvanic couples, and water velocity in the design of corrosion control chemistry. Note that corrosion can generally only be controlled, not eliminated.

A major problem with new galvanized cooling towers is "white rust", which is an accelerated corrosion of the zinc coating on galvanized steel forming a bright white zinc carbonate deposit. The problem became common when the lead content of the zinc used for galvanizing was reduced due to **environmental restrictions**, giving a much easier corroded zinc alloy. White rust is serious problem in any cooling system operated at pH values above 8.2, which is typical of the popular "alkaline" cooling water treatment programs.

The amount of white rust corrosion which occurs is directly proportional to both the total alkalinity and pH of the cooling water: higher values of either parameter result in an increased rate of corrosion. Softening of high alkalinity and hardness waters to obtain higher cycles, or zero blowdown, substantially increases the rate of white rust corrosion as the calcium ion, removed to prevent scale, functions a low level corrosion inhibitor. Once the protective galvanized coating is removed from galvanized steel, it becomes substantially more susceptible to corrosion.



**White Rust, Bright White Deposit, Shown With Gray Calcium Scale on Condenser Tube**

Methods to control white rust include pH control of the cooling water to below 8.2, reduction of cycles so that the cycled pH never exceeds 8.2, and continuous application of a zinc corrosion inhibitor chemistry, like the proprietary ZincGard discovered by ProChemTech in 1993. We have also found that the numerous "pretreatments", based on phosphate compounds, do not control white rust for more than a few weeks time after the treatment.

### **Corrosion Monitoring**

The effectiveness of the corrosion inhibitor portion of a cooling water treatment program should be monitored by regular use of corrosion monitoring coupons to determine actual corrosion rates within the cooling water system. While electronic corrosion rate meters have been developed to the point where they are often fairly accurate and quite valuable, they are substantially more costly than corrosion coupons and do not give long term rate data. In addition, a complete chemical analysis of the makeup and cooling waters can often be used by a skilled technician to spot problems such as excessive corrosion of copper alloys, or zinc, in the system. Corrosion rates above the acceptable levels are cause for immediate remedial action.

A good cooling water treatment program should be able to reduce corrosion rates to the following generally accepted average levels reported as mil/yr:

<b>Mild Steel</b>	<b>1 to 2</b>	<b>Copper Alloys</b>	<b>0.1 to 0.2</b>
<b>Aluminum</b>	<b>1 to 2</b>	<b>Zinc</b>	<b>2 to 4</b>

Note that we recommend use of pure zinc coupons, instead of galvanized metal coupons, for monitoring of white rust corrosion. Attainment of these control levels, which equate to a corrosion rate reduction of 85% to 95% over uncontrolled levels, can be difficult due to the factors already noted.

### Corrosion Inhibitor Chemistry

Purchasing agents have often been quoted as saying "all water treatment chemicals are the same, so we will buy the cheapest one." This statement sums up some of the misinformation that abounds on water treatment chemistry. While it is true that most suppliers have products with similar chemistries and can often duplicate each other's products, it is the application of specific products to a particular facility makeup water and cooling system design that differentiates success from failure.

Many specific and blended chemical corrosion inhibitors are commonly utilized in cooling water treatment programs. The following list notes some common corrosion inhibitors with pertinent comments.

Chemical	Comments
<b>Chromate</b>	Excellent steel corrosion inhibitor, the standard against which all others are compared, <b>banned by the USEPA</b> for environmental reasons
<b>Zinc</b>	Good supplemental inhibitor at 0.5 to 2 mg/l level, some environmental restrictions, can cause scale if improperly applied
<b>Molybdate</b>	Non-toxic chromate replacement, often used as tracer, controls pitting corrosion control at 4 to 8 mg/l, primary inhibitor for steel at 8 to 12 mg/l, higher levels, 35 to 250 mg/l in closed loop and severe environments, <b>very costly material</b> , some environmental restrictions
<b>Polysilicate</b>	Excellent steel and aluminum inhibitor at 6 to 12 mg/l, not commonly used due to formulation difficulty
<b>Azoles</b>	Three specific azole compounds, MBT, BZT, and TTZ, which are excellent yellow metal inhibitor compounds at the 2 to 8 mg/l level
<b>Polydiol</b>	A proprietary organic steel corrosion inhibitor at 2 to 4 mg/l, also a good deposition dispersant
<b>Nitrate</b>	Specific corrosion inhibitor for aluminum in closed loop treatments at 10 to 20 mg/l
<b>Ortho phosphate</b>	Good steel inhibitor at 4 to 12 mg/l, needs a minimum of 50 mg/l calcium present with a pH above 7.5 to be effective
<b>Polyphosphate</b>	Good steel and yellow metal inhibitor at 4 to 12 mg/l, needs a minimum of 50 mg/l calcium present with a pH above 7.5 to be effective
<b>Phosphonates</b>	Includes AMP, HEDP, and PBCT, which are commonly used as scale control compounds. Fair steel corrosion inhibitors when operated with pH values above 7.5 and more than 50 mg/l calcium present
<b>Nitrite</b>	Excellent steel corrosion inhibitor at 500 to 700 mg/l, commonly used only in closed loops due to high level needed, attack by micro-organisms, and reaction with oxygen
<b>ZincGard™</b>	Proprietary inhibitor developed by ProChemTech for control of white rust, zinc corrosion, at 4 to 12 mg/l

Most successful cooling water treatment programs utilize several chemical inhibitors blended into one product to take advantage of a synergistic effect where the net reduction in corrosion from use of the mixture is greater than the sum obtained from individual components. For example, adding 2 mg/l of zinc to a phosphonate product at 10 mg/l reduced the corrosion rate on mild steel from 2.2 mils/yr to 0.9 mils/yr.

Because of this substantial increase in effectiveness, almost all successful cooling water programs use several corrosion inhibitors blended together such as molybdate-silicate-azole-polydiol, phosphonate-phosphate-azole and zinc-phosphonate-azole. The exact inhibitor chemistry to be used must be determined by the water treatment program supplier following an evaluation of makeup water chemistry, system construction materials, and operating conditions.

### Soft Water Notes

In cooling systems operated using naturally soft, or softened, makeup water, control of corrosion is the major challenge for the water treatment program. The **common water treatment industry** practice of using makeup water hardness and alkalinity to provide the bulk of corrosion control action **does not work** with these types of makeup water. In fact, the most commonly used corrosion inhibitors, polyphosphates and phosphonates, do not work if less than 50 mg/l calcium hardness is present in the cycled cooling water. This often overlooked fact has been responsible for many documented problems where this chemistry was applied to soft water makeup systems with horrible results.



The use of softening to render a hard water source suitable for use as cooling tower makeup should be evaluated very carefully as to the potential for increasing "white rust" corrosion of new galvanized steel components. Due to the normally high level of alkalinity associated with hard waters, softening with operation at higher cycles may accelerate white rust corrosion by factors exceeding 100 times. We have inspected new softened makeup cooling tower systems and found that over 50% of the galvanize had been removed from the cooling tower in less than thirty (30) days. As soft water makeup is used to achieve high cycles or zero blowdown operation, for water use reduction or environmental reasons, this specific problem will become more common. Many schemes for reuse/recycle of treated industrial wastewaters, particularly in the electronics industry, provide a soft water for use as cooling tower makeup.

Note should be made that ProChemTech has filed a patent for operation of cooling systems with zero blowdown using a process based on softened makeup water, specific corrosion inhibition chemistry, and bypass filtration. The process has been commercialized as Zero Blowdown Technology, or ZBT.

#### IV. SCALE

Deposition of scale is a chemical process that results when the concentration of dissolved salts in the cooling water exceeds their solubility limits and precipitates form on surfaces in contact with the water. The most common scale formers, calcium salts, exhibit reverse solubility in that they become less soluble as the temperature of the water increases. This property causes scale formation in the most sensitive area, the heat transfer surfaces of production equipment.

Since the thermal conductivity of scale is substantially less than metal, heat removal is reduced. In extreme cases, enough material precipitates to physically block the cooling water passages, resulting in the affected equipment being removed from operation for either chemical (acid) or mechanical cleaning. Scale formation on the condensers of chillers substantially reduces the efficiency of these units, increasing the power needed to obtain a given volume of chilled water. Various studies have shown a non-linear electrical power cost increase with increased scale thickness, for instance 0.5 mils of calcium scale results in a power cost increase of 3.5%, while 1.5 mils increases power cost to approximately 12.5%.



*Scale*

#### Control

Scale can be controlled or eliminated by application of one or more proven techniques. Typical measures taken to control scale are:

- Controlling cycles at a set level
- Chemical scale inhibitor treatment
- pH adjustment by acid addition
- Softening of cooling water system makeup

As previously noted, cycles are best controlled by installation of a high quality system for automatic blowdown based on conductivity or metered makeup.

#### Chemical Scale Inhibitors

Chemical scale inhibitors function by either selective adsorption on growing scale crystals, converting the crystal structure into a non-scaling type which does not form a hard scale, or through chemical reactions with the scale forming ions, converting them into non-scale forming materials. The following list notes some of the chemical scale inhibitors commonly encountered.

<b>Chemical</b>	<b>Comments</b>
<b>Polyacrylate</b>	Commonly used polymer, cost effective for calcium scale at 5 to 15 mg/l
<b>Polymethacrylate</b>	Less common polymer for calcium scale at 5 to 15 mg/l
<b>Polymaleic</b>	Very effective polymer for calcium scales at 10 to 25 mg/l, higher cost
<b>Phosphonates</b>	All three common phosphonates are excellent calcium scale inhibitors at levels from 2 to 20 mg/l
<b>Chelants</b>	Both EDTA and NTA, as well as citric acid and gluconate, have seen some limited use for calcium scale control at levels from 5 to 100 mg/l
<b>Copolymers</b>	These products commonly incorporate two active groups, such as a sulfonate and acrylate, to provide superior performance to a single group compound at use levels at 5 to 20 mg/l, higher cost
<b>Terpolymers</b>	Like the co-polymers, only incorporate three active groups to give yet better performance under severe conditions at use levels of 5 to 20 mg/l, costly
<b>Polyphosphates</b>	Fairly good calcium scale control under mild conditions, can revert and contribute to calcium phosphate scale

As with corrosion inhibitors, mixtures of scale control chemicals generally provide superior performance to single component products. Therefore most formulated products contain at least two materials: typically a phosphonate and a polymer.

It has been found that operation at the higher Saturation Index (SI) values, typical of higher cycles, requires that the ratios of the phosphonate and polymer be varied. For instance, a 1:1 phosphonate to polymer ratio will permit operation up to an SI of 1.0. Going to a 1:2 ratio will permit operation up to an SI of 2.0, while a 1:3 ratio will allow an SI of 3.0 to be obtained. Use of co- and ter-polymers is normally only required when other problems, such as iron, phosphate, or silica in the makeup water interferes with operation of typical polymer chemistry for scale prevention. Many water treatment firms have reported operation of cooling systems scale free at cycled SI values from 2.0 to 3.5 without pH adjustment.

### **pH Adjustment**

Control of scale with pH adjustment by acid addition functions via chemical conversion of the scale forming materials to more soluble forms. Thus, calcium carbonate is converted to calcium sulfate (using sulfuric acid for pH adjustment), a material several times more soluble. Normally, it is not desirable to add sufficient acid to convert all of the scale forming materials due to a substantial increase in the corrosivity of the cooling water if this is accomplished. Note that addition of excessive acid to the cooling water results in depressed pH values and extremely rapid corrosion of all system metals.

The SI is generally utilized for system setup when pH adjustment by acid addition is used for scale control as it is a convenient means of reducing the integrated parameters of calcium, alkalinity, pH, dissolved solids, and temperature to a single value, which indicates the tendency of water to form a calcium scale or promote corrosion.

A positive SI number indicates a scale forming water while a negative SI number indicates a scale dissolving, or corrosive, water. SI can be easily calculated as already noted with a hand calculator or computer program.

Normal practice is to maintain a slightly positive SI number, +.2 to +.5, when utilizing pH adjustment by acid addition and add some chemical scale inhibitor to cope with the resultant slight tendency to scale. Instances have been reported where scale has been controlled with makeup calcium water hardness values up to 3000 mg/l as CaCO<sub>3</sub> with a combination of pH adjustment by acid addition and chemical scale inhibitors.

An important point to remember is that acid addition to cooling water should only be undertaken with an automatic pH control system and well trained operators. This caution is included as serious corrosion damage will occur in a very short period of time if excessive acid is added to the cooling water. Only high quality pH controllers equipped with acid pump lockout timers should be considered for this critical application. **Daily plant control testing is required with use of pH control systems.**

### **Makeup Softening**

While this technology is limited to only a few water management firms, scale can be completely eliminated by softening all cooling system makeup water. Using softened makeup water for scale control is the safest, most cost effective method available for obtaining high cycles, or zero blowdown, with hard makeup water. Normally, the added cost of softened makeup water is balanced by the decreased chemical and water usage resultant from the increased cooling system cycles made possible by the soft water. Note that operation above six (6) cycles generally requires use of bypass filtration to prevent deposition problems.

The increased general corrosiveness of the softened water is countered by the high pH values (8.5 to 9.5) developed when the cooling system is cycled up with softened makeup. This, in combination with a good chemical corrosion inhibitor program, usually results in lower corrosion rates than the same cooling system using chemical scale inhibitors or pH control by acid addition. Specific inhibitor technology for control of white rust and corrosion of copper must be utilized with softened makeup water.

As noted, use of softened makeup water is also employed to obtain zero blowdown from cooling systems for either fresh water use reduction or environmental reasons. Reference to the equations given in Section II show that zero discharge can be attained if windage equals or exceeds blowdown. Therefore an increase in cycles to reduce blowdown to the point where it is equaled or exceeded by windage will result in zero blowdown from the cooling system. In practice, zero blowdown is attained between twelve and thirty cycles with cooling water conductivities up to 60,000 mmhos reported. Facilities attempting to attain zero discharge are advised to use a water management firm which has experience in this area due to the increased potential for corrosion when using softened makeup water, control of white rust, and possible increased deposition from the high cycles required.

## V. DEPOSITION

Deposition is a general term for all the things that can cause problems in a cooling water system that are **NOT** due to scale, corrosion, or biological activity. We find that such deposition can result from scrubbing of airborne material from the ambient air by the cooling tower, process contamination of cooling water by such things as leaking oil coolers, and suspended material in the makeup water.

Deposition affects process operations much like scale, the deposits act as a thermal insulator to decrease heat transfer efficiency in production equipment. Deposition can also cause physical blockage of cooling water passages and increase corrosion rates by blocking corrosion inhibitor access to the base metal, i.e., under deposit corrosion.

### Control

Measures taken to control deposition depend on the cause of the problem. Process contamination problems are best corrected by elimination of the process leakage, while most suspended solids deposition can be controlled by addition of dispersant/surfactant chemicals to the cooling water. These materials function by charge neutralization of the suspended particles and emulsifying binding agents, breaking up existing deposits and preventing agglomeration of the particles to form new deposits.

The following list notes some of the dispersant/surfactant chemicals commonly encountered with comments:

<b>Chemical</b>	<b>Comments</b>
<b>Polyacrylate</b>	Commonly used scale control polymer which is also cost effective for clays and silts at 5 to 15 mg/l
<b>Polymethacrylate</b>	Less common scale control polymer also effective for clays and silts at 5 to 15 mg/l
<b>Polymaleic</b>	Scale control polymer which is also very effective for clays, silts, and iron based deposits at 10 to 25 mg/l, costly
<b>Polystyrene</b>	Effective polymer deposition inhibitor which is effective with higher iron levels, commonly used at levels of 10 to 20 mg/l
<b>Copolymers</b>	These products commonly incorporate two active groups, such as a sulfonate and acrylate, to provide superior performance to a single group compound at use levels at 5 to 20 mg/l
<b>Terpolymers</b>	Like the co-polymers, only incorporate three active groups to give yet better performance under severe conditions at use levels at 5 to 20 mg/l, costly
<b>Polydiol</b>	A corrosion inhibitor that also has a surfactant action which breaks up many deposits at 2 to 10 mg/l
<b>Surfactants</b>	Several specific surfactants are used to break up many process related deposits such as oil

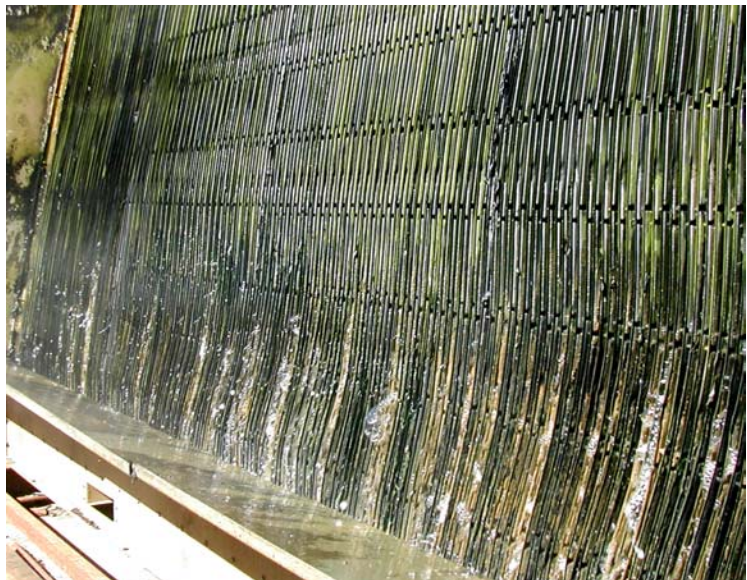
Severe suspended solids deposition should be treated with a combination of chemical dispersants/surfactants and an element filter, hydrocyclone, or media filter in a side stream configuration.

Note that the most difficult to control suspended solids in a cooling tower system are in the range of 2 to 35 microns, below 2 microns dispersants work quite well, above 35 microns removal devices like hydrocyclones can be employed as well as simple sedimentation. For removal of suspended solids in the critical 2 to 35 micron range, we have found multi-media, automatic backwashing filters to be most effective.

In general, if a cooling system is to be operated at over six (6) cycles, some form of bypass filtration is required to prevent deposition and resultant corrosion problems underneath deposits. In dusty environments, such filtration may be required regardless of the chemistry or cycles operated.

## VI. BIOLOGICAL FOULING

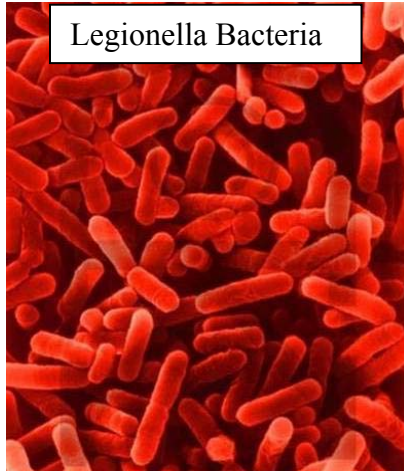
Microbiological growth within a cooling water system, if not controlled, can result in formation of biological fouling layers (biofilm) on all surfaces in contact with the cooling water. This biofilm affects process operation much like the previously discussed scale and deposition: the biofilm acts as a thermal insulator to decrease heat transfer efficiency in the production equipment. Biofilm usually results in a substantial corrosion rate increase due to formation of anaerobic areas under the fouling layer. This creates galvanic couple corrosion and forms metabolic byproducts such as hydrogen sulfide, which actually attack the base metals.



Severe cases of biological fouling have resulted in complete cooling system failure due to the biomass physically plugging cooling water passages in production equipment and cooling towers.

Waterborne diseases such as **Legionnaire's Disease** are also a major health and safety concern with operation of many cooling water systems. Legionnaire's Disease is a bacterial infection spread by inhalation of particles containing legionella bacteria.

One of the recognized primary sources of such particles is the windage, or drift, produced by normal operation of a cooling tower where cooling water is entrained in the air stream and subsequently discharged into the atmosphere. If the cooling water contains legionella, the resulting particles can be a source of infection.



Legionella bacteria are generally controlled by maintaining a biologically clean system, which is defined by the Centers for Disease Control (CDC) as having no visible biological debris in the system and having dip sticks below  $10E4$  and ATP below 2000 RLU. OSHA, in their Technical Manual, Section III, Chapter 7, discusses control of legionella. OSHA notes oxidizing biocides, "such as chlorine and bromine have been proven effective in controlling legionella in cooling towers" while "little information exists on the demonstrated effectiveness of many commercial biocides". OSHA has further set recommended action levels for legionella bacteria in cooling water of below 100 cfu/ml, no action; from 100 cfu/ml to 1000 cfu/ml, prompt cleaning and/or biocide treatment of system; and above 1000 cfu/ml, immediate cleaning and/or biocide treatment, take prompt steps to prevent employee exposure. Two tests per year are recommended to confirm that the legionella level in any cooling system is below the OSHA recommended action levels. We have found that the Special Pathogens Laboratory in Pittsburgh is one of the best laboratories available for this specialized testing.

### **Biocide Chemistry**

Present practice for control of biological fouling is to periodically dose the cooling system with a biocide to kill as many of the organisms present as possible. The **dose makes the poison**: a biocide does not work unless a **critical dosage is reached and maintained** for a set time period. The critical dosage point and time required for effective microbiological control varies substantially with the specific biocide in use and the overall condition of the cooling water system.

The most commonly used biocides can be separated into two major classes, oxidizing and non-oxidizing.

Oxidizing biocides function by chemical oxidation of the cellular structure of the organism, which effectively destroys it and kills the organism. Due to the destructive form of attack, it is impossible for any organism to show, or develop, significant immunity to an oxidizing biocide. Oxidizing biocides are usually quite cost effective due to their low unit cost, rapid effect on the target organism, and low effective dosage. Unfortunately, oxidizing biocides do have some drawbacks.

- Some can decrease cooling water pH in an uncontrolled manner.
- Most increase the corrosive nature of the cooling water.
- Some, such as chlorine, produce undesirable by products from an environmental standpoint
- Some corrosion and scale control chemicals can be inactivated by contact with specific oxidizers.
- None of the oxidizing biocides have any dispersant effect for removal of dead microbiological growth.

- Process contamination can neutralize many oxidizers.
- Some oxidizers are sensitive to water pH as to effectiveness.

We believe that bromine, in its various delivery forms, is the best oxidizing biocide for use in most cooling water applications as it is very effective at the high pH values typical of most cooling waters today and has fewer adverse effects than other oxidizers.

The following list notes some common oxidizing biocides:

<b>Chemical</b>	<b>Comments</b>
<b>Electrolytic bromine</b>	Non-hazardous (green) delivery method for bromine, most cost effective bromine delivery system
<b>Hydantoin</b>	Very effective organic bromine product at 12 to 36 mg/l, costly for an oxidizer on a per pound basis
<b>Stabilized bromine</b>	Another effective organic bromine, n,n,dibromosulfamate, more cost effective than hydantoin, commercialized by ProChemTech in 1993
<b>Chlorine dioxide</b>	Extremely effective product at 0.5 to 2 mg/l active, must be generated on-site from reactive ingredients, lowers system pH, contact measured in minutes, major health and safety problems
<b>Chlorine</b>	The "old" standby and often the most cost effective product available at levels of 0.5 to 1.0 mg/l. Problems include SARA Title III status, danger of working with pressurized gas, and lowering of system pH. Some environmental problems with chlorinated hydrocarbons noted. Ineffective at higher pH values, above 7.5
<b>Ozone</b>	Very effective biocide, major problem is cost and maintenance of on-site generator and pure air needed. Ozone emissions from cooling tower may create a first class environmental problem

Based on our opinion that bromine is the best biocide for cooling water use, we have proceeded to develop and have a patent pending on an on-site electrolytic bromine generator. This unique unit is substantially less costly (factor of 3) than other electrolytic units and uses non-hazardous precursors which eliminates the health, safety, and cost problems with using bromine. In short, this development is the only cost effective non-hazardous biocide on the market. An ElectroBrom™ Model EB 30 capable of generating up to 30 lbs/day of aqueous electrolytic bromine, a mixture of bromine, hypobromous acid, and hypobromite, is shown at the right.



Non-oxidizing biocides function by interference with the metabolism of the organism in a variety of ways which, by preventing normal processes, kills the organism. Due to the large variety of organisms, those that are immune to a particular non-oxidizing biocide will rapidly replace those that are killed by a single dosage. Following doses will become progressively less

effective as the organism population shifts to those varieties that are immune to the particular biocide employed.

Due to this natural effect, the typical recommendation is that at least two different non-oxidizing biocides, or a oxidizing and a non- oxidizing biocide, be utilized in biological control programs on an alternating basis.

Non-oxidizing biocides are generally quite costly due to the high effective dosage, long contact times, and often high unit cost.

However, non-oxidizing biocides do have advantages in that most function in the presence of process contamination, no effect on corrosivity is evident from their use, corrosion and scale control chemicals are usually not effected by them, often they can be targeted at a specific class of problem organism, and several have a definite dispersant effect for removal of dead microbiological growth. The following list notes some of the non-oxidizing biocides commonly encountered:

<b>Chemical</b>	<b>Comments</b>
<b>Hydroxymethyl nitro (Trisnitro)</b>	Effective only with a long residence time, dosage of 70 to 140 mg/l as product needed, generally poor in cooling water uses
<b>Methylene bithiocyanate</b>	Product effective at 15 to 90 mg/l at pH values below 7.8
<b>Quats and Polyquats</b>	Effective against bacteria and algae at 25 to 600 mg/l, high foamers, inactivated by oil/grease, high hardness. Generally low cost
<b>Quat-bistributyl tin</b>	Quite effective against most biology, (Quat/tin) foams and can be deactivated by oil/grease and high calcium. Potential environmental problems due to persistence of tin component. Dosage levels of 40 to 100 mg/l
<b>Carbamates</b>	Very effective at dosages from 40 to 60 mg/l against most everything, excellent against algae. Very toxic to employees and environment, can cause precipitation problems with metals
<b>Isothiazolin</b>	Moderately effective against everything but algae at levels of 35 to 883 ppm. Very dangerous for employees to handle due to attack of eye structure. Very costly due to high dosage and product cost
<b>Glutaraldehyde</b>	Generally effective biocide with major drawbacks being high dosage of 130 to 660 mg/l needed for effective control and toxicity to employees. Very costly product due to high dosage and product cost.
<b>Dibromo nitrilo propionamide (DBNPA)</b>	Generally effective biocide, higher dosage needed for algae, dosages of 25 to 100 mg/l, pH values between 6.0 and 9.5, fast acting

Standard practice by many cooling water treatment suppliers is to employ both an oxidizing and non-oxidizing biocide, with usage alternated on a weekly, or biweekly, basis. Thus a typical combination would be to dose hydantoin twice a week, with carbamate as an alternative every other week.

The cost for oxidizing and non-oxidizing biocides varies substantially on a product basis, with actual use cost complicated by the widely varying strengths (% actives) and dosages of the various products, thus making cost comparisons difficult. The following generic product use costs were calculated as \$ to treat 1000 gallons of cooling water and based on typical product strengths, recommended average dosages, and the list prices for the various biocides as supplied by ProChemTech.

Chemistry	Ave. dose mg/l	lb/1000 gal system vol.	\$/lb list	\$/1000 gal system vol.
20% poly quat	35	0.29	2.30	0.67
16% quat	62.5	0.52	1.80	0.94
30% carbamate	50	0.42	2.30	0.97
20% quat 2.9% tin	80	0.67	2.85	1.91
10% MBT	47.5	0.40	3.25	1.30
20% chlorophenol	212.5	1.77	3.40	6.02
12.5% sodium hypochlorite	30	0.25	0.45	0.11
50% polyquat	68	0.57	3.90	2.22
98% bromochloro hydrantoin	26	0.22	3.90	0.86
20% DBNPA	37.5	0.31	3.30	1.02
25% trisnitro	105	0.88	2.25	1.98
1.5% isothiazolin	127	1.06	3.25	3.45
15% glutaraldehyde	227.5	1.90	2.45	4.67
electrolytic bromine 12.7% bromine precursor	28	0.23 +0.04/power	1.05	0.28
14% stabilized bromine	37.5	0.31	2.00	0.62

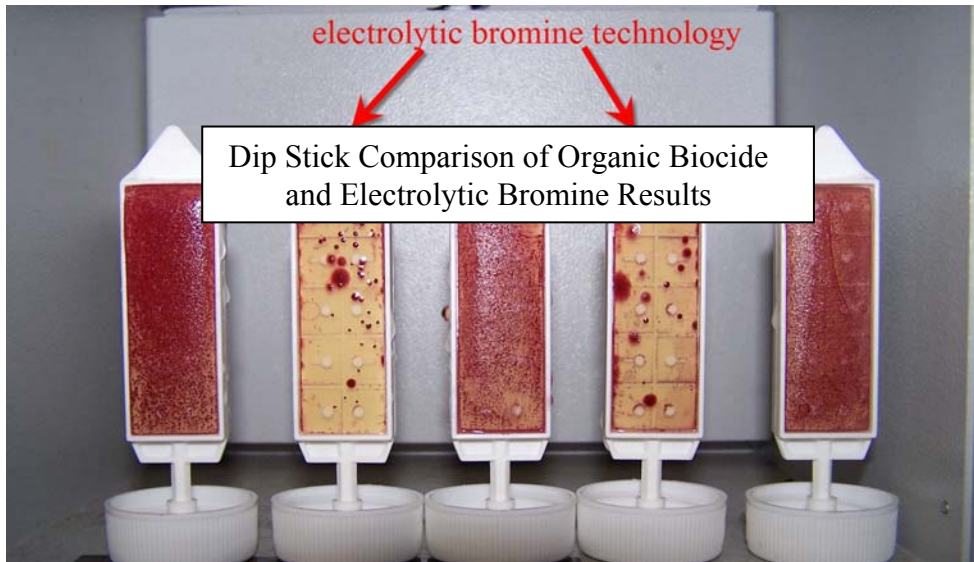
On review of this chart we note the use costs for the commonly specified glut and iso products are shocking. This is a case where many water management firms, through a let's follow the leader, or let's make more money, attitude, have failed to take proper care of their customers.

Note should also be made concerning several "all in one" products which package a non-oxidizing biocide with an inhibitor chemistry for control of corrosion, scale, and deposition in one drum. These products are almost worthless for effective control of biological fouling due to the inability to alternate biocides, adjust biocide dosage independent of the other inhibitors, and the particular chemistry of the biocide mandated by the other components in the product.

**Control**

With the noted OSHA recommendation to use an oxidizing biocide for control of legionella, overall selection and control of a biocide program has become much simpler than in the past. The basic program should be based on routine feed of an oxidizing biocide with supplemental use of non-oxidizing biocides, or biodispersants, as required.

Routine dosing with bromine biocides, two to three times per week, appears to provide excellent control of legionella. Use of a continuous oxidizing biocide does not appear to be required for excellent control of legionella and has a number of bad effects on other portions of the water management program. First of these is increased corrosivity of the water, which is made worse by the oxidation of several corrosion inhibitors, destroying their effectiveness. Continuous feed of oxidizers also adversely affects many scale and deposition inhibitors, also reducing the effectiveness of this portion of the program. When using an oxidizer, a general rule for establishing proper dosage is have 0.5 to 1.0 mg/l total oxidizer present in the treated water one (1) hour after completion of the biocide dose.



The various "dip stick" culture plates and the ATP test kits are also of value in determining how effective a biocide program is.

Our guidelines, as well as the CDC, are to maintain test results no greater than 10E4 for dip sticks and 1000 to 2000 RLU for ATP.

Values above these require increased dosage levels/more frequent applications of biocides. Continued high readings indicate that a switch in biocide chemistry is required.

Based on our experience since 2003 on cooling towers across the United States, a low cost, very effective biological control program can be maintained by simply using only a bromine based biocide, hydantoin, stabilized bromine, or electrolytic bromine; two or three times a week to the recommended bromine residual. The "typical" practice of using two alternating biocides is not required when using a bromine oxidizer.

For calculation of the initial dosage for any biocide, a good starting point is to determine the actual volume of the cooling system by the lithium salt dilution technique and use the suppliers' suggested dosage. The dosage can then be adjusted based on the observed results, "dip stick" or ATP testing, and total oxidizer testing.

If it is not possible to determine the actual system volume, the following "rules of thumb" give good starting point volumes.

Standard cooling tower systems	15 gallons/ton
Evaporative condenser systems	2 gallons/ton

## VII. CHEMICAL PROGRAM SELECTION

While the chemistries of makeup waters are almost unlimited, a few generalizations can be made concerning classes of makeup water and the specific treatment chemistries which have been found to be most effective.

- Natural low alkalinity, low hardness waters with SI less than -1.0 are found in some areas of the country and, like softened waters, are normally very corrosive. Many of the treated industrial wastewaters being considered for reuse as cooling tower makeup fit within this classification. These waters were formerly treated successfully using programs based on the now environmentally outlawed high chromate-zinc chemistry. They are now best treated by using a blended product containing at least two good inorganic corrosion inhibitors, such as polysilicate, zinc, or molybdate; an organic inhibitor such as polydiol; and an azole for yellow metal protection. A dispersant to control deposition and some phosphonate to control deposition of products of corrosion will complete the program. In most cases, all of the above chemistry can be blended into a single product such as ProChemTech's trademarked SoftTek™ products.

- Makeup waters with alkalinity and calcium hardness values between 50 and 200 mg/l, SI -1.0 to +1.0, are commonly found throughout the country. These waters permit a much wider selection of water treatment chemistries, which are all capable of giving acceptable performance with proper selection and control. The following chemistries are generally applicable to these waters:

- The classic water treatment chemistry for this type of water was to control scale formation by pH adjustment, using a high chromate-zinc chemistry, sometimes with phosphate, to very effectively control corrosion. Dispersants were added to the later formulations to control deposition. While programs based on this chemistry are very effective and economical, they were outlawed by environmental regulations.

- Programs which use only phosphonate and polymer chemistry to control scale formation, commonly referred to as "all organic," have been introduced and used with good results. Scale is handled as noted, while corrosion is controlled by formation of a layer of absorbed calcium/iron phosphonate on the metal surfaces, and developed hardness and alkalinity. The better programs also include azole for yellow metal protection and may have additional dispersants for better deposition control. Molybdate is often added as an easy to test for tracer and, at levels of 4 to 6 mg/l, additional pitting corrosion control.

- Phosphate inhibitor chemistry using pH adjustment to maintain the cooling water in a non-phosphate scale forming region (usually 7.0 to 7.5 su) has been used as a low cost program which can give good results.

This type of program depends upon pH adjustment to control scale, while high levels of ortho phosphate, 6 to 12 mg/l, are used to control steel corrosion. Use of an azole for yellow metal protection is a good idea, as well as inclusion of a dispersant and polymer to assist in control of both deposition and scale.

- Alkaline phosphate, or stabilized phosphate, programs depend upon phosphonates and advanced co-polymers to control scale formation without pH adjustment. Corrosion is controlled by the ortho phosphate, high developed alkalinities, and deposition of a controlled layer of calcium phosphonate/calcium phosphate on steel surfaces. Use of an azole for protection of yellow metal surfaces is required, while additional dispersants may, or may not, be needed depending on which polymer(s) are in use. Molybdate has been added to some programs as basically a tracer for control testing and for added protection against pitting corrosion.

- In all of the above programs, zinc can be added as a supplemental corrosion inhibitor, but use of this metal is under increasing environmental pressure. At least two organic corrosion inhibitors, polydiol and maleic-phosphonate, are also being used to provide additional corrosion protection.

- Makeup waters with calcium hardness and alkalinities over 300 mg/l and giving SI values exceeding 2.5, at only 2 to 3 cycles, are less common, but are coming into increased use in some parts of the country due to water shortages. Three proven chemistries are available to treat this type of makeup water: pH adjustment with use of either organic or phosphate inhibitors, HighCycle™ chemistry, and softened makeup with use of good inhibitors.

We have already discussed pH adjustment for control of scale, with very hard, alkaline makeup waters much more acid is required which drive the cost of a normally economic technology up substantially.

Control of scale with cycled SI values exceeding 3.0 and calcium hardness values exceeding 2000 mg/l has been demonstrated with HighCycle™ chemistry which basically utilizes PBCT phosphonate with a high ratio blend of selected polymers.

The use of softened makeup water has proven to be very successful with these hard waters. Corrosion is routinely controlled to levels of 1 mil/yr or less on mild steel, while program cost is equal to, or less, than other programs, with no scale formation. Softened makeup is also required for obtaining zero discharge. The high cycles required for balancing blowdown against windage cannot be obtained without scale formation unless the makeup water is softened.

### **VIII. USGBC LEED Program**

The USGBC LEED program is designed to minimize the environmental impact of building operations via a certification program for new and retrofit buildings. Certification points are awarded for various aspects of the building in areas such as site planning, water management, energy management, material use, indoor air quality, and innovative design.

Four levels of certification are presently awarded based upon the total number of certification points obtained during the LEED certification process: Certified, Silver, Gold, or Platinum.

In the water management area, LEED points can be awarded for elimination of hazardous chemical biocides, reduction of water usage, elimination of wastewater discharge, and use of innovative technology. The number of points and criteria used are at the discretion of the LEED certification evaluator on the specific project.

### **Biocide Replacement**

The greatest adverse environmental impact, and a major safety hazard, from cooling tower operation is the use, with subsequent discharge in the blowdown, of hazardous chemical biocides to control biological growth. Hazardous chemical biocides can be easily replaced by the non-hazardous electrolytic bromine biocide system developed by ProChemTech. This advanced, patent pending technology converts a harmless aqueous solution of sodium bromide and chloride into electrolytic bromine, via direct current electrolysis, on-site as needed. After addition to the cooling tower and reaction with target biota, the electrolytic bromine rapidly degrades back to harmless bromide ion as found in sea water. LEED points can thus be attained by switching to electrolytic bromine from hazardous biocides.



### **Increasing Cycles to Decrease Water Use**

As discussed, there are three methods to increase cycles; acid feed to control pH, advanced scale prevention chemistry, or softening of the makeup water. Acid feed, using hazardous acid, is not practical due to safety and control concerns. In some cases, an improved the scale inhibitor chemistry can be used to increase cycles. Softened water can be used as makeup in hard water areas to provide an increase in cycles to the maximum level (without bypass filtration) of six (6). LEED points can be awarded by operating at higher cycles levels, reducing water usage.

### **Zero Blowdown**

In situations where water is in very short supply, or maximum LEED points are desired, blowdown can be eliminated by softening of makeup water and increasing cycles to the point where windage, the small amount of actual water removed by passage of air through the cooling tower, equals blowdown. Generally, zero blowdown is obtained between 12 and 20 cycles, which **requires use of bypass filtration to control deposition.** Due to the high corrosivity of highly cycled soft water, very specialized chemistry is required for corrosion control. LEED points can be awarded for zero blowdown in the areas of both water use reduction and elimination of wastewater discharge.

A 2007 zero blowdown LEED Platinum project by ProChemTech for the City of Tempe, AZ, shows a water use reduction of 756,000 gpy on a 176 ton cooling tower by going from three (3) cycles to zero blowdown. ProChemTech is providing the water softener, bypass filter, electrolytic

bromine unit, and a complete water management program based upon our specialized soft water chemistry.

## **IX. SUPPLIER SELECTION**

While the foregoing provides the cooling water user with the basics for proper cooling water treatment, the actual chemistry of the program is in the hands of the supplier selected by the facility. It is thus important that a knowledgeable supplier be selected who can provide appropriate control systems and chemistry tailored to the facility cooling systems and specific makeup water quality. The following are some comments on the selection of a water management program supplier.

### **Business Concerns**

The supplier selected should be in the water management business and deal on a routine, direct basis with various commercial facilities and industrial manufacturing plants. There are many firms in the market, in particular sanitation firms, product distributors, and HVAC contractors that deal in such things as floor cleaners, solvents, oils, HVAC equipment/maintenance, or water softeners, who would also be happy to sell a few drums of cooling water treatment "Brand X" to anyone.

Frequently these non-water management firms, while in some cases being quite large, have a very limited product line, no expertise in actual water treatment chemistry, little or no control system expertise, and no analytical laboratory support for resolution of any cooling water treatment problems which appear.

While there are many successful companies which utilize "toll blenders," experience indicates that product quality cannot be adequately controlled with outside product manufacture. The very large water treatment firms have also been touting ISO 9001:2000 certification as a "quality indicator". However, all the ISO 9000 process means is that they have a quality assurance and control program for manufacture and delivery of their chemical products; it has no impact on the quality of the actual water management program. ISO programs are generally fairly costly and add little or nothing, to indicate the potential for success of a proposed water management program.

Comments that "the chemicals are all the same" are obviously incorrect to anyone who has some knowledge of the water treatment field. A product that would provide excellent results with a hard, alkaline makeup will provide nothing but high corrosion rates and early system failure if used with a soft, low alkalinity water.

Proper selection of the specific chemistry and product formulation to be used in any cooling water system should be under the supervision of an experienced water treatment chemist. The AWT "Certified Water Technologist (CWT)" program, put in place in 1996 and open to anyone in the water treatment industry, is the one means of establishing the needed expertise in this field.

## **Environmental Concerns**

Expertise in environmental regulations and water conservation is also becoming a major consideration in selection of a water management program supplier. The supplier should have the capability to consider the effect of environmental regulations on the specific chemistry to be used, and provide any information needed by the regulatory authorities for discharge of blowdown.

While molybdate was first introduced to the water treatment industry as a low environmental impact product, we note that several regulatory agencies have banned its use due to accumulation in POTW treatment sludges. If the molybdate level of the sludge exceeds specified levels, the use or disposal of the sludge as a fertilizer is banned and it must be landfilled at a substantial increase in cost. This problem, combined with the recent high cost of molybdate, has reduced its use by many water treatment program suppliers. To replace the use of molybdate as a tracer, ProChemTech has developed a non-toxic colorant, BlueTrace™, for use in cooling water products. Replacement of molybdate as a corrosion inhibitor has been addressed by the industry in general via increased use of several organic and inorganic corrosion inhibitors.

While the returnable bulk containers being "pushed" by several of the large firms in the water treatment industry for avoiding container disposal problems sound good, they do present some problems of their own. The increased cost of the bulk container, as compared to the standard drum, usually results in a higher cost for products delivered in this mode as compared to drum prices.

A major adverse environmental consideration is the potential for environmentally damaging spills. Loss of 200 to 350 gallons from a bulk container is several times more damaging than a loss of 55 gallons from a drum. As an example, note that SARA reporting limits being based on the amount of material spilled, may often be triggered by a bulk spill, but not by a drum spill.

The container disposal issue should be simply and economically addressed by using a supplier that will simply accept return of all empty product containers, from five gallon pails right through bulk containers. This permits the most economical packaging to be selected from both the usage and cost standpoints, avoiding a lot of the marketing hype for which the water treatment industry is known. Return of all empty containers totally eliminates any container disposal problem and improves the environment by recycle of the packaging.

From a standpoint of water conservation, the supplier should have specific in depth knowledge of blowdown reduction and zero discharge technologies. As noted, this is a specialized area and few suppliers have yet developed the expertise, equipment, and chemistries needed to provide cost effective programs. The best means of obtaining a firm with expertise in this field is to note any technical presentations made by the firm and references as to completed projects. Experience is the best means to ensure quality work in this new and rapidly evolving part of the water treatment field.

### Health and Safety Concerns

Many cooling water treatment chemicals are hazardous (DOT, OSHA, and EPA) and in some cases very toxic. In the case of biocides, by definition they must be, excepting the ElectroBrom™, technology, toxic, hazardous materials and must be handled carefully. Several water treatment firms, including ProChemTech, have formulated specific products for cooling towers which are non-hazardous so as to address the health and safety problems associated with handling and use of toxic chemicals. The use of such "safe" products is the simplest means for a user to avoid potential future chemical accidents.

The case of safe handling and use of biocides is complicated by the fact that chemical biocides are by their nature hazardous materials. At present, there are only two biocide products on the market that are non-hazardous, certain ozone generators and the ElectroBrom™.

### Local Service

The local service representative of the supplier is also very important to the success, or failure, of any water treatment program due to intimate involvement in chemistry specification, program control, and troubleshooting. The user is advised to carefully screen the supplier representatives and obtain one who has both a technical background and experience in the cooling water treatment field.

## X. MAGIC DEVICES



Hydrodynamic Device

In many ways the water management business and water treatment field resembles the used car market. While there are many reputable companies that maintain high professional standards and will do an excellent job in most cases, there are also many "snake oil" firms that sell technologies that are basically worthless or not appropriate.

Examples of such worthless items are the many magnetic, electronic, hydrodynamic, and catalytic, non-chemical water treatment devices (NCD) that have been sold for the past sixty years.

Objective testing has never found a single such device to perform as advertised. Comparison of generally accepted scientific principals and laws with the NCD advertising literature supplied shows that the methods of operation of these devices violates multiple basic scientific principles: it is scientifically impossible for non-chemical devices to function as claimed.

Extensive research literature exists on tests of such devices and can be accessed via the International Water Conference, Cooling Technology Institute, and US Army Corps of Engineers.

There are also many excellent technologies that perform very well for in their intended uses, but have been marketed as all-encompassing cures. An excellent example of a technology that has been marketed for inappropriate uses is ozone. Several firms have claimed that ozone can be used to control corrosion, scale, and deposition; as well as its established use as an excellent oxidizing biocide. Again, objective testing has proven that ozone is basically ineffective as a corrosion, scale, and deposition control agent.

The best protection against the use of fraudulent technology and inappropriately applied technology is to ask for, and check out, some well-informed, reliable references.

## **XI. SUMMARY**

Poor cooling water treatment and control increases facility costs via destruction of expensive equipment, damage to the facility, increased costs for water and sewerage, and increased energy use and cost. Selection of a cooling water management program and supplier based on some knowledge of the chemistry and controls needed will increase the probability of obtaining reliable equipment cooling with maximum heat transfer efficiency at the lowest total cost. Those facilities that devote sufficient time and resources to this vital area will be rewarded by lowered costs and more reliable operation.

Knowledge of the field will also enable the buyer to separate counterfeit products from valid technologies and guard against the problems that can result from use of such something for nothing products.

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