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For Immediate Release

Contact: Chairman, CTI Multi-Agency Testing Committee

Houston, Texas, 1 - January - 2008

The Cooling Technology Institute announces its annual invitation for interested thermal testing agencies to apply for potential Licensing as CTI Thermal Testing Agencies. CTI provides an independent third party thermal testing program to service the industry. Interested agencies are required to declare their interest by March 1, 2008, at the CTI address listed.
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It is again time for the CTI Annual Conference and I look forward to seeing each of you in Houston, Texas. This year’s conference is being held at the Westin Galleria, a new venue for CTI and the Annual Conference. I know each of you will enjoy this fine facility, plus the surrounding area abounds with great restaurants and world class shopping.

The CTI Annual Conference always provides great educational value and affords a wonderful place for networking and socializing. The recent growth in owner/operator participation, as well as first time attendees, is very important to the future of CTI. Without new ideas, new experiences, new perspectives and everyone’s participation, CTI will not be able to keep up with the world’s ever advancing technologies. I look forward to seeing all of the regular attendees at the Annual Conference, but I am especially looking forward to meeting all of the new faces!

One of the events that occur at each Annual Conference is the retirement of three members of the Board of Directors. This year, the three retiring Board members are Ken Kozelski of DuPont, Tom Bugler of Evapco and Jim Kanuth of ChemTreat. These three Board members have put forth much effort towards the betterment of CTI. Please join me in congratulating each one of them for a “job well done”!

In conjunction with the above, I am pleased to announce your three new Board members. They are Chris Lazenby of Southern Company (Owner/Operator representative), Ken Mortensen of SPX Cooling Technologies (Manufacturer representative) and Gary Geiger of GE Water & Process Technologies (Supplier representative). I know all three of these new Board members will continue to serve CTI’s interests and represent its membership for continued growth and well being.

Along with the new Board of Directors, it is time to install your new President, Denny Shea. Denny brings a tremendous amount of cooling industry experience as your new President. I am sure he will have many new programs and ideas that will continue to propel CTI to even higher levels.

With that said, it is time for me to say good-bye. At the beginning of my term, I thought a two-year term seemed like an eternity, but it has absolutely flown by. I have learned so much about CTI that I never knew existed. I have had the privilege to meet many new friends that I would not have if I had not served as your President. I want to thank the Board of Directors for their support, especially when we were faced with difficult issues. And I especially want to thank Vicky Manser and the CTI staff for all of their assistance and support. I will be forever grateful for serving as your President and thank you again for this tremendous opportunity.

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As we reflect on the changes that have occurred in our industry over the last five years, many have a lot to do with CTI.

The certification program for the thermal performance of open and closed-circuit cooling towers has grown significantly. The growth in Asia has been particularly strong. CTI STD-201 is now a part of both the ASHRAE STD 90.1 energy efficiency requirements for cooling towers, and of the California Title 24 requirements. These are both requirements by law for minimum energy efficiency. CTI provides an important benefit to the industry, which it has an obligation to maintain effectively.

CTI has long been a producer and maintainer of Codes and Standards affecting the industry. In recent years CTI has adopted the American National Standards Institute basis for its re-design of the development and approval process. All new task groups since that time have been using this ANSI basis process, and a pipeline of what should become American National Standards are coming. This has and will enhance the professional status of CTI as an organization.

The CTI thermal and drift testing programs have not only survived, but have grown stronger through several changes in the ownership and participation of previous licensed CTI agencies. The administration of these programs needfully must be administered in a fair and balanced way. The professional status of CTI has been and will continue to be affected by perceptions of this program, which continues to serve the industry well.

New programs are in development for re-engagement of STD-202 and for licensing of sound testing agencies. STD-202 was approved and unfortunately only one company was willing to participate, preventing its initiation. STD-202 is a standard for publication of the results of thermal testing for the larger custom cooling towers, by manufacturer STD-202 is near to approval after modifications to reduce the barriers to participation by more manufacturers. It has the potential to be another strong influence on the perception of CTI and our industry. The Sound Testing Task Force is working on development of a licensed testing program based on the revised sound test code and similar to the other licensed test programs. This has the potential to expand the benefits of supervised licensed testing to the acoustic performance arena.

Many codes and standards are under development within CTI. Some, as mentioned above, start whole new programs. We have both an opportunity to strengthen the status and reputation of our organization, and an obligation to effectively follow through on our commitments to the ANSI based process and the programs we administer.

Many transitions are ahead in our industry and the CTI organization as the baby boomers become whatever they will call us when we leave the workforce. The purpose of this editorial is to challenge those of us who are working now on the codes, standards, programs and issues to look ahead at what we can do to enhance the future of the organization and our industry. More than a few opportunities for creativity and clear thinking await us.

Respectfully,

Paul Lindahl
Editor-in-Chief
CTI Journal

Dennis P. Shea
CTI Board of Director President For 2008 and 2009

Denny Shea is President of Shea Top Dog, Inc. He is under contract to Yoh Engineering as an inside Engineering Services Consultant at Solutia, Inc. Chocolate Bayou Plant in Alvin, Texas. He graduated from University of Missouri at Rolla with BS in Mechanical Engineering in 1970. He earned a MS in Engineering Management from University of Missouri at Rolla in 1973 with emphasis in area of Sanitary Engineering.

Denny’s prior work history includes 4 years with Union Electric Company in St. Louis at Labadie Power Plant and Central Engineering. In 1974 he joined Monsanto Chemical Company’s Central Engineering Utilities Design Department in St. Louis. He transferred to Environmental Control and Utilities Department at Chocolate Bayou Plant in Alvin, Texas in 1978. He retired from Solutia, Inc. (Monsanto) as Engineering Fellow after 31 years as Corporate Water Treatment Specialist. He has experience in design, operation and maintenance of Boilers Systems, Cooling Towers, Compressed Air Systems, and Water Treatment Systems. His primary expertise is the design/operation of water treatment systems and cooling tower/pump basin design.

Denny has been involved in Cooling Technology Institute for 30 years. He has served on Board of Directors 3 times. He has been CTI Treasurer and CTI Secretary. He is currently Chairperson of Policies and Procedures and Response and Referral Committee’s. He is active in Water Treatment Committee, Engineering Standards and Maintenance and Owner/Operator Council. Denny is honored to be President and looks forward to growth and expansion of CTI.

Denny is married to Susan Shea has a married daughter Kelly (30), married son Patrick (28) and a granddaughter Isabel (2). Denny owns and operates a dog training school with his wife Sue. They enjoy competing in Obedience and Agility Trials. In addition, Denny is active in Al Garza Martial Arts and Filipino Martial Arts. He has earned black belts in both styles of Martial Arts.
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Living in a Material World: Proper Selection of the Materials of Construction for Cooling Towers in Commercial HVAC and Industrial Applications

Frank Morrison
Baltimore Aircoil Company

Abstract
Evaporative cooling equipment can often be subjected to harsh, corrosive water conditions during daily operation, including the risk of unexpected system upsets. To ensure long life, owners and operators have requested improved corrosion resistance for their cooling towers, closed circuit cooling towers, and evaporative condensers. Manufacturers have responded with new materials of construction to meet these needs. These materials can be arranged in unique combinations to offer improved corrosion resistance at a competitive price for virtually any installation.

Introduction
Many key criteria must be taken into consideration when selecting the proper heat rejection device for a given process. First, the type of heat rejection must be determined, whether water-cooled or air-cooled. This decision is often dictated by equipment size, energy usage, and maintenance requirements of one system versus another. Water-cooled systems are more compact, occupying less space than comparable air-cooled systems. Energy usage is reduced 30% to 40% over air-cooled alternatives due to the efficiency of water-cooled systems and the ability to cool using the cooler wet bulb temperature of the air, rather than the dry bulb temperature. The design day wet bulb temperature is typically 10°F to 30°F (5.6°C to 16.7°C) lower than the dry bulb temperature in a given area, depending on the climate. The lower airflow requirement also results in lower sound levels for water-cooled equipment versus air-cooled. Additionally, because water-cooled systems run at lower operating temperatures and pressures, maintenance is reduced and mechanical equipment life is extended.

Once the decision to go water-cooled is made, there are many options to choose from, including open cooling towers, closed circuit cooling towers, evaporative condensers, and hybrid wet/dry systems. Each type offers unique features that can be beneficial to the user, depending on his or her application. Open circuit cooling towers dominate the market due to the energy efficiency resulting from the direct contact of the air and water, coupled with their relatively low first cost.

Closed circuit cooling towers, which combine a cooling tower and heat exchanger into a single compact unit, have many advantages when used in lieu of open circuit cooling towers. The process fluid to be cooled, usually water or an aqueous glycol solution, flows through a heat exchange coil and is kept separate from the outside airstream and spray water. This results in significantly less process heat exchanger fouling. Any fouling that might occur on the outside of the closed circuit cooling tower coil surface can be controlled relatively easily by the water treatment program for the recirculating spray flow. A closed loop also reduces system maintenance, reduces pumping costs, and provides location flexibility (unlike an open tower, a closed circuit cooling tower can be located below the process to be cooled thanks to the pumping advantage of the closed loop). These advantages must be evaluated against the higher first cost as well as generally higher fan energy requirement and operating weight of the closed circuit tower design.
horsepower required to move the same airflow. The wide availability of low sound axial fans options and attenuation features make their use very practical in most applications. Centrifugal fan units still have applicability in legacy applications, indoor locations, and very sound sensitive locations.

The next step is to size the tower for the anticipated thermal duty, taking into consideration peak loading, part load duties, and reserve capability requirements. Necessary options should then be selected, such as low sound axial fans, sound attenuators, access platforms, handrails, vibration cutout switches, variable speed drives, motor controls, electric water level controls, sump sweeper piping, and basin heaters.

Lastly, the proper materials of construction should be determined. The proper materials of construction are installation specific and often vary depending on the particular tower component and where it is located in the tower. This decision will often dictate the longevity of the tower as well as the maintenance program required to assure a long life. Many choices are available and budgetary considerations must be weighed against many other factors in the decision-making process. This is the main focus of this technical paper. Guidance is offered in the selection of materials, primarily for factory assembled towers for commercial HVAC and industrial applications. References to field erected tower construction are included where appropriate.

Material of Construction Selection Considerations

In many ways, the proper selection of materials at the time of system design is the most important consideration in ensuring the longevity of the cooling tower. Changes to water treatment regimes, such as the legislative ban on the use of chromates and the increasing use of non-chemical devices, is changing the industry. Raw material inflation has altered the balance between different materials of construction. So the initial choice of materials has many consequences:

**Helps to establish the required water treatment program**

More corrosion resistant materials allow the operator to run higher cycles of concentration in the tower, which can save water and treatment chemicals. Using coated metal or stainless construction can also avoid issues with white rust that can occur with galvanized steel construction. Note also that the designer and operators must also keep in mind all the other equipment with which this process water will come into contact with, such as water-cooled refrigerant condensers, plate & frame heat exchangers, and process piping. All too often, the cooling tower is the weakest link in the system from a materials standpoint.

**Determines the allowable water quality that can be used for make-up**

Depending on the constituents in the make-up water, more corrosion resistant materials of construction may be required. Or the decision could be made to go with less corrosion resistant materials and call for a more aggressive and frequent upgrade / replacement schedule. Some operators have chosen to pre-condition a portion of problematic make-up water through the use of reverse osmosis or water softening systems. This conditioned water is then blended into the normal make-up flow to improve the water quality. This eases the burden on the water treatment program and may allow the use of less corrosion resistant materials.

**Helps to guard against system upsets, providing an “insurance policy” against a costly oversight**

The more corrosion resistant the materials of construction are, the more forgiving the system will be in terms of tolerating temporary upsets, such as an acid pump sticking on over a weekend or corrosive water resulting from a fouled conductivity meter used for blowdown control.

**Establishes the budget for the project**

Manufacturers’ offer a wide array of materials and material combinations to suit users’ needs and budgets. Generally, the more corrosion resistant materials will be higher in cost, but may not be necessary for all applications, as will be discussed later.

**Influences the maintenance program and replacement schedule**

Manufacturer’s guidelines must be followed to ensure long service life. Corroded areas need to be addressed early before more major repairs are required. The expected maintenance budget and replacement schedule should be taken into account when evaluating life-cycle costs on cooling tower material choices.
Many factors go into the selection of materials for a specific cooling tower installation. These factors include the following:

**Project Budget**

First and foremost, how much money is available versus the specific goals of the project? Is the goal to achieve a certain level of energy efficiency and sustainable design? Or is it to bring the project in at the lowest first cost? Good judgment must be exercised on this decision as towers can often be the forgotten backend of larger systems, yet are absolutely necessary for proper operation and overall system efficiency. A poor decision on materials of construction at this stage can be very costly later on.

**Where the tower is located**

Decisions on materials are often dictated by the locale of the tower along with the specific location within that locale. Material choices for a tower in Baltimore, Maryland area, for example, will likely be unsuitable for a tower to be located in Phoenix, Arizona. This would be due to make-up water quality, UV exposure, and climatic differences between the two locations.

**Expected useful life of the installation**

Some sites may be considered temporary (less than five years), so a tower constructed of galvanized steel, which typically offers the lowest first cost, will be used. For larger, short-term installations at process facilities, field-erected wood construction is often the most economical alternative as compared to concrete, metal, or fiberglass designs.

**Duty cycle for the tower**

Establishing the duty cycle for the tower can help to determine the most suitable materials of construction. For instance, will the tower only be operated in the Summer months, then drained and shut down for the Winter? Is the tower cooling a critical facility that must operate 24/7/365? Or will a tower in a process facility be subject to temporary excursions when the recirculating water temperature can exceed 130°F for a period of time?

**Make-up water quality**

The source of make-up water will be a major determinant of the proper material for the tower. Water quality can vary greatly from location to location, so be sure to check the source first. Complicating matters, the quality of water can vary over time, perhaps as aquifers change due to varying rainfall amounts. Additionally, the local water utility can switch its source of water seasonally or even more often, such as occurs in the Phoenix, Arizona area.

**Corrosive environments from external sources**

External factors such as salt air in coastal areas can influence material selections. Salt air can attack the outside of the tower as well as affect the water chemistry within the tower. In addition, towers located near boiler exhausts can produce acidic conditions in the recirculating water (ideally, towers should be located as far away as possible from these exhausts). As towers are also excellent air washers, sand, dirt, and organic matter can be drawn in, which can add to the corrosion potential of the recirculating water.
Typically, mill galvanized steel is used for the centrifugal fan wheels. Coated metals or stainless components may be used if the unit is installed in a coastal area where the salt air would lead to premature failure of these air inlet components.

**The criticality of the process being cooled**

How long can the system be down in the event of a failure due to corrosion on the tower? Many critical sites select premium materials of construction for this reason, besides building in redundancy in the cooling system. Examples would include data centers that require 24/7/365 up-time operation or process plants where downtime is measured in hundreds of thousands of dollars per hour of lost production.

**Federal, State and Local Codes**

Building codes may require the use of a seismic and/or wind resistant structure for the tower and material strength considerations come into play here. Building and fire codes can also strongly influence the selection of tower materials. Regulations on water treatment chemicals or sewage discharges may also influence material selection, especially for the cold water basin. Lastly, some local regulations may require a certain level of recycled content and/or the ability to properly dispose of or recycle the tower components after their useful life is over.

**Unique site considerations**

Requirements stemming from unique site conditions can lead to changes in the standard materials of construction. These can include desert environments subject to intense UV from sunlight and high ambient temperatures or coastal regions with salt air environments. When designing a system for a region outside of your own area, consider consulting a source familiar with that area and the unique needs that might be required.

**Access to the tower**

Is the tower readily accessible for maintenance, so that corroded parts, should they occur in the future, can be easily repaired or replaced? If not, more corrosion resistant materials may be called for. Examples include towers located in tight refinery areas, on top of very tall buildings, or indoor ducted locations.

**Weakest link in the tower**

Be on the lookout for the weakest link in any section or specific component of the tower. For instance, when specifying a tower with a stainless steel cold water basin, be sure that all casing structural elements that extend below the overflow water level are also stainless steel. Additionally, watch out for dissimilar metals in direct contact with one another in wetted areas of the tower (for instance, a stainless steel coil for cooling deionized water on an induction furnace mounted on galvanized steel supports should utilize non-conductive isolators, such as neoprene pads, between the metal contact points).

**One material does not fit all circumstances**

What may have worked on the last project, may not work on the next. And what works in one locality, may not work in another halfway across the country or the world. The specific requirements for each project should be determined to help ensure that the project is not under or over designed. This applies to the entire tower as well as individual components.

**Availability of a material from a particular manufacturer**

A designer may select a certain tower type and configuration as ideal for a particular project, but the available materials of construction from the supplier may not be suitable for that particular project. All of the above factors must be carefully considered to ensure a successful tower installation that will operate at peak performance for many years.

**Available Materials**

Towers today are available in a wide variety of configurations and materials of construction to suit virtually every need. Some of the more common materials used in the commercial HVAC and industrial markets are as follows:

- Galvanized steel
- Stainless steel
- Fiberglass
- Plastics
- Concrete
Galvanized steel is the most common material of construction for factory assembled cooling towers and many components of field erected cooling towers. A zinc layer, consisting of a zinc-steel alloy region and a pure zinc layer, forms a protective, sacrificial barrier to corrosion over black steel. Galvanized steel is suitable for most common water conditions and is the most economical material choice for the typical application. There are many examples of galvanized towers lasting 25 years or more.

Coatings, such as a hybrid polymer epoxy, can be applied to galvanized steel to further its corrosion resistance. Proper surface preparation and application techniques are critical as zinc is a reactive surface that does not readily accept coatings or paints. Coatings can also help guard against white rust formation and reduce the need for a passivation process on new galvanized steel towers.

Factory assembled towers typically use G-235 galvanized, which is defined as 2.35 ounces of zinc per square foot of steel (note that this value is for both sides of the steel, implying 1.175 ounce per side). This is a substantial increase in the amount of zinc compared to the previous industry standard of G-90 (0.90 ounce of zinc per square foot). Note that G-235 is the heaviest commonly available “mill” galvanized steel available today.

Hot dip galvanization after fabrication is often used to protect closed circuit cooling tower coils and mechanical equipment assemblies from corrosion. The hot dip process typically deposits 1.5 ounces of zinc per square foot of steel per side, which is heavier than even G-235. This value is dependent on the thickness of the part that is galvanized, with the thicker parts picking up proportionally more zinc.

When working with galvanized metal, any black steel areas exposed during welding, cutting, or drilling during post-galvanizing assembly or fabrication should be repaired. The affected area must be thoroughly cleaned and coated with a suitable zinc rich compound. This also applies to any similar modifications that may be made to the tower after installation.

Stainless steel is called for in more corrosive environments or as an insurance policy against temporary system upsets. The relatively high chromium and nickel content of stainless steel provides an improved level of corrosion resistance compared to galvanized steel due to the hard, protective chromium oxide film (passivation layer) that forms on the surface. Type 304 is the most common and economical stainless steel for cooling tower duty, though Type 316 is also utilized for special applications that require added protection and can justify its added cost.

Type 304 and 316 stainless steels are very similar in chemical composition. The largest difference is that Type 316 contains two to three percent molybdenum, which is not found in Type 304 stainless steel. Note that while more corrosion resistant than Type 304 in certain instances, Type 316 stainless steel will provide only marginally longer service life in a poorly maintained tower.

Additionally, temperature plays an important role in the rate of corrosion – the higher the temperature, the faster the rate of corrosion; the lower the temperature, the slower the rate of corrosion. Temperature levels in the typical HVAC or process system are at the low end of this range. With this moderate temperature duty, Type 304 stainless is more than adequate on the vast majority of projects at a substantially lower cost than Type 316 (typically 25% to as much as 35% lower due to recent steep increases in raw material costs such as nickel and chromium).

Note that plate and frame heat exchangers are typically supplied with Type 304 stainless steel plates, which are approximately 0.5 mm thickness. These plates are exposed to the same cooling water that flows through the cooling tower. Additionally, a chiller will typically have copper tubes and the system piping will usually be
black steel. Therefore, keep in mind that an environment harsh enough to warrant Type 316 stainless steel in the tower will have serious consequences for the rest of the system if these other components are not made out of comparable materials. Even the best water treatment program will be limited by the least corrosion resistant component of the system.

Fiberglass is used for many tower components as well as for complete towers. Traditional fiberglass is a hand-laid composite consisting of multiple layers of glass and resin. Newer pultruded designs have much more strength and consistency, but at a higher cost. Both need a top layer to protect against UV and weathering. In general, fiberglass is impervious to most water chemistries and water treatment chemicals found in cooling towers. However, thermal stresses can result in cracking, primarily with hand-laid designs. Flammability can also be a concern. On the plus side, fiberglass can often be repaired in the field if necessary.

Like fiberglass, plastics can also be used for many tower components as well as complete towers. This can make the tower very corrosion resistant. For instance, the standard spray water piping for closed circuit cooling towers and internal single inlet piping on open towers is made from polyvinyl chloride, or PVC. For towers fabricated entirely of plastic, the relatively low stiffness of plastics, especially unreinforced plastics, must be taken into consideration. As with fiberglass, thermal cycling, cracking, and flammability are also concerns. The ability to repair the tower, should damage occur in the future, must also be determined. Plastics are also tied to the price of oil, which has climbed in price in recent years, leading to potentially higher equipment first costs.

Lastly, cooling towers made from concrete usually fall into the category of “architectural” towers, designed to blend in with their surroundings. These types of towers are used when the site lacks space for a traditional tower or as a way to meet structural codes. Tower evaluations for large heat rejection loads on heavy industrial and power sites often consider concrete towers, depending on the cost and availability of cement in the local area relative to other materials of construction. For a discussion of concrete requirements, refer to the discussion on concrete cold water basins in the next section.

Building a Tower from the Ground Up – Which materials to use?

Now that we have reviewed the basics, let’s build a tower to illustrate the options that are available and highlight any potential pitfalls or opportunities. Cooling towers typically consist of a cold water basin, a structure containing the fill (and / or coil in the case of a closed circuit design), a water distribution system, and an air moving system. Other major components include air inlet louvers, drift eliminators, and casing. Each area of the tower presents its own set of challenges when it comes to corrosion resistance. Additionally, let’s not forget the accessories on the tower, such as access platforms, basin heaters, control enclosures, and sound attenuation, which must also be protected as well as be compatible with the remainder of the tower.

Cold Water Basin

Let’s start with the tower from the ground up – the cold water basin or sump. This is considered by many the most critical component because it must not only hold the tower water volume, but the basin also supports the rest of the tower. The cold water basin is also the most difficult component to replace. Additionally, leaks of treated cooling water can be expensive as well as a nuisance and safety hazard for operating personnel, especially in cold weather.

A wide variety of material options exist for the cold water basin, as listed below:

- Galvanized Steel
- Coated Steel
- Lined Basins
- Type 304 Stainless Steel
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Brentwood Europe  
In September, the Brentwood Europe engineering & sales office opened in Prague, Czech Republic, centrally-located to serve our customers across Europe and Eurasia.
Galvanized steel is the most common material for cold water basins, followed closely by a growing use of Type 304 stainless steel. With proper care, good make-up water quality, and a good water treatment program, a galvanized cold water basin can last the lifetime of the tower. Coated galvanized steel can help extend the life of the basin and reduce issues with white rust. However, the water quality limitations for the specific coating should be noted and consistently followed, especially in the basin area.

For more aggressive water conditions, Type 304 basins are often used. This material also has the advantage of protecting against temporary system upsets even on sites with good water quality. One concern with the use of stainless steel is the possibility of chloride attack resulting in cracks and/or pits. However, for a chloride attack to occur, oxygen, chloride ions, and high temperature are required. Due to the relatively low temperatures found in the cold water basins of cooling towers, the rate of such corrosion is usually very low. Type 316 stainless or concrete is sometimes specified for sites where very high chlorides are an issue. In the cases where high chlorides are unavoidable, Type 316 may provide only marginal additional life compared to Type 304. More cost-effective alternative materials should be considered in these circumstances, such as fiberglass or polyurethane liner systems.

The key to longevity in any cold water basin installation, but especially those fabricated from stainless steel, is to keep the basin relatively clean to avoid setting up corrosion cells. Stainless steel works by forming a protective barrier to corrosion in the presence of oxygen. If deprived of oxygen by dirt deposits on the floor of a basin, corrosion cells can be formed and pitting can occur. Locating the tower where dirt and dust cannot be readily drawn into the tower, maintaining a proper bleed rate, and regularly cleaning the basin can minimize dirt and sediment deposits. Furthermore, the use of sump sweeper piping and either a separator or filtration system can significantly improve the cleanliness of the cold water basin.

Welded stainless steel basins are also an advantage in that leaks are minimized compared to bolted basins. This is due to the fact that bolts loosen as the elastomeric sealer relaxes over time. Welding of the seams eliminates the need for sealer and thus the potential for leaks. Proper welding techniques must be followed to allow the protective barrier to reform and thus prevent corrosion in the welded joints.

When specifying stainless steel cold water basins, be sure to be very clear about which components are stainless steel and which are not. At a minimum, all components below the maximum water
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level in the tower should be stainless or some other non-corrosive material. Manufacturers offer basin designs that include a greater stainless content for more difficult duties. This can be especially important on forced draft centrifugal fan designs, such as illustrated in the Figure 19 on the next page.

Figure 19  All Stainless (left) versus Water-contact (right) Stainless Steel Cold Water Basins (Stainless Steel Components Shown in Blue and Galvanized in White)

As an alternative to stainless steel, polyurethane liner systems are available to extend the life of the cold water basin. These are applied over galvanized steel and provide an inert, durable barrier between the basin water and the galvanized steel. As the galvanized surface is a reactive surface, a bonding substrate, such as a primer or epoxy coating, is used for proper adhesion of the barrier. Surface preparation and cleanliness are important to the bonding process.

Figure 20  Cold Water Basin with Factory Applied Polyurethane Liner Undergoing Production Test

Proper health and safety precautions should be followed in the applications of these liners, which involve the proper mixing of chemicals, some of which can be hazardous. Once applied and cured, however, the polyurethane is inert, has no volatile organic compounds, and can be disposed of in a land fill. While these liners can be field applied on new towers, factory application is preferred to ensure optimum quality, longevity, and the lowest first cost (avoiding costly field labor and difficult site conditions).

Concrete can also be a suitable material for cold water basin construction, especially for systems with very long life expectancies. Concrete cold water basins are typically used for field erected towers, but also can be used for factory assembled towers. Existing concrete basins may be reused when a field erected tower is replaced by factory assembled cells. Or for new installations, the Owner may want a common sump for multiple tower cells to simplify equalization and piping. The factory assembled towers can simply drain into the concrete sump or can be basinless, designed with a base frame to mount directly in the sump. Some basinless designs are available with a stainless steel base frame below the water line.

Figure 21  Factory Application of Polyurethane Liner System under Quality Controlled Conditions

Figure 22  Factory Assembled Cooling Tower Mounted on a Concrete Sump (left) with Typical Basin Diagram Showing Mounting Piers (left)

To achieve a successful installation, concrete basins must be watertight, durable, and corrosion resistant. Cracking should be minimized by proper design and detailing, a good quality concrete must be used, and waterproof barrier systems should be used where required. To minimize cracking, design for the expected service loads, provide well distributed reinforcement, include adequately spaced and designed expansion joints, and use coated or galvanized rebar where required by the service conditions. Good quality concrete can be obtained by using suitable raw materials, providing as low a water-cement ratio as possible without compromising workability, and providing air entrainment and adequate moist curing while paying special attention to construction practices.

Waterproofing barriers for concrete basins can be used to enhance water tightness. Membranes are the most effective when subject to hydrostatic head, which means putting the barrier on the inside of the basin. This location can subject the barrier to damage over time and care must be exercised when cleaning these basins to avoid damaging the barrier. Keep in mind that waterproof barriers are not a substitute for good quality, crack-free concrete.

Fiberglass cold water basins are used on many designs to provide corrosion resistance and long life. Issues to guard against are cracking and UV degradation. Often a metal support frame is used with these liners in order to provide the proper support. Plastic basins can also be used. Plastic offers corrosion resistance and light weight. Both fiberglass and plastic have concerns with flammability, such as the risk of an electric basin heater malfunction or workers’ use of a cutting torch or welding machine near the tower.
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Lastly, remote sumps are often used in cooling systems. These sumps, typically located indoors, are used to keep water from freezing, centralize the collection of water from multiple tower cells, or to provide a reserve of cooling fluid for the system. Remote sumps can be made of many of the same materials as the tower basin itself and thus the same guidelines should be followed. However, as the tower itself now contains little to no standing water, the corrosive load on the basin is greatly reduced. This may allow more economical, standard materials of construction to be used.

**Air Moving Section**

The material of construction for the air moving section depends primarily on whether the tower is a forced draft or induced draft design. Forced draft units have the fan system in the dry entering airstream, which is usually a less corrosive environment than in the tower itself. Forced draft centrifugal fan units will typically use galvanized wheels while axial fan units can use galvanized or aluminum fans with success. Belt driven sheaves can be painted cast steel. The fan motor can be standard duty, rather than corrosive duty.

The exception to this is when external sources, such as a location near a seacoast or near a boiler stack exhaust, lead to a corrosive atmosphere entering the tower. In these cases, coated galvanized or stainless steel centrifugal fan wheels should be used as well as corrosive duty motors.

While an induced draft axial fan design generally results in significant energy savings over a forced draft centrifugal fan design, the fan system is located in the warm, moist discharge airstream. In addition to saturated air leaving the tower heat exchange section, drift or carryover is also included in this discharge air. While typically a small amount, ranging from 0.001% to 0.005% of the recirculating flow, the drift can make for a difficult corrosive environment.

Because of this, when using an induced draft design, either crossflow or counterflow, more corrosive resistant materials must be used. This includes the fans, drive system, and motor. This decision is critical to the longevity and serviceability of these components as
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well as to ensure the integrity and safety of the mechanical equipment system.

Fans should be aluminum or fiberglass, with the appropriate hardware suitable for this environment. Smaller towers will occasionally use galvanized sheet metal fans. Sheaves for belt drive systems need to be aluminum rather than cast iron. The corrosion on cast iron sheaves will lead to excessive wear on the belts. Belts should be neoprene and backed to ensure proper contact in this wet environment.

Motors should be specifically designed for this duty with corrosion resistant paint, special insulation, proper seals, and the proper drain holes for the application (shaft up / shaft down / shaft horizontal). Fan shafts and bushings should also be appropriately protected for the duty with a removable protective coating (so sheaves and fans can be changed if necessary). Bearings should be of a design that prevents moisture from washing out the grease.

Figure 28 Cut-away Illustration of a Cooling Tower Duty Motor

Gear boxes in this environment should also be protected with corrosive duty coating. Vent lines should be run outside of the plenum to prevent moisture from entering the gear box. Oil should be checked regularly for signs of water and replaced on the recommended manufacturer’s interval. Drive shafts and couplings should be corrosion resistant, made of fiberglass or stainless steel. When the layout will allow, gear drive systems can use an external motor arrangement, where the motor is outside the discharge airstream.

Figure 29 Gear Drive Fan Systems: External Motor (left) versus Internal Motor (right) Arrangement

Structure

After the cold water basin, the most critical part of the tower is the structure, as it must support the unit under all expected wind and seismic conditions. The structure must also support all the other components of the tower, such as the mechanical equipment and fill. And like the basin, the structure is also difficult to replace in the field.

Galvanized steel is the most common material and is suitable for most applications, considering that the tower water only comes in intermittent contact with the structure, unlike the basin. Coated galvanized steel has the benefit of eliminating issues with white rust. Stainless steel offers the greatest level of protection and should be considered for applications with high corrosion rates, such as near seacoasts or where access for repair and replacement are limited. Smaller towers can be fabricated from plastic or fiberglass, but watch the rating for wind and seismic loading and check local fire codes as well. In the larger field erected towers, wood, metal, and pultruded composite structures are available.

Figure 30 Crossflow Cooling Tower Structure before Installation of the Casing Panels (note welded stainless steel cold water basin) Heat Transfer Components

Modern fill today is typically made of PVC, making it impervious to rot, decay, corrosion, and biological attack. Standard PVC is suitable up to approximately 130°F (55°C) depending on the particular design and configuration (crossflow or counterflow). For higher temperature applications, CPVC can be considered which increases the upper limit by approximately 10°F (5.6°C). Crossflow designs can also have integral drift eliminators and / or louvers for a compact design. UV is generally not an issue, as the fill is typically “shaded” by other tower components. The exception is the case where the fill uses integral louvers that can be in direct sunlight. This can cause brittleness and damage, so the fill should be inspected regularly. If this occurs, then the damaged fill sheets would need to be replaced. This is not an issue where separate louvers are used, which can be more easily replaced if damaged or corroded.

Figure 31 Crossflow Fill with Integral Drift Eliminators (left) and Counterflow Fill (right)
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Coils for closed circuit cooling towers are typically constructed of black steel that is hot dip galvanized after fabrication. Hot dip galvanizing yields the heaviest zinc layer available as mentioned earlier and provides excellent resistance to corrosion. The black steel coils are designed for closed loops utilizing water or aqueous solutions of glycol. Note that while the coils are galvanized on the outside, they are still black steel on the inside surfaces. Here the operator will want to make sure oxygen is kept out of the loop or corrosion will be very rapid. Most galvanized coils that fail, fail do so for this reason.

On occasion, stainless steel or copper coils are required, but this is usually as a result of the type of fluid to be cooled, such as deionized water for induction furnace cooling. Closed circuit cooling towers of a combined flow design which combines coil and fill surface require less heat transfer surface area. These designs can make these expensive coils more affordable for these projects. Rarely is stainless or copper required due to external corrosion reasons in these markets.

Critical to long coil life with any material of construction is to make sure the entire surface area is thoroughly wetted. This can be accomplished by regular maintenance of the spray distribution system over the coil(s). Wet / dry areas on the coil can lead to the formation of scaling and corrosion. This effect can be especially severe on stainless steel coils, where a corrosion cell is set up between the scaled and unscaled areas.

**Water Distribution System**

Water distribution systems are critical to both the performance and life expectancy of a cooling tower. Proper water distribution allows the entire heat transfer surface area to be effectively utilized, ensuring the lowest energy usage by the fan to reject the heat load. This also provides the proper temperature fluid back to the process ensuring that it also operates efficiently. Secondly, proper distribution avoids wet/dry areas which can be a major source of corrosion in a tower while allowing the water treatment to reach all areas of the tower.

Distribution systems fall into two categories – gravity flow and pressurized. Gravity flow systems utilize a distribution basin with metering nozzles located in the bottom of the basin. The orifices in the nozzles are sized to produce a small head of water in the basin (typically 2” [5 cm] to 6” [15 cm]). The duty is not as severe as the cold water basin as the recirculating water drains from these basins at shutdown. However, the water is warmer than that in the basin which can accelerate corrosion rates slightly (a rule of thumb is that the corrosion rate doubles for every 10°F (5.6°C) increase in temperature).

Another difference from the cold water basin is that the hot water basins are located at the top of tower so they are more easily replaceable if necessary. Galvanized steel is the standard material of construction for these basins. Upgrades would include coated steel, stainless steel, and fiberglass. The covers for the basins, required to keep debris and sunlight out, should be of a compatible material.

**Air Inlet Louvers**

Air inlet louvers are designed to keep water in the tower and in crossflow configurations also serve to protect the fill. The louvers can be one of two designs; either integral with the fill or a separate assembly. From our earlier discussion on fill, integral louvers are made of the same material as the fill, typically PVC. This helps to ensure long service life. However, if something happens to the integral louvers, perhaps from wind, icing, or UV damage, splashout from the tower can occur. To repair, the fill sheets that are damaged must be replaced.
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Separate air inlet louvers can be made of either PVC assemblies or fiberglass, steel, or PVC panels. Both types offer long life, but the panel arrangement has wider spacing which is less susceptible to scale buildup, which can block the air inlet openings. The panels are also more robust and can withstand cleaning with a high pressure hose. Both have the advantage of being able to be replaced if damaged. In cases where fire or insurance codes, such as Factory Mutual, require, metal louvers can be substituted on the tower. The metal louvers can be galvanized steel, coated steel, or stainless steel. In these instances, either coated or stainless steel is recommended as this is an area subject to high corrosion due to the wet/dry nature of the location.

Drift Eliminators
The drift eliminators are designed to strip any recirculating water that may get carried over into the airstream. Here, PVC is the preferred material of construction for long life. On crossflow towers, the eliminator is usually integral with the fill sheet (see Figure 12), while they are separate assemblies on counterflow towers, mounted on top of the water distribution system. Some crossflow designs utilize separate removable eliminators sections, such as the closed circuit cooling tower shown below.

Casing
The casing of the unit keeps the cooling air and the recirculating water in the unit. Some casings do double duty and also provide unit structure. Decisions on casing material must take into account corrosion concerns from both inside and outside the unit. Inside aspects would include water quality and temperature. Outside concerns would be the local environment, such as near a sea coast and UV exposure, as well as the design wind pressure for the locale.

Fiberglass panels are a typical material for the casing. They provide great corrosion resistance, but be sure to check the resistance to UV. FRP panels can be either standard or fire-retardant, so check the requirements of local codes and the insurance carrier. These panels are also easily replaceable if necessary due to wind damage. This damage is typically a result of objects that are blown by the wind impacting the tower, rather than the panels being torn off the unit by the wind.

Metal panels, either galvanized steel, coated galvanized steel, or stainless steel can be substituted for the fiberglass panels when there is a fire code or insurance issue. Some users also prefer the steel panels for hurricane-prone areas, such as Southern Florida.
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Note: As of 1999, this technology no longer is sold in the USA as a biocide. The original chemistry was EPA registered (1993) as biocide and also sold as a biofilm removal agent (1994) by The Dow Chemical Company.
Other designs utilize panel construction, whereby the casing itself serves a structural purpose. Here again, the panel material must be selected to be compatible with both internal and external environments. The most common material here is again galvanized steel, followed by coated steel and stainless steel for more aggressive environments. fiberglass sections can also be used as structural members, either hand laid up or pultruded. Entire towers can be made from these sections. Pultruded fiberglass has become extremely popular for larger field-erected towers. This is due to the light weight, fast erection times, and longevity of these designs. This material also eliminates concerns over fire and preservative chemical issues with wood tower construction.

Installation

Obviously, the manufacturer’s guidelines should be followed regarding installation of the tower. For unit anchorage, use the appropriate fasteners between the supporting steel and the basin material. If welding the unit to the anchorage, be sure to apply an appropriate corrosion resistant compound to the weld area. Service personnel should have safe and secure access to all major areas and components of the tower for required maintenance. Some thought should also go towards the ability to repair and replace key tower components as well as the ultimate replacement of the entire tower should that prove necessary in the future.

Manufacturers offer a wide array of options that can make access safer and easier for maintenance personnel. These include ladder and handrail packages, working platforms at the base and elevated portions of the tower, internal walkways, and motor removal davits. The material of construction for these access assemblies should be compatible with the expected environment.

Auxiliary Equipment

Now that the tower has been built from the ground up, the specifier must not forget the many accessories and options that are often called for on cooling towers. This can include electric basin heaters, sound attenuation packages, and access platforms with ladders. Be sure that this equipment is compatible with the materials of construction of the tower itself as well as suitable for the intended duty cycle. For instance, an external galvanized steel access platform would be acceptable on a stainless steel tower when the potential source of corrosion is due to the internal recirculating water and not a corrosive atmosphere near a coastline. Lastly, the fasteners used on the tower must be compatible for the intended duty as well as with the materials they come in contact with.
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Maintenance
Once a new tower is installed on the jobsite and begins operating, it is then up to the operators and maintenance personnel to follow manufacturer’s guidelines to ensure a long, trouble-free service life. The most important aspect to consider is to maintain proper control of the water quality in the tower on a consistent basis and to take the necessary precautions to avoid system upsets.

- If corrosion is detected, take corrective action as soon as possible to stop the problem from getting worse.

Retrofits and Upgrades
As pointed out earlier in the paper, selecting the appropriate materials for the cold water basin and the tower structure are the two most critical decisions. Most other components can be replaced if necessary. This includes items such as fill, coils, louvers, drift eliminators, water distribution systems, and casing panels. Many of these parts or sections can easily be replaced during a scheduled unit shutdown. Field-applied polyurethane liner systems or other coatings can be applied to extend the life of corroded cold water basins. Proper preparation of the corroded surfaces and use of an appropriate primer is critical to the long-term adhesion of these aftermarket liners.

A side benefit of replacement is that these components improve over time and the replacement can provide added benefits to the user. These benefits include conserving energy, restoring or improving thermal performance, or facilitating maintenance. For instance, new replacement fill designs can often improve tower performance both over the reduced dirty tower and the original levels. Modern drift eliminators can reduce the drift rate of older towers. New spray nozzle designs often are more clog-resistant and can offer improved spray coverage over the original. To facilitate installation of these new components, manufacturers and suppliers provide complete aftermarket kits with all parts, fasteners, and instructions for field installation.

Figure 44 Regular Maintenance and Inspection Pays Off in Long Service Life
Recapping key maintenance points to consider from a materials viewpoint from our discussion of materials of construction:
- Monitor and adjust the water treatment regime as required for the site conditions and materials of construction selected; especially guard against system upsets
- Consider use of corrosion coupons of the metals used in the system in order to monitor corrosion rates and effectiveness of the treatment program over time
- Monitor make-up water quality over time and adjust the treatment program as necessary

Figure 45 Keep the Area around the Tower Free of Debris and Clutter for Safe Maintenance Access
- Keep the tower clean either manually or through the use of sump sweeper piping and use of a separator or filtration system
- Regularly inspect the water distribution system to assure proper spray water coverage and avoid wet/dry areas
- Maintain drift eliminators in good condition, especially on induced draft towers to protect the mechanical equipment from unit carryover
- Ensure safe and easy access to all key maintenance points on the tower, including following all fall protection guidelines

Figure 46 Fill Being Removed from a Tower (left) and the Same Towers with the New Fill the Same Day (right)
For any components that fail prematurely, the Owner/operator should consider upgrading the material of construction of the replacement component. This decision will depend on the service life of the original component versus the anticipated remaining life of the tower. For instance, if galvanized hot water basins corrode and need to be replaced on a particular installation, then fiberglass or stainless steel basins should be considered for replacement. Note that fiberglass basins have an advantage in terms of lighter weight, which makes them easier to handle and install in the field.

At some point, the entire tower may need to be replaced. The rule of thumb is that when the repair and upgrade cost for the existing tower exceeds approximately 60% to 70% of the installed cost of a new tower, it is better to opt for the new tower. Special modular tower designs are available from a variety of manufacturers to facilitate installation in tight or restricted spaces. Towers can also be shipped “knocked down”, or disassembled, for assembly on the jobsite. These designs can reduce or even eliminate the cost of a crane.
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Many project designers are concerned about designing systems that are environmentally friendly, with a goal toward a sustainable world. Programs such as Leadership in Energy Efficiency and Design (LEED) from the United States Green Building Council (USGBC) promote such designs for buildings. Buildings can earn silver, gold, or platinum ratings depending on the level of sustainability they achieve. One area in the program covers the use of renewable resources, primarily the materials used in the building itself. Note however that mechanical equipment, such as cooling towers, is not included in these material calculations (reference LEED for New Construction, Version 2.2, MR Credit 4.1). This growing concern with green design and sustainability should be monitored and taken into consideration on all future projects, even if LEED certification is not officially sought for the specific project.

Many questions may be asked when designing for sustainability. Can the materials used in the tower be recycled? What is the recycled material content in a given cooling tower? Are there harmful products used in the tower, such as treatment chemicals used to preserve wood in a wood cooling tower?

For instance, stainless steel is 100% recyclable while some plastic and fiberglass is not. Additionally, the average stainless steel is composed of 60% recycled material, 25% coming from end of life products and 35% coming from manufacturing processes. Some materials of construction may also require a disposal fee, rather than a credit for the scrap metal which can be recycled.

Compatibility with the Remainder of the System

As mentioned earlier, cooling towers are always part of a larger system. This includes such components as piping, valves, chillers and heat exchangers. Water treatment must be designed to protect not only the cooling tower but these other elements as well. The goal should be to balance the life expectancies and the relative costs of replacement of all system components.

Conclusion

A wide variety of materials of construction are available for cooling towers. Selection of materials should reflect the specific requirements and budget for the project. The specifier of the cooling tower should consider the site conditions, expected maintenance, water quality, and duty cycle of the proposed installation.
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A New Closed System Treatment Program for Industrial Applications

William Beer
Rosa Crovetto
GE Water and Process Technologies

Introduction

The recent world supply shortage of molybdate and subsequent increase in price has made its use as a steel corrosion inhibitor more costly. Nitrite, while an established performer in closed systems, has well known microbiological vulnerabilities. Both inhibitors have come under fire from environmental agencies. The most recent of which was a total ban on molybdate use for cooling systems in the Denver Metro Wastewater District Service Area. Canada has strict regulations banning molybdenum in waste treatment sludge due to issues concerning contamination in the food chain. Clearly the need for a high performing organic closed system treatment program has increased.

Closed cooling systems exist in a wide array of industries and have an equally wide array of water chemistry, thermal profiles, metallurgies, and configurations. Water is circulated in a closed cycle and is subjected to alternating cooling and heating without air contact for evaporative heat rejection. The heat rejection is normally accomplished by a water-to-water heat exchanger.

Closed cooling systems have the advantage of being an entirely captured water loop. There is typically very little water loss which allows for critical temperature control of processes, the use of expensive pure water to meet unique process demands like high temperature or low conductivity, conservation of water, and economic use of high treatment residuals that produce superior corrosion and deposit control results (<1 mpy, for mild steel and <0.1 mpy, on copper-based metallurgy and no mineral scale).

Treatment technology applied to closed systems may include corrosion inhibitors, dispersants, pH buffers, and biocides for microbiological control. Typical steel corrosion inhibitors are molybdate, and nitrite. Certain characteristics make molybdate, nitrite, and azole combinations attractive as corrosion inhibitors. They stay soluble under a wide range of conditions, do not produce objectionable deposits, and they perform well under a wide range of water chemistry and temperature. These inhibitors are commonly applied under alkaline conditions (pH 8.0 – 9.0) to achieve optimal steel corrosion protection. The use of silicate, inorganic phosphate, and phosphonates occasionally are found but their use is limited compared to molybdate and nitrite formulations. Most of the typical steel corrosion inhibitors are teamed with a triazole (BZT or TTA) to provide corrosion protection for copper based metallurgy. Dispersants, such as low molecular weight polymers, are sometimes used to keep particulate solids, migratory corrosion products, and precipitated calcium salts in suspension. Non-oxidizing biocides are separately added to the system for microbiological control. Microorganisms can cause fouling and corrosion problems. Microbes can bio-oxidize nitrite and some organic based treatment constituents and render them useless.

To address performance, cost, and environmental needs, a new organic closed system treatment program has been developed by GE Water & Process Technologies.

The New Program

The newly developed organic treatment program provides performance equal to that of the benchmark molybdate and nitrite based program without the necessity of pH buffers to produce a pH in the range of 8.0 – 9.0. This has the added benefit of less deposition potential and a better environment for systems containing aluminum metallurgy (aluminum corrosion potential will tend to increase as pH climbs past 8.3).

The newly developed mild steel corrosion inhibitor for closed loops is a blend of a proprietary Polyphosphonate, a carboxylic Diacid and a Tertiary amine (PDT). PDT has also proven to be a good corrosion inhibitor for Aluminum.

This new inhibitor program can be used for corrosion protection in both hot and cold closed loop applications. It is a unique blend of organic components designed to replace current nitrite and molybdate technologies in these applications. For complete closed system protection, it also includes tolyltriazole (TTA) for yellow metal protection and a polymer for deposit control1.

Experimental

Laboratory testing was performed to assess the performance of this new program under a variety of conditions described in this section. Field evaluations are ongoing in several mixed metallurgy closed loop systems.

Beaker Corrosion Test

A standard protocol for beaker corrosion testing has been established for many years and we have followed this internal protocol in our testing. The protocol has incorporated the best practice procedures from ASTM G-59-91. In the beaker corrosion test apparatus (BCTA), corrosion rates are measured by a linear polarization technique [1,2,3]. In the linear polarization technique a variation of potential φ25 mV from the corrosion potential is applied to the working electrode while measuring the intensity of the current in the circuit. From the intensity vs. voltage values the polarization resistance and the corrosion rate are calculated.

The schematic of the set up, details of the electrodes used, and a description of the parameters of the technique are shown in Figure 1. Five synthetic water chemistries were used in the screening search and in all testing during the development of the new corrosion inhibitor. The synthetic water composition, electrical conductivity, and abbreviated name for identification are given in Table 1.

It is well known that the corrosion rate for mild steel in aqueous systems increases with temperature. The temperature chosen for
testing and screening was 49 °C (120 °F). Preliminary linear polarization experiments at 49 °C (120 °F) showed that a steady state is generally reached in 10 to 12 hours. All the experiments were conducted with the system open to the atmosphere and at pH 8.

After testing many different water compositions, it became clear that the real differentiator in corrosion inhibition performance was the low carbon steel corrosion achieved in an iron oxide laden system. Existing organic treatments that appeared to work well in previous evaluations did not perform well under these iron stressed conditions. This phenomenon is often observed in actual field applications.

Dissolved iron and/or the iron oxides can deplete the available corrosion inhibitor by different mechanisms. The loss of the inhibitor can occur by:

- Formation of an insoluble iron salt that causes precipitation of some the corrosion inhibitor
- Decomposition catalyzed by iron oxides
- Chelation of soluble iron
- Absorption to solid iron oxides

The capability of an inhibitor to survive and perform well in the presence of soluble and insoluble iron is necessary in a closed loop system because closed loops operate with little or no water make up. Therefore oxidized iron (both soluble and insoluble) can accumulate over time and might be present to stress the performance of the corrosion inhibitor.

The benchmark for mild steel corrosion performance in the laboratory was a molybdenum / nitrite blend (A) with 150 to 200 ppm of molybdate as MoO₄²⁻ plus 200 to 250 ppm of nitrite as NO₂⁻. The performance of PDT was compared against two other organic corrosion inhibitor blends previously found effective for mild steel:

- a monocarboxylic phosphonate / azotriamine tricarboxylic (B).
- a tricarboxylic phosphonate / phosphonic nitro (C)

The corrosion rate in each blend was measured at their recommended dosage. Table 2 presents corrosion rates calculated from the polarization resistance values measured after a day of exposure at temperature.

It is not necessarily anticipated that control water III (iron and iron oxide laden) would be the least corrosive to mild steel. This behavior of control water III, is likely due to deposits of loosely adherent iron oxides that can isolate the surface of the metal, having the overall kinetic effect of slowing down the total corrosion rate [4].

It can be seen from Table 2, that the newly developed inhibitor performed as well as the benchmark A in all the five synthetic waters tested.

Table 2 also shows that the other organic products, B and C, start losing their corrosion inhibition efficacy in synthetic water that has iron added to it (synthetic water II) and that they are not effective in synthetic water that is iron and iron oxide laden (mimicking the accumulation of corrosion by-products that can occur in a real world circulating cooling loop).

Figure 2 presents the time evolution of the corrosion rate for mild steel as measured using polarization resistance for the benchmark and for PDT in the “difficult to treat” water III. As seen in the figure, the new treatment can successfully compete with the benchmark.

**Evaluations Under Heat Transfer**

Chemicals that showed good short-term corrosion inhibition were further tested in Laboratory Heat Exchanger Bench Test Units (BTU) used as closed loop circulating units. All the tests were performed for more than 30 days.

An overview of a BTU assembly is given in Figure 3. The conditions for all the BTUs runs reported here were:

- Skin temperature of the heat exchanger tube 60 °C (140 °F)
- The temperature of the sump was 49 °C (120 °F).
- The recirculation rate in the loop was 4 gallons per minute (4.5 feet per second, 1.4 m/s on the heat exchanger tube).
- The evaporative loses per week were less than 5% of the total volume and the system was replenished periodically.

Table 3 shows the corrosion rate for mild steel measured by coupon weight loss for organic treatment B and for the new treatment both applied to synthetic water III. The coupons are located in the circulating part of the loop after the heat exchanger tube. Figure 4 shows the corrosion rate as measured with an on-line corrosion meter for the same two runs reported in Table 3. As can be seen from the figure, organic treatment B failed to protect mild steel from corrosion at day 12. In contrast, PDT performs very well for the entire period of the run (78 days).

Only heat exchanger tubes treated with the benchmark and with the newly developed product were free of any signs of corrosion after at least 30 days of exposure.

Testing in a high temperature BTU completed the evaluations under heat transfer conditions. This BTU works at 180 °F (82 °C) in the sump. The skin temperature on the mild steel heat exchanger tubes is 190 °F (87.8 °C). With the newly developed product, the corrosion rates measured were < 0.3 mpy (7.6 µm/m) in several of the synthetic waters after at least 30 days of run time.

**Static Test Results:**

Static tests attempt to simulate stagnant conditions that may occur in actual closed loop systems due to periodic down times, “dead legs”, etc.

The picture in Figure 5 shows coupons immersed in TRV tap water with no treatment (control), benchmark A (Molybdenum/ Nitrite program), organic treatment B, and the new closed loop inhibitor, respectively from the left to the right side of the picture.

At the time the picture was taken the coupons had been immersed for a year. The first three months were at 49 °C (120 °F). The remainder of the test was conducted at room temperature.

It is clear from the picture that the organic treatment B does not protect the metal in a stagnant system even in an easy to treat synthetic tap water. The newly developed inhibitor is as good as the traditional Molybdenum/Nitrite benchmark. In actual field applications, most closed system programs have difficulty with stagnant conditions without major modifications and implementation of special practices.

Because PDT is of organic nature it is reasonable to suspect that the product could be affected by microbiological degradation or
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that it might increase the potential for microbiological growth in a system. However, by applying a normal level of non-oxidizing biocide when the system is charged with the new program no increased microbiological impact has been observed in the trials conducted.

**Mechanistic Hypothesis**

The newly developed steel corrosion inhibitor works by increasing anodic polarization behavior\(^4\). It protects mild steel by creating a thin, stable metallic oxide that is passive. The oxide film is formed through strong unique molecular interactions of the inhibitor with the iron oxide itself. Surface analysis of the protective film confirms the presence of the inhibitor\(^5\).

This passive layer is maintained by dynamic equilibrium between the oxide layer and the corrosion inhibitor present in solution. Total elimination of the inhibitor from the solution leads to slow degradation of the passive film by dissolution. The dynamic equilibria can be accounted for using Stumm’s\(^6\) interpretation of minerals growth/dissolution. Stumm’s suggests the formation of a modified superficial oxide by interaction between the iron oxide and the phosphonate in solution.

**Field Testing**

Trials of the new product at customer facilities are on going.

**Case Study 1**

The application of the new product to a cold closed loop circulating system at a Southeastern US Pharmaceutical plant started on April 19th 2006.

In this system the maximum water bulk temperature is 42°F (5.6°C) and the volume is 500 gallons (1894 liters). This system has proven to be very “tight” and does not need frequent top off with product to maintain treatment levels.

The make up water composition determined by Inductively Coupled Plasma (ICP) for this system before adding the treatment was:

- 30 ppm of Ca as CaCO\(_3\), 7 ppm of Mg as CaCO\(_3\), 12 ppm of Si as SiO\(_2\), 15 ppm of SO\(_4\) as SO\(_4\), 9 ppm Fe as Fe, 52 ppm of M alkalinity as CaCO\(_3\), 6 ppm of Chloride as Cl, and the electrical conductivity was 168 μS/cm\(^{-1}\) at room temperature.

Table 4 shows corrosion rates from coupon weight loss measurements for mild steel and copper coupons from this site. The results show very good corrosion inhibition for both metallurgies. Below the table are the pictures of the coupons when they were taken from the system and the number of days of exposure.

The results so far demonstrate very good corrosion protection for both copper and mild steel and no microbiological growth.

**Case Study 2**

The new product was also applied to the Southeastern Pharmaceutical customer’s hot closed loop system for three months.

Maximum operating bulk water temperature was 120°F (48.9°C) and the volume was about 500 gallons (1894 liters). This system had constant substantial leaks that made it difficult to maintain the desired dose of product.

The make up water composition determined by ICP for this system before adding the treatment was:

- 1 to 2 ppm Ca as CaCO\(_3\), 3 ppm Mg as CaCO\(_3\), 15 ppm Si as SiO\(_2\), 8 ppm SO\(_4\) as SO\(_4\), 3 ppm Fe as Fe, 36 ppm M alkalinity as CaCO\(_3\), 6 ppm of Chloride as Cl, and the electrical conductivity was 167 μS/cm\(^{-1}\) at room temperature.

Table 5 shows the corrosion rate from coupon weight loss measurements for mild steel and copper and the days of exposure. Below the table are pictures of the coupons.

As can be seen from table 5, when the treatment level of the product was in control and in the desirable range the corrosion rate was at or less than 0.1 mpy (<2.54 μm/y) for both mild steel and copper.

**Case Study 3**

A small closed circulating system that is used to provide heat to an industrial building in the Northeast was treated with the new product. The volume of the circulating loop was 120 gallons (454 liters) and the water temperature varied between 130 and 175°F (54.4 and 79.4°C).

The makeup water composition as determined by ICP for this system before adding the new treatment was:

- 92 ppm Ca as CaCO\(_3\), 63 ppm Mg as CaCO\(_3\), 14 ppm Si as SiO\(_2\), 40 ppm Chloride as Cl, 72 ppm SO\(_4\) as SO\(_4\), 1 ppm Fe as Fe, 67 ppm M alkalinity as ppm of CaCO\(_3\) and the conductivity was 456 μS/cm\(^{-1}\) at room temperature.

Unfortunately the system had neither an on line corrosion rate meter nor a coupon rack. Corrosion inhibition was monitored by periodically taking 2 liters (0.528 gallons) of water from the sample port and measuring the corrosion rate for mild steel in this sample water using the BCTA unit. The water sampled from the system was reheated to 180°F (82.2°C) to be more representative of actual operating conditions.

Results of the corrosion rates for mild steel are given in Figure 6. Pictures of the electrochemical probe used for the measurement as well as the coupon taken out from the beaker test are presented. This trial began on October 28th 2005 and was successfully terminated on March 7th 2006.

**Conclusion**

Based on laboratory testing and case studies the new organic mild steel corrosion inhibitor for closed loop cooling systems that has been developed is capable of replacing molybdate/nitrite inhibitors with the same degree of corrosion inhibition efficacy and without the environmental or microbiological issues associated with those programs.

**References**

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Footnotes

1. The addition of TTA and the polymeric dispersant will be common and implicit in the final formulation of all the mild steel corrosion inhibitors that we will discuss in this study.

2. Open to the atmosphere assures that the oxygen and carbon dioxide levels in solution correspond to the free dissolution equilibria. Additional corrosion rate measurements have been performed with sparging oxygen and/or carbon dioxide at room temperature with no impact on corrosion inhibition.

3. Represented by the synthetic water III.

4. The corrosion rest potential measured against a Ag/AgCl, KCl 1 M reference electrode for all the treated synthetic waters tested was at least 500 mV more positive than the corrosion rest potential of any of the five synthetic water with no treatment. The potential shift positions the metal at the passive zone in the thermodynamic potential vs. pH Pourbaix diagram [5].

5. X-ray Photoelectron spectroscopy (XPS) has been done on the surface of mild steel coupons treated PDT. The superficial passive oxide layer is < 90 Å thin.
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Table 1

<table>
<thead>
<tr>
<th>Synthetic Waters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbreviated Name</td>
</tr>
<tr>
<td>TRV²⁰</td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>I²</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
</tbody>
</table>

²⁰ Initial concentration as Fe from FeSO₄. ²¹ Synthetic tap water ²² At 49 °C(120 °F).

All five synthetic waters were formulated at the same M alkalinity, 35 ppm as Ca CO₃ and:
- 4 ppm silica as SiO₂
- 20 ppm Mg as CaCO₃.

Table 2

<table>
<thead>
<tr>
<th>Corrosion rates for mild steel measured for the control, benchmark, other organic treatments and the new product</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE 2</td>
</tr>
<tr>
<td>Control (no treatment)</td>
</tr>
<tr>
<td>TRV</td>
</tr>
<tr>
<td>Control (no treatment)</td>
</tr>
<tr>
<td>64 (16.26)</td>
</tr>
<tr>
<td>75 (19.05)</td>
</tr>
<tr>
<td>125 (37.15)</td>
</tr>
<tr>
<td>167 (48.77)</td>
</tr>
<tr>
<td>0.05 (&lt;1.3)</td>
</tr>
<tr>
<td>0.12 (3.74)</td>
</tr>
<tr>
<td>0.73 (21.57)</td>
</tr>
<tr>
<td>11 (32.88)</td>
</tr>
<tr>
<td>2.9 (84.3)</td>
</tr>
<tr>
<td>17 (49.2)</td>
</tr>
<tr>
<td>37 (108)</td>
</tr>
</tbody>
</table>

Values for corrosion rate presented in the table correspond to the conditions: at least 24 hours at 49 °C(120 °F) of exposure with beaker open to atmosphere and stirring.

Highlighted are the values of the corrosion rates that are considered as failures.

Each set of values separated by a semicolon represent one test run.

TABLE 3

<table>
<thead>
<tr>
<th>Corrosion rates measured by coupon weight loss in BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product at dose</td>
</tr>
<tr>
<td>µg/m² (mg/ft²)</td>
</tr>
<tr>
<td>Average corrosion rate µg/m² (mg/ft²)</td>
</tr>
<tr>
<td>Organic B</td>
</tr>
<tr>
<td>241 ± 31 (9.5 ± 1.2)</td>
</tr>
<tr>
<td>Newly developed product</td>
</tr>
<tr>
<td>2.0 ± 0.0 (0.07 ± 0.01)</td>
</tr>
</tbody>
</table>

Highlighted are the values considered as a failure.
Table 4 - Case Study 1
Circulating Cold Loop Coupon Data

<table>
<thead>
<tr>
<th># days exposed</th>
<th>Mild Steel</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>&lt; 2.54</td>
<td>&lt; 2.54</td>
</tr>
<tr>
<td>27</td>
<td>&lt; 2.54</td>
<td>&lt; 2.54</td>
</tr>
<tr>
<td>52</td>
<td>&lt; 2.54</td>
<td>&lt; 2.54</td>
</tr>
</tbody>
</table>

Table 5 - Case Study 2
Hot Loop Coupon Data

<table>
<thead>
<tr>
<th># days exposed</th>
<th>Mild Steel</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>15°</td>
<td>&lt; 2.54</td>
</tr>
<tr>
<td>27</td>
<td>46°</td>
<td>&lt; 2.54</td>
</tr>
<tr>
<td>52</td>
<td>&lt; 2.54</td>
<td>&lt; 2.54</td>
</tr>
</tbody>
</table>

* System lost treatment due to leaks.
Seismic Rated Factory Assembled Evaporative Cooling Equipment

Scott Nevins
Evapco, Inc.

Abstract:
The International Building Code (IBC) is a comprehensive set of regulations addressing the structural design and installation requirements for building systems. As of September 6th 2006, 47 states plus Washington D.C have adopted the International Building Code (Figure 1). Compared to previous building codes that solely examined anchorage, the earthquake provisions contained within the International Building Code address anchorage, structural integrity, and operational capability of a component following a seismic event. This paper will focus on the seismic provisions of the 2003 International Building Code as it pertains to factory assembled evaporative cooling equipment and emphasize the methodology for determining the applicability of the code to specific projects.

Background:
The development and publication of the first edition of the IBC was initiated in 1997 by the International Code Council (ICC). The intent was to develop a comprehensive set of regulations for building systems to replace: BOCA’s The BOCA National Building Code, ICBO’s Uniform Building Code and SBCCI’s Standard Building Code. The latest versions of these codes were utilized as the basis for the development of the International Building Code. Representatives from each of the model building code organizations: Building Officials and Code Administrators International, Inc. (BOCA), International Conference of Building Officials (ICBO), and Southern Building Code Congress International (SBCCI) contributed to the development of the inaugural edition, the 2000 International Building Code.

A new edition of the International Building Code is published every three years, containing the code as originally issued and all changes that have been approved through the ICC code development process. The 2003 IBC coincided with the consolidation of BOCA, ICBO, and SBCCI into the ICC. As states and local jurisdictions continue to move toward adoption of the IBC, the International Code Council is tasked with providing all services previously provided by the individual model code organizations.

The International Codes (I-Codes) are comprised of 14 volumes that encompass all aspects of the building design and associated functionality. The first volume of the set is entitled the International Building Code. This volume contains Chapter 16 Structural Design and Chapter 17 Structural Tests and Special Inspections detailing the minimum design criteria and test methodology for structures and nonstructural components. Sections within these chapters detail the seismic provisions of the International Building Code.

Whereas previous model building codes focused exclusively on the structure of the building to provide resistance against seismic forces, the IBC has broadened the scope to include nonstructural components. These components include all aspects of the building architectural, electrical and mechanical systems. The failure of these components during a seismic event has been a common occurrence in recent history. Although the structure of the building may be relatively undamaged from an earthquake, the damage to the nonstructural components could be significant and result in considerable secondary damage to the building (ie. flooding, fire, structural damage). As a result, the International Building Code specifies that all components be designed to resist the equivalent seismic forces as the structure to which they are installed.

Seismic Design:
The seismic provisions of the IBC are contained within Chapter 16. These requirements are based on the National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings and Other Structures published by the Building Seismic Safety Council (BSSC). Section 1613 through Section 1623 of the International Building Code outline the design and construction criteria for structures and components subject to earthquake ground accelerations. The requirements are intended to minimize the loss of life hazard for all buildings and improve the capability of essential facilities to operate, per their intended purpose, after a seismic event.

Section 1621 Architectural, Mechanical and Electrical Component Seismic Design Requirements specifies that all installed components must meet the requirements of Section 9.6 of ASCE 7-02 (American Society of Civil Engineers, Minimum Design Loads for Buildings and Other Structures). Exemptions noted in the code are for all mechanical components assigned to seismic design categories A or B. Section 9.6 of ASCE 7-02 explicitly states that in addition to the attachment and supports, the component itself must be designed to withstand the seismic forces prescribed in the code. This is a major shift from previous model codes. Simply stated, the code provisions require that evaporative cooling equipment and all other components permanently installed on a structure must meet the same seismic design criteria as the building.

The seismic design force, utilized for component design, represents an equivalent static force that is applied to the components’ center of gravity.
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- 3 1/2" x 1 1/2" x 3/16" IBeam replaces 2 x 4 lumber
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\[ F_p = \frac{0.4(a_p)(S_{DS})(W_p)(1+2\frac{z}{h})}{(R_p/I_p)} \quad (Eq. \, 9.6.1.3-1) \]

- \( F_p \) = Seismic Design Force centered at the component’s center of gravity
- \( S_{DS} \) = Design spectral response acceleration, short period
- \( a_p \) = Component amplification factor
- \( I_p \) = Component importance factor
- \( W_p \) = Component operating weight
- \( R_p \) = Component response modification factor (2.5 for mechanical components)
- \( z \) = Height in structure of point of attachment of component with respect to the base. For items at or below the base, \( z \) shall be taken as 0. The value of \( z/h \) need not exceed 1.0
- \( h \) = Average roof height of structure with respect to the base

Maximum and minimum design force limits are specified as:

\[ F_{p,\text{max}} = 1.6 \, S_{DS} \, I_p \, W_p \quad (Eq. \, 9.6.1.3-2) \]

\[ F_{p,\text{min}} = 0.3 \, S_{DS} \, I_p \, W_p \quad (Eq. \, 9.6.1.3-3) \]

**Seismic Use Group:**

Determination of the seismic design force begins with assigning a seismic use group to the structure. Table 1604.5 from the International Building Code has been modified below to illustrate the classification of buildings for seismic use group designation.

### Building Seismic Use Group

#### Seismic Use Group

<table>
<thead>
<tr>
<th>Seismic Use Group</th>
<th>Nature of Occupancy</th>
</tr>
</thead>
</table>
| I                 | Buildings and other structures that represent a low hazard to human life in the event of failure  
  *Agricultural facilities  
  *Certain temporary facilities  
  *Minor storage facilities |
| II                | Buildings and other structures that represent a substantial hazard to human life in the event of failure  
  *Elementary & secondary schools  
  *Colleges or adult education facilities  
  *Jails & detention facilities |
| III               | Buildings and other structures designed as essential facilities  
  *Hospitals & other health care facilities having surgery or emergency treatment facilities  
  *Fire, rescue and police stations and emergency vehicle garages  
  *Desated emergency centers  
  *Power-generating stations and other public utility facilities required as emergency backup facilities for Use Group III buildings or structures  
  *Structures containing highly toxic materials  
  *Aviation control towers, air traffic control centers and emergency aircraft hangars  
  *Buildings and other structures having critical national defense functions  
  *Water treatment facilities required to maintain water pressure for fire suppression |

#### Spectral Response Acceleration & Site Classification:

The next step of the process is to determine the maximum considered earthquake spectral response acceleration for short periods, \( S_s \), and 1-second period, \( S_1 \). Contour maps (Figure 2) are located in the IBC Figures 1615(1) through Figure 1615(10). If the project site is located between two contour lines, then straight line interpolation is permitted by the code. It should be noted that all acceleration values obtained from the maps are for site class B, and will need to be adjusted for the project site class, if necessary.

Site specific soil classification and associated site coefficients (\( F_s \) and \( F_v \)) are the next parameters that are required. Table 1615.1.1 provides three soil properties that may be utilized to determine the appropriate site classification: shear wave velocity, standard penetration resistance, and undrained shear strength. When the soil properties are not known, the code specifies that site class D shall be used as the default site class unless the building official determines that site class E or F may be present at the site location.

### Table 1615.1.1

<table>
<thead>
<tr>
<th>Site Class</th>
<th>Soil Profile Name</th>
<th>Soil shear wave velocity ( v_s ) (ft/s)</th>
<th>Standard penetration resistance ( N_p )</th>
<th>Undrained shear strength ( s_u ) (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Hard Rock</td>
<td>( v_s &gt; 2000 )</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>B</td>
<td>Loose</td>
<td>2500 ( \leq v_s \leq 5000 )</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>C</td>
<td>Very dense soil</td>
<td>1200 ( \leq v_s \leq 2000 )</td>
<td>( N_p = 50 )</td>
<td>( s_u &gt; 2000 )</td>
</tr>
<tr>
<td>D</td>
<td>Soft soil Profile</td>
<td>600 ( \leq v_s \leq 1200 )</td>
<td>15 ( \leq N_p \leq 50 )</td>
<td>1000 ( \leq s_u \leq 2000 )</td>
</tr>
<tr>
<td>E</td>
<td>Soft soil Profile</td>
<td>( v_s &lt; 600 )</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>F</td>
<td>Unlikely plasticity limits and minimum site classification</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Table 1615.1.2(1)

<table>
<thead>
<tr>
<th>Site Class</th>
<th>( S_s \geq 0.25 )</th>
<th>( S_s = 0.5 )</th>
<th>( S_s = 0.75 )</th>
<th>( S_s = 1.00 )</th>
<th>( S_s \geq 1.25 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>B</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>C</td>
<td>1.2</td>
<td>1.2</td>
<td>1.1</td>
<td>1.1</td>
<td>1.0</td>
</tr>
<tr>
<td>D</td>
<td>1.6</td>
<td>1.4</td>
<td>1.2</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>E</td>
<td>2.5</td>
<td>1.7</td>
<td>1.2</td>
<td>0.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>

*Site specific analyses shall be performed to determine appropriate values*

#### Table 1615.1.2(2)

<table>
<thead>
<tr>
<th>Site Class</th>
<th>( S_s \leq 0.1 )</th>
<th>( S_s = 0.2 )</th>
<th>( S_s = 0.3 )</th>
<th>( S_s = 0.4 )</th>
<th>( S_s \geq 0.5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>B</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>C</td>
<td>1.7</td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>D</td>
<td>2.4</td>
<td>2.0</td>
<td>1.8</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>E</td>
<td>3.5</td>
<td>3.2</td>
<td>2.8</td>
<td>2.4</td>
<td>2.4</td>
</tr>
</tbody>
</table>

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communications@chemtreat.com
As mentioned previously, the maximum considered earthquake spectral response acceleration for short periods, \( S_{S3} \), and 1-second period, \( S_1 \), must be adjusted for the project location site classification, if necessary. Tables 1615.1.2(1) and 1615.1.2(2) contain the site coefficients \( F_a \) and \( F_r \) that are used to adjust for site classifications other than site class B. Equations 16-38 and 16-40, and 16-39 and 16-41 have been combined below to determine the design spectral response acceleration for short periods, \( S_{DS} \), and 1-second period, \( S_{D1} \), respectively.

\[
S_{DS} = \frac{2}{3} F_a S_S
\]

\[
S_{D1} = \frac{2}{3} F_r S_1
\]

Based on the values calculated above and the assigned seismic use group, the seismic design category can now be determined via Tables 1616.3(1) and 1616.3(2). It is necessary to determine the seismic design category utilizing both tables, since the code specifies that the more severe category be assigned to the structure.

### Table 1616.3(1)
Seismic Design Category Based on Short Period Response Acceleration

<table>
<thead>
<tr>
<th>( S_{DS} )</th>
<th>Seismic Use Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_{DS} \leq 0.167 \text{ g} )</td>
<td>I ( \quad ) II ( \quad ) III</td>
</tr>
<tr>
<td>( 0.167 \text{ g} &lt; S_{DS} &lt; 0.33 \text{ g} )</td>
<td>B ( \quad ) B ( \quad ) C</td>
</tr>
<tr>
<td>( 0.33 \text{ g} \leq S_{DS} &lt; 0.50 \text{ g} )</td>
<td>C ( \quad ) C ( \quad ) D</td>
</tr>
<tr>
<td>( 0.50 \text{ g} \leq S_{DS} )</td>
<td>D(^a) ( \quad ) D(^a) ( \quad ) D(^a)</td>
</tr>
</tbody>
</table>

\( S_{DS} \) is the maximum considered earthquake spectral response acceleration at 1-second period, \( S_1 \), equal to or greater than 0.75 g shall be assigned to seismic design category E. Seismic use group III structures with a maximum considered earthquake spectral response acceleration at 1-second period, \( S_1 \), equal to or greater than 0.75 g shall be assigned to seismic design category F.

### Table 1616.3(2)
Seismic Design Category Based on 1-Second Period Response Acceleration

<table>
<thead>
<tr>
<th>( S_{D1} )</th>
<th>Seismic Use Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_{D1} \leq 0.067 \text{ g} )</td>
<td>I ( \quad ) II ( \quad ) III</td>
</tr>
<tr>
<td>( 0.067 \text{ g} \leq S_{D1} &lt; 0.133 \text{ g} )</td>
<td>B ( \quad ) B ( \quad ) C</td>
</tr>
<tr>
<td>( 0.133 \text{ g} \leq S_{D1} &lt; 0.20 \text{ g} )</td>
<td>C ( \quad ) C ( \quad ) D</td>
</tr>
<tr>
<td>( 0.20 \text{ g} \leq S_{D1} )</td>
<td>D(^a) ( \quad ) D(^a) ( \quad ) D(^a)</td>
</tr>
</tbody>
</table>

\( S_{D1} \) is the maximum considered earthquake response acceleration at 1-second period, \( S_1 \), equal to or greater than 0.75 g shall be assigned to seismic design category F.

### Component Importance Factor:

In order to properly assign a value to the component amplification factor (\( a_p \)), one must understand the dynamics of the equipment and the method by which the equipment will be installed. The IBC categorizes all components as either flexible or rigid. A flexible component is defined as any equipment, including its attachment, having a fundamental period greater than 0.06 seconds. Similarly, a rigid component is defined as any equipment, including its attachment, having a fundamental period less than 0.06 seconds. Although most evaporative cooling equipment would fall under the category of flexible, there may be some exceptions. In these instances, it is important for the design professional to understand the site installation. ASCE 7-02 assigns a value of \( a_p = 1.0 \) to equipment that is deemed rigid, whereas a value of \( a_p = 2.5 \) is assigned to equipment that is considered flexible. Furthermore, ASCE 7-02 stipulates that any mechanical equipment, even that which is proven to meet the definition of rigid, installed with vibration isolation must be assigned an \( a_p = 2.5 \).

### Component Importance Factor:

The final parameter that must be determined prior to calculating the seismic design force is the component importance factor (\( I_p \)). Section 9.6.1.5 of ASCE 7-02 clearly defines the component importance factor as:

<table>
<thead>
<tr>
<th>Component Importance Factor, ( I_p )</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>Life safety component required to function after a seismic event</td>
</tr>
<tr>
<td>1.0</td>
<td>Component containing hazardous content</td>
</tr>
<tr>
<td></td>
<td>All other components</td>
</tr>
</tbody>
</table>

In addition, the code also stipulates that any structure assigned to seismic use group III (essential facilities) shall designate an \( I_p = 1.5 \) for all components that are required for continued operation of the facility.

### Testing & Analysis:

Aside from the inclusion of structural provisions for mechanical components, the most important aspects of the International Building Code are the requirements for structural testing and inspections of mechanical equipment. Section 1707.7.2 Component and attachment testing of the IBC states:

“The component manufacturer shall test or analyze the component and the component mounting system or anchorage for the design forces in Chapter 16 for those components having a Component importance factor of 1.0 or 1.5 in accordance with Chapter 16. The manufacturer shall submit a certificate of compliance for review and acceptance by the registered design professional responsible for the design, and for approval by the building official. The basis of certification shall be by test on a shaking table, by three-dimensional shock tests, by an analytical method using dynamic characteristics and forces from Chapter 16 or by more rigorous analysis. The special inspector shall inspect the component and verify that the label, anchorage or mounting conforms to the certificate of compliance.”

This singular section of the code mandates manufacturers to demonstrate the capability of their equipment, including its attachment, to withstand the seismic design forces for the region which they are specified. An independent approval agency must analyze and certify the capability of the component to resist the appropriate seismic design force for all components installed at locations classified as seismic design category C, D, E, or F. A certificate of compliance is issued to the building official by the manufacturer stating that the design and manufacture of the component, including its attachment, comply with the seismic provisions of the Inter-
national Building Code.

Conclusions:
As a result of the steadily increasing costs associated with natural disaster recovery, the Federal Emergency Management Agency (FEMA) has broadened its focus to incorporate hazard mitigation as the foundation of emergency management. At the core of this philosophy is the belief that building codes are the most effective way to ensure the capability of new construction to withstand future seismic events. All states that meet the hazard mitigation planning criteria, which include the adoption and enforcement of the International Building Code, are eligible for additional federal funding following a natural disaster.

Once viewed solely as a structural guide to building design, the International Building Code encompasses building systems and components. The IBC provides seismic design requirements for nonstructural components which address anchorage, structural integrity, and operational capability of a component following a seismic event. The purposes of these provisions are to minimize the loss of life hazard of all structures (structural and nonstructural) and improve the capability of essential facilities to operate, per their intended purpose, after a seismic event.

In order to achieve this goal, design professionals must supply the building official with sufficient information regarding structural details and seismic design load data. Specifying mechanical equipment to meet these seismic design loads will ensure delivery of components that are seismically compliant per the provisions of the International Building Code.

- 47 states plus Washington, D.C. use the International Building Code
- 45 states plus Washington, D.C. use the International Residential Code
- 42 states plus Washington, D.C. use the International Fire Code

![Figure 1: International Code Adoptions](source: www.iccsafe.org)

![Figure 2: Maximum considered earthquake spectral response acceleration map](source: International Building Code 2003)
Material Balance Control and Information Systems For Cooling Water Treatment

Charles Kuhfeldt
Ashland, Drew Industrial

Abstract:
Control of water treatment chemistry utilizing instrument measurement of system water flow and cycles of concentration provides precise control of chemical additives. The chemical testing performed then becomes a check on the control, rather than a primary control input. On-line chemical analysis is not needed. Statistical analysis of data proves the control capability is excellent. Opportunities exist to utilize existing instrumentation in some cases along with new measurements to synthesize systems that are effective, economical and fully connected with today’s information technology.

Keywords: material balance control, feedforward, feedback, control limits, specification limits, cycles of concentration, on-line chemical analysis, information systems

Introduction:
Open recirculating cooling system chemical control methods evolved as the application of cooling systems became more common. Further change resulted from the use of electronic or computer-based control systems. The basic control algorithms, or control methods, have not changed greatly, but the application of the algorithms utilizing computer-based controllers and information systems allows precision in control and review and great flexibility in application. Material balance control is a fundamental control method utilizing feedforward of a control signal that can be applied to chemical control of open recirculating cooling systems. The other fundamental control method utilized for these systems is feedback control based on chemical analysis generating a control signal for the chemical feed rate. Both of these methods can provide very good results. This paper offers a brief review of chemical feed methods, and the relationship of these methods to material balance control and feedback control. After the review of the various feed methods and their evaluation, data from cooling systems using material balance control will illustrate the effectiveness of material balance control.

Cooling system users and operators have viewed statistical process control as a valuable tool in to understand the system’s chemical treatment results and needs. Computer-based information systems and statistical control methods that can access data directly from control systems provide valuable information to the users and operators in a very easy to utilize tool. Statistical data from a system utilizing automatic material balance control will show the effectiveness of that control method.

Appendix A contains definitions of some key terms for this discussion.

Discussion:
Chemical Treatment Programs:
The typical modern cooling water treatment program consists of a corrosion inhibitor and a dispersant or anti-scalant or anti-foulant. There will also be some type of oxidant or microbiocide to control microbiological growth. A pH control additive may or may not be utilized depending on the requirements of the other chemical components, the heat exchange equipment, and the water. The corrosion inhibitor and dispersing, anti-scaling, anti-fouling functions may be present in one mixture, and even may be provided by a combination of chemical molecules that have multiple functionalities.

Our discussion is about the methods of controlling the continuous feed of corrosion and deposition inhibitors and dispersants and is not about controlling acid or an oxidant or any product dosed as a slug or intermittent feed. These continuously fed inhibitor and dispersant treatment products generally have dosage ranges that are specified, and may be somewhat broad. For a well-managed, monitored and inspected system these ranges can be refined over at period of time to become very near the optimum target. The concept of an optimum target for a chemical additive as a single point or a narrow range in an open recirculating cooling system depends on some factors remaining constant over time. The factors that can lead to a constant optimum target include system temperatures, system water flows and makeup water supply chemical composition. Changes in any of those factors would move the optimum target to a different point. To facilitate comparison of control methods we will talk about dosing a single product that has a well-defined target residual in the system. Also, for the purposes of this discussion the system is constant; that is there are no changes in equipment or metallurgy or other external changes, except a step change in heat load to test the control response.

Product Dosage Versus Residual:
Many assume that a dosage is the same as a residual. This is not the case. A dosage is the amount of material fed into a system, while a residual is the amount of material present or detected in the circulating water. The difference, if any, between the dosage and the residual is the amount of material that is reacted and therefore not functional, or is no longer in the water phase, leaving the water phase as a vapor or a solid. Corrosion inhibitors function when they adsorb or react into the solid phase on the surface of pipes or...
heat exchangers. Salts or other materials that go into the solid phase are generally considered to be scales or fouling.

**Cycles of Concentration**

Cycles of concentration is a water treatment term that is very versatile and helpful to water treatment practitioners but that often confuses those new to water treatment. Cycles of concentration can be defined in terms of mass flow or concentrations of solids or salts in the makeup and the system water. The result should be the same if all the measurements are accurate, and no precipitation of salts is occurring.

The mass flow calculation is \( C = \frac{MU}{(BD + W)} \), where \( C \) = cycles of concentration, \( MU \) = make-up flow, \( BD \) = blowdown flow, and \( W \) = all other water losses including windage, drift, and any other loss.

The concentration of salts or ions calculation is \( C = \frac{S_{MU}}{S_{BD}} \), where \( S_{MU} \) is the salt or ion concentration in the make-up and \( S_{BD} \) is the salt or ion concentration in the blowdown. The best choice of the ion for this calculation depends on the specific application. If no chlorine or halogen compounds are used, chloride works well. Other commonly used choices include magnesium, total hardness, and silica. If the system is prone to precipitation, then using a salt that precipitates will give erroneous results.

The cycles of concentration value is helpful to water-treaters because when the cycles of concentration is known and the concentration of a given ion or salt in the makeup is also known then the concentration of that ion or salt that is expected in the system is calculated simply by multiplying the makeup concentration by the cycles.

Cycles of concentration is also the inverse of the blowdown and water loss fraction. If a given system is operating with 12.5% blowdown or a blowdown fraction of .125, the system is operating at 1/.125 or eight cycles of concentration.

Cycles of concentration is critical in figuring the dosage of an additive for a cooling system. The systems are considered to be well mixed so that the concentration of an additive in the blowdown is the same as the concentration of the additive in the system. Because of windage, drift and unmeasured blowdown it may be difficult to obtain a convenient and accurate measurement of the blowdown rate. If a measurement of the makeup rate is available and one also knows the cycles of concentration target then the dosage calculations are easy. The dosage is based upon the makeup rate divided by the cycles of concentration. The dosage of product concentrates to the target value in the system just as if it were a salt or ion in the makeup water.

**Feedback and Feedforward:**

Control processes that adjust to changes in the process being controlled utilize closed loops. That is, information is fed into a response mechanism that alters the manipulated variable to cause a change or adjustment in the controlled variable. Figure 1 illustrates a feedback and a feedforward control loop.\(^1\)

*Feedback:* A feedback controller measures a change in a system variable and adjusts the manipulated variable to cause a deviation in the controlled variable from the target value by changing the manipulated variable.

*Feedforward:* A feedforward controller measures a change in a system variable and adjusts the manipulated variable to prevent a deviation from the set point. For example, if the makeup rate increases the controller increases the phosphate feed rate to keep the residual on target.

Feedback control is particularly advantageous in systems that have slow dynamic response but are subject to frequent disturbances.\(^1\) Cooling systems have slow response because of the mass of water present relative to the circulation rate and thermal response and chemical residual changes. Also the blowdown and chemical feed controls must act on a large part of entire mass of water before a complete change is produced. The mass flow rate into a cooling system, however, is immediately affected by a change in load, allowing only for the control response of the level control. This enables the feedforward controller to take action promptly and to react to eliminate deviations in the manipulated variable rather than having to respond to a deviation in the controlled variable that may only become measurable after a significant time delay.

**Review of Chemical Feed Methods and the Theoretical Residual Produced**

The chemical feed methods reviewed in this process are: daily slug feed, periodic slug feed, continuous manually controlled feed, automatic alternating blowdown and feed, automatic feed controlled by chemical or physical analysis, and automatic feed controlled by material balance.

To provide a visual evaluation of the effectiveness of each feed method a model cooling system was constructed in a spreadsheet including blowdown control and various manual and automatic chemical control methods. The model cooling system uses conductivity to control blowdown via a Proportional-Integral-Derivative controller emulation in the spreadsheet.\(^1,2\) The operating parameters for the model cooling system are tabulated table 1. The spreadsheet is able to produce charts showing the residual chemical produced by the different feed methods over time. These charts are located at the end of this paper. By utilizing a model system in a spreadsheet all sample time errors and other variations are eliminated and the theoretical best response of each method can be compared.

The six chemical feed and control methods are described and evaluated. The evaluation process of the chemical feed methods consists of:

- An examination of the range of the chemical residual that each method requires to control the residual above a given minimum. The minimum residual selected was 100 ppm of a single product. This evaluation examines whether the controller requires a small range like 1 percent or less of the residual above the minimum to hold the minimum residual or if the range above the target is greater. The amount neces-
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if the range above the target is greater. The amount necessary above the minimum is excess or wasted product. This leads to the evaluation of the relative potential operating economy of each method in terms of excess chemical employed.

- The effectiveness of each method is also indicated by the range of the residual required because a more narrow range or control capability for a method would allow the control scheme to maintain a given minimum residual while not exceeding a given maximum residual. This capability becomes more important as the cooling system becomes more stressed in terms of corrosivity and scaling. There are stressed cooling systems that require the water chemistry to be stringently controlled within a tight range. Only the best automatic control systems can do this.

- Finally the ability of the feed method to maintain the target residual through a heat load change in the system is evaluated. Many systems are subject to load changes, even as much as 100% is not uncommon. In this test a change in the tower heat load causing the tower delta T to go from 15 degrees to 30 degrees was used. This represents a change of 100%.

These results are tabulated in table 2 and discussed below

**Daily Slug Feed:**
This may be the oldest method of controlling water chemistry and cooling systems. This involves introducing a day’s worth of product into the system all at once. The residual then starts out at its highest level and washes out along an exponential curve over the next 24 hours. This is the least efficient method for use of the products, but it requires almost no equipment or attention. It has the widest range of residuals of all the methods, 50 percent excess in this case. The product dosage in this method depletes along the same curve that is used to calculate the half-life of a product in a system. The daily slug feed method makes no attempt to respond to a changed system load. Therefore given a changed, higher system heat load, this method can result in the product residuals going beyond a given maximum residual. This capability becomes more important as the cooling system becomes more stressed in terms of corrosivity and scaling. There are stressed cooling systems that require the water chemistry to be stringently controlled within a tight range. Only the best automatic control systems can do this.

**Periodic Slug Feed:**
Periodic slug feed is the same method as daily slug feed except it is done several times a day usually on 12 hour, eight hour, or four hour basis. This means it the method is more efficient in terms of chemical usage but requires more man-hours. It also cannot make an adjustment for a change of heat load unless that is built into the operating procedure. Figure 4 shows the results of periodic slug doses. The excess product in this four slug per day example is between 10 and 11 percent.

**Continuous Manually Controlled Feed:**
This feed method consists of a manually set pump rate or drip rate. The accuracy of this method depends on the ability to set the rate to match the system requirement. In theory if that setting were perfect the product would remain exactly in control. This would produce excellent control, a very narrow range of residual, perfect economics, minimum equipment investment, and reduced chemical handling. In practice this method provides none of these results. The settings are never perfect, and the settings are checked and adjusted based on wet chemistry test results. The adjustments are never perfect and the test results are never perfect. Therefore the residual moves up and down within a range of test results and there is a range of product residual that is specified for this feed method.

This range is the specification range commonly seen in water treatment. They are set by balancing the control capability of the manually set pump rates and manually produced test results against the control range required by the chemistry and the cooling system. Often they work very well. However when the control capability of the adjustments is broader than the requirements of the system usually there are problems in the system as a result. This control method can respond to heat load changes via manual testing and adjustment, a form of feedback control, but the response tends to be slow. Figure 5 illustrates the residual from a manually set pump feeding into a steady-state system, showing perfect control until the heat load changes. Then the residual passes below the desired range.

**Alternating Blowdown and Chemical Feed:**
This method developed after observation that the blowdown controller would open for a period of time necessary to remove the mass of water required to reduce the conductivity to its set point and that because the blowdown generally occurred in a fixed rate one could use this controller output to turn on a pump at a fixed rate and feed product based on the mass of water removed from the system. This is a material balance based control system. This control method is most often seen today utilized by controllers that totalize the blowdown time and then operate the feed pump when the blowdown valve is closed. The pump is run for an appropriate length of time based on the blowdown time period. The controllers are programmed to know the pump capacity and rate so the time of feed can correspond to the amount of product needed.

The alternating blowdown and chemical feed method can operate within a relatively narrow range of product residual depending on the blowdown rate, the pump size, and the overall capability of the system. It can respond to changes in heat load because the increased heat load will require increased blowdown time, and the chemical feed is based on blowdown rate over time. Thus it can control the chemistry within its target range during a process heat load change. In Figure 6 the chemical feed is off when the lines representing conductivity and residual are moving downward during the blowdown phase. Then when the blowdown is off, the chemical feed pump can turn on to replenish the product as needed to replace the product removed during the blowdown. We see the residual increase and the conductivity also increases because the blowdown valve is shut. Note that during the increased heat load period the cycle time increases automatically, driven by the need to blowdown more water to control conductivity. The chemical feed pump must be set to a fast enough rate to maintain the residual in
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its range while pumping for less than a continuous time. The width of the chemical residual control range and therefore the excess amount of product needed depends on how frequently the control cycle operates. This depends on the blowdown rate and the controller capability. These units can cycle frequently, yielding a relatively flat saw tooth pattern. These controllers can be relatively inexpensive, but there is a tradeoff in chemical residual range needed to offset the saw tooth pattern. In this example the excess product needed is eight percent. Also, the pump rate must be high relative to a continuously fed product’s pump rate, often requiring a larger pump. These factors tend to limit the control method to smaller systems.

Automatic Feed Controlled by Chemical or Physical Analysis:

Several different types of chemical and physical analysis of chemical residuals and cooling water are currently being used to drive pump controllers to change pump rates in a feedback loop and control the product dosages. These analyzers include those that read a physical property or wavelength of light related to the product to determine concentration and those that operate automatic chemical analyzers. These systems can provide very good control within a narrow control range and respond to heat load changes very well. They do not require significant intervention by operations personnel.

This control method introduces an element the other methods do not contain: an automatic chemical analyzer. There are several concerns with the analyzer element that must be addressed before the system can reliably perform at the theoretical optimum. These include the following items:

- Maintenance of the analyzer
- Accuracy of the chemical analysis
- The PID controller for the pump must be set up or tuned correctly for the individual system
- Attention must be paid to time lags in sampling or analysis
- There is a need for instrument calibration
- In some cases reagents must be supplied
- Often there are concerns whether the specialty chemicals used to provide for physical property-based analysis add a continuing cost to the treatment program.

Resolution of those factors and questions is not within the scope of this paper.

In practice, when all of the above concerns are addressed, the control of chemistry by on line analysis provides very accurate control. Figure 7 shows the excellent response these systems can have, note the residual rising to the setpoint during the start-up on the left, and the flat line control through the heat load change.

Automatic Feed Controlled by Material Balance Control:

Controlling a cooling system’s water chemistry using material balance control means that the rate of water flow into or out of the system is measured or calculated and the chemical additives are dosed to the system in the correct amounts to yield the desired residual in the system. This method has been used for many years, and indeed is the starting point for determining the expected usage of products in chemical treatment applications.

The measurements utilized to determine the material flow to be treated vary from system to system. In the practical application of applying a cooling system material balance chemical controller to an existing system, one can take the necessary system operating information from many combinations of available inputs. Often a system will have every measurement needed already in place, or the new control system can include an added measurement to enable the system to calculate the product dosages. The following listing covers the common methods employed to provide a measurement to the controller of the mass of water to be treated:

- Makeup water flow: this is a direct measurement of the mass of water to be treated. Makeup water rate is combined with system conductivity and a manually input conductivity for the makeup water, or, if the makeup water conductivity is variable, then a makeup water conductivity meter is added.
- Blowdown flow: this flow is also a direct measurement of mass to be treated, but there is an adjustment needed to account for the windage and drift removed from the tower as well as any uncontrolled blowdown such as cooling water used for washing or other unplanned usages or system leaks.
- Cooling water supply and return temperature: these measurements may appear less direct than the flow measurements but they are also fundamental. The temperature difference between supply and return water temperatures is the “delta T” (“T”) utilized in the calculation of tower evaporation. The simple form of that calculation is \( T \text{ in degrees times a factor times the circulation rate equals the evaporation rate.} \) Then evaporation rate divided by cycles of concentration equals the blowdown rate. Since humidity and other factors can affect this evaporation rate, there is an additional adjustment factor that must be applied to this calculation.

After the mass of the water to be treated is determined, the product dosages, specific gravities and the chemical pump capacities are input to the cooling water chemical controller. The computer then calculates the amount of chemical to be fed and pulses the pumps as needed. If water is added to the system that is not accounted for by the controller, such as during a cooling system maintenance period, then a slug of product or an adjustment is added. This is added by the controller based on input from a chemical test. After the adjustment the system control is based on measured water input.

The material balance controller can provide very good control within a narrow range and immediate response to any heat load changes. Figure 8 shows the control after a start up with the residual rising to the control point based on the slug adjustment and then showing flat line control using material balance control. This control continues through the heat load change. Material balance controllers require very little intervention from operations personnel and very little maintenance.

Results Improvements Obtained by Material Balance Control

A large Gulf Coast petrochemical production facility operates multiple cooling towers within one site. Over an extended period of time the existing cooling system chemical control became inadequate to prevent frequent control excursions and some elevated
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corrosion rates. This problem developed slowly and had several causes, including reduced operations manpower availability, increasingly stringent discharge limits limiting treatment options, deteriorating makeup water quality, aging equipment, increased demands on staff time and others. Recognizing the difficulties that were impending due to these frequent excursions the plant elected to upgrade the cooling water chemistry control and selected material balance based control systems that integrate with the existing plant instrumentation for makeup water flow. These controllers were installed on several of the cooling systems to allow the evaluation of their effectiveness in this site and performance data was collected. Then the remaining systems were upgraded. The performance data showed a significant improvement. Table 3 compares out of control events per system per week before and after the installation of the controllers. The dramatic improvement shown was from 0.796 events per system per week to 0.089 events per system per week.

Table 4 shows corrosion rates for four of the systems analyzed over a three-year period, split into approximately 1 year prior to the installation and two years after. All of the corrosion rates showed a significant improvement both by instantaneous corrosion measurement and by corrosion coupon measurement with the rates decreasing from an average of one mpy prior to the control upgrade to 0.5 mpy after the upgrade.

The improvement in corrosion rates resulted from a significant improvement in control and monitoring of the water chemistry in multiple systems. This control and monitoring improvement resulted from the installation of new controllers at each system and connection of those controllers to a central computer system that allowed viewing a system data values, changing setpoints, alarming for out-of-control values, data gathering, and statistical analysis. Figure 9 shows a pictorial representation of the types of equipment used to construct one of these systems. Figure 10 is a screenshot of the control interface from the system being discussed. From this overview screen it is possible to analyze the communication status of each system, to look at individual controlled or monitored values, to change operating setpoints, to take manual control of any control point, and to do statistical analysis. This interface is located in the central utilities control room for the large complex. It is accessible via remote access through secure computer access methods. The system is capable of sounding alarms locally, of utilizing a phone system to page for assistance, and of utilizing the Internet to send alarms and routine and special data reports as needed.

The data analysis capability of the system allows effective viewing of large amounts of data with statistical analysis to show control capability and to identify and highlight control concerns. Figure 11 shows a screenshot from the data analysis program with statistical analysis values displayed. The screenshot shows a year’s worth of data from the conductivity controller and gives an indication of the level of control that can be achieved with these modern control systems. During the one year long period shown by the conductivity chart in Figure 11, wet chemistry check tests were run every week. Figure 12 shows the series of wet chemistry check tests that were run over the course of the year. All of these tests fall within the 10 to 14 ppm control range that had been established for this product in this system.

Conclusion:
Based on the examination of the control potential of various chemical feed methods using a calculated model cooling system, several control methods provide good results but excellent control within a narrow range even through significant heat load variations can be provided only by automatic control based on chemical analysis or material balance.

Utilizing material balance control with modern computer-based control systems can significantly improve control of cooling water chemistry. Material balance control utilizing the systems discussed in this paper can provide precise control and excellent results and can be integrated with existing plant instrumentation.

The automated data gathering and analysis capabilities of the systems allow simplification of data assessment and control target adjustments, yielding excellent results in complex systems.

Footnotes
2) “Proportional-Integral-Derivative Control” by Dr M.J. Willis, Dept. of Chemical and Process Engineering, University of Newcastle. http://lorien.ncl.ac.uk/ming/pid/PID.pdf

Acknowledgement:
The author would like to thank Mark Pantazes, Harland Pond, Anne Cantafio and Jim Inklebarger, Matt Matlock, and Craig Worley all of Ashland Water Technologies, for their assistance in developing this paper.

Appendix
Definitions:
Control limits: control limits are calculated from process data and should not be confused with engineering specifications or specification limits. 1

Material Balance Control: a material balance is an accounting of the mass flows and changes in inventory of mass for a system. The mass of water in or flowing within a cooling system is generally constant so the material balance depends simply on the flow of water and water vapor into and out of the system. Cooling water corrosion inhibitors and dispersants stay in the liquid phase except for a very small amount of the corrosion inhibitor, unless there is a treatment problem causing solids to form. Therefore the dosage in the system can be calculated from the makeup water flow and the cycles of concentration or calculated from the blowdown rate when the blowdown rate includes all water losses. One can include a calculated amount for the system volume if desired, but for the long-term operation, the only amount of product necessary to implement dosage control is the amount of product to treat the amount of water that is fed into and concentrated in the system.

Process capability: Also known as potential capability. This is the simplest and most straightforward indicator of process capability. It is defined as the ratio of the specification range to the process range; using ± 3 sigma limits we can express this index as: $C_p =$
(USL-LSL) / (6*Sigma). Put into words, this ratio expresses the proportion or part of the range of the normal curve that falls within the engineering specification limits (provided that the mean is on target, that is, that the process is centered). The lower the Cp number is, the more capable the process is because more of the specification range is within the actual performance of the process. In water treatment operations, events that put the process measurement outside the specification limits are called control excursions or out of limits operation. If the specification limits are correct, then there are negative impacts from operating outside the limits. We seek to have the water chemistry operate inside the specification limits so we want to have Cp less than 1.0.

**Specification:** the engineering requirement for judging the acceptability of a particular characteristic. Water treatment product dosages generally are specifications based on previous results and other engineering input.

**Specification limits:** the upper and lower limits of the specification, upper specification limit (USL) and lower specification limit (LSL). In statistical control is important to recognize that the specification limits are not control limits.
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**Table 2: Summary of Control Method Characteristics**

<table>
<thead>
<tr>
<th>Control Method</th>
<th>Range (%) above minimum required to hold 100 ppm minimum dosage</th>
<th>Control response to load change</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily slug feed</td>
<td>50</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Four slugs per day</td>
<td>10-11</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Manually controlled pump feed</td>
<td>Variable, large</td>
<td>Variable, slow, size</td>
<td>Systems or people dependent</td>
</tr>
<tr>
<td>Alternating blowdown and chemical</td>
<td>Variable, small, 8 in the model</td>
<td>Good</td>
<td>Practical to smaller systems</td>
</tr>
<tr>
<td>Automatic chemical analyzer</td>
<td>Minimal</td>
<td>Excellent</td>
<td></td>
</tr>
<tr>
<td>Automatic material balance</td>
<td>Minimal</td>
<td>Excellent</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3: Average Cooling System Out of Control Events per System per Week**

<table>
<thead>
<tr>
<th>Five Cooling Systems in One Plant Location</th>
<th>Before Material Balance Control</th>
<th>With Material Balance Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Non-Compliance Readings (48 Weeks)</td>
<td>Weekly Average</td>
<td>Total Non-Compliance Readings (36 Weeks)</td>
</tr>
<tr>
<td>50</td>
<td>3.68</td>
<td>10</td>
</tr>
</tbody>
</table>

**Table 4: Corrosion Rate Statistics**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Instantaneous Corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation</td>
<td>Before Material Balance Control</td>
</tr>
<tr>
<td>Maximum Corrosion Rate, mpy</td>
<td>2.3</td>
</tr>
<tr>
<td>Minimum Corrosion Rate, mpy</td>
<td>0.4</td>
</tr>
<tr>
<td>Average Corrosion Rate, mpy</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**Figure 6: Automatic control by On/Off Blowdown and Feed Controller**

**Figure 7: Automatic Control by Chemical Analyzer Controller**

**Figure 8: Automatic control by Material Balance Analyzer**

**Figure 9: Control and Monitoring Equipment Pictorial Representation:**
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Figure 10: Screen shot of Control Interface, Multiple System Material Balance Control Unit

Figure 11: Conductivity Data Screenshot from Control System Viewed in the Data Analysis Software

Figure 12: Inhibitor Test Results for Cooling System 2

This chart contains one year’s worth of wet chemistry check tests showing control within the 10 to 14 ppm control range for all tests.
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Rehabilitation of Hyperbolic Cooling Towers at Electric Generating Station

By Kevin A. Michols  
CTLGroup

Abstract
Two concrete cooling towers serving a generating station exhibited concrete deterioration, steel corrosion, and water leakage. These towers needed major repairs that could be done only during scheduled outages.

Detailed structural analysis helped determine the maximum size, relative location, and sequencing of repair areas to ensure stability during repairs. Materials were chosen to withstand conditions within the towers.

Structural engineers and construction material consultants took part in condition evaluation, repair design, and construction quality assurance. Repair crews removed deteriorated concrete and used specialty shotcrete materials for structural restoration. Durability enhancements included a waterproofing coating on the interior. They sealed tower surfaces and sealed cracks with epoxy. Meticulous quality control testing and inspection helped ensure the project’s success. After more than 15 years of continuous service, the repaired towers show no evidence of on-going deterioration or structural distress.

Introduction
The natural-draft concrete cooling towers at the PPL Montour steam electric station were completed and placed into service in 1972 and 1973. By 1985, these two massive towers, crucial to the operation of the power plant and to the region’s power infrastructure, were exhibiting significant signs of concrete deterioration, corrosion of embedded steel, and water leakage through the shells.

Concerned about these problems and their potential to affect the towers’ operation and structural integrity, the owner initiated an investigation to determine the extent and causes of the deterioration. The power company assembled a multidisciplinary team made up of both staff and consulting engineers. The team included civil engineers, concrete material and construction consultants, structural engineers, and specialists in testing and evaluation.

The size and configuration of the towers made access for thorough inspection and repair difficult. Repairs were expected to be time-consuming and costly, so it was crucial that the evaluation be as thorough and the execution as meticulous as possible to yield satisfactory and long-lasting results. Accomplishing the work without curtailing plant operations also was a priority.

Today, more than 15 years after completion of repairs to the second tower, there are no signs of distress. The cooling towers continue to function as designed, serving the needs of the owner and its clients.

Tower Structure
The two towers are designed to cool steam condenser cooling water for the power plant. The base of the hyperbolic shell of each tower begins at 18.3m (60 ft) above grade and the cornices are located 113 m (370 ft) above plant grade. The shell diameters vary from 75.5m (248 ft) at the base to 49m (160 ft) at the throat to 55m (180 ft) at the top. The base of the shell tapers from 0.9m (3 ft) in the first lift to 15.2cm (6 in.) the fifth lift. The tower cornices increase in thickness from 15.2cm (6 in.) to about 0.6m (2 ft) at the top. A ring beam resting on 32 cross-shaped columns supports each shell.

The concrete shells are reinforced circumferentially, with bars arranged in horizontal layers. Additional bars are oriented diagonally in both directions to the vertical axis. The towers were constructed of normal weight concrete, designed for a nominal 4000-psi 28-day compressive strength.

Signs of Trouble
Concerns about the cooling towers stemmed from the appearance of significant concrete deterioration, corrosion of embedded steel, and water leakage through the shells. The owner observed evidence of deterioration in the form of concrete spalling, delaminations, honeycombing, exposure of reinforcing steel on the outside surface, water leakage and staining at lift joints, and progressive disintegration of the inside surface of the shell. Cracks were also noted in the support columns and ring beams.

Inspection and Evaluation
Access
Before the rehabilitation, there was no way to get to the top of the towers, even for preliminary rigging, without the use of a large crane. The contractor brought in a crane that could reach the cornice, 113m (370 ft) above the plant grade, and then erected a platform on the outside of the shell just below the top of the tower. A trolley rail was mounted below the platform to provide horizontal movement for cable-climber scaffolds that were suspended from the platforms. These scaffolds provided access for work on the tower exterior.
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The McHale cooling tower testing program is being lead by Mr. Gene Culver, who has more than 27 years of experience working in the cooling tower industry, has been an active member of a number of CTI technical committees, and is a highly skilled CTI test representative through his significant experience in providing drift, plume, and thermal testing services.

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Gene Culver
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On the outside of the shell, steel tension cables were installed from the top platform to the bottom platform. Several steel “belly bands” located near the tower throat held these cables close to the tower. This system kept repair crews within reach of the concrete surface as the scaffolds moved up and down the cables.

**Methods**

Evaluation of the cooling tower concrete was based on detailed inspection and testing. The owner initiated the project by removing core samples and submitting them to a laboratory for petrographic analysis and compressive strength and accelerated freeze/thaw testing. Copper-copper sulfate half-cell measurements were used to assess active corrosion.

Once the rehabilitation project was underway, an inspection team hammer-sounded every square meter of concrete in both towers. After hammer sounding, questionable areas were examined using nondestructive pulse-echo microseismic tests. Inspectors marked deteriorated concrete with paint for subsequent removal by the contractor. A grid system also was established at this time. Grid markers identifying every fifth lift and every 20º of longitude were attached to the shell. These were used in mapping the deteriorated and repaired areas, for planning the work, and in quality control documentation.

**Findings**

The main cause of the shell deterioration was freeze/thaw action on non-air-entrained, poorly consolidated concrete. The inside shell deterioration was the result of leaching of cement paste by the demineralized water from the tower operation. Cracks in the support columns and ring beam that parallel the reinforcing steel were attributed to shrinkage cracking.

**Recommendations**

The study recommended the deteriorated concrete be replaced, the cracks sealed and a coating applied to the inner surface of the shells. This would seal and dry out the existing non-air-entrained, saturated concretes to increase their long-term resistance to the freezing and thawing environment.

**Selecting the Repair System**

Investigators chose a series of materials and tested each to evaluate its potential performance as an inside shell surface sealer. The material selected would have to minimize moisture penetration into tower concrete when exposed to the tower environments. The various surface coatings were tested to evaluate their effectiveness when exposed to freeze-thaw cycling, when immersed in actual cooling-tower water and exposed to water vapor in a fog room, in a range of temperatures, and under hydrostatic pressure. The coating selected is a 2-component, solvent-type epoxy system.

The exterior repairs would need to take place while the towers were operating, and the techniques and materials used would vary depending on the severity of damage observed at the surface and on the existence of internal voids detected by nondestructive testing. Potential materials were tested for resistance to freezing and thawing and for tensile bond to the existing concrete surfaces. Their durability was evaluated with and without coatings.

Ultimately, four types of repairs were used: full-depth concrete replacement, partial-depth repair, spot repair, and filling of internal voids. Wherever it was possible, the inner 5cm (2 in.) of shell thickness was saved, and full-depth repairs were avoided. The inner 5cm (2-in.) shell served as the interior form for partial-depth repairs.

Dry-mix shotcrete was used for large repairs, and dry-mix mortar or a polymer-modified cement-based mortar for small repairs. Cracks greater than 0.25mm (0.01 in.) wide were repaired by epoxy injection; those less than 0.25mm (0.01 in.) wide were sealed with an epoxy to help prevent corrosion of the reinforcement.

**Structural Analysis Governs Repair Sequencing**

The engineers used finite-element computer modeling to perform an in-depth stress analysis for the towers. The structure was analyzed under the assumptions of gravity, thermal conditions, wind, and seismic loads. Input data were based on visual inspection and sounding results, as well as measured concrete strengths of various shell elements. Shell elements of differing thicknesses were used to model the cooling tower walls, in order to account for membrane and bending effects.

The objectives of the structural analyses were to evaluate potential sequences of material removal in the cooling tower shell and to define an optimal repair process while maintaining the towers in a safe and operational condition. As a result of these analyses, the engineers recommended a maximum opening size of 1.5m x 2.4m (5 ft x 8 ft).

The 1.5m x 2.4m (5x8-ft) opening limitation was imposed during the repair of the first third of Tower 1. Then, for the sake of economy and efficiency that would allow the completion of Tower 1 repairs in one construction season, the engineers undertook additional structural analyses. These used input data that reflected the repairs already done and considered recommendations from the field on ways to improve the repair process. The new analyses led to several changes that increased efficiency, including changes in the size of openings allowed and the total number of simultaneous repair areas.

**Repair Execution and Quality Control**

The basic process was to remove the deteriorated concrete with pneumatic chipping hammers and then to fill the created voids with dry-mix shotcrete (gunite). For full-depth repairs, crews inserted tongue-and-groove boards through the tight reinforcing steel and used them to create a form. They wire-tied the boards to the rebar to hold them in place against the interior of the shell.

Problems arose, however, because the boards did not fit tightly against the rough interior surface. Condensation on the shell wall leaked past the boards and washed out the shotcrete be-
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fore it had set. To combat these problems, the repair crew switched to Regulated-set Cement, which substantially reduced setting time and accelerated strength development so that adjacent concrete could be repaired sooner.

The consulting engineers provided a field inspection team to oversee and inspect all shell repairs, support-column repairs, and application of the epoxy coating. To ensure high-quality shotcrete application, the engineers pre-qualified nozzlemen and shotcrete crew members who would be working on the towers. Quality-control testing included visual inspection of rebar encasement, in addition to compressive strength and freeze-thaw durability tests. Shotcrete experts supervised all shotcrete testing and onsite application.

Tensile bond pull-off tests were conducted on partial-depth shotcrete repairs and on the epoxy coating being used on the interior, to check for adequate adhesion to the substrate.

**Longevity of Repairs Cited**

Meticulous quality control testing and inspection during repairs helped ensure the project’s success. The work accomplished between 1988 and 1990 demonstrated its durability and significantly extended the towers’ service life. There is still no sign of distress, more than 15 years after the completion of repairs to the second tower. That the cooling towers continue to function as designed, serving the needs of the owner and power consumers, is evidence of the care and skill that were applied during the rehabilitation project. In 2005, these factors earned the project an Award of Excellence in the Longevity category from the International Concrete Repair Institute.
Figure 5  Shotcrete repairs were finished using a sponge float.

Figure 6  Engineers supervised shotcrete sample application and pre-qualified nozzlemen to work on the tower rehabilitation project.

Figure 7  Repair crews worked from cable-climbing scaffolds applying epoxy coating to tower interior.

Figure 8  In 2005 photo, Tower 1 concrete shows no deterioration. Note that work platform at crown was left in place to facilitate periodic inspections.
Etiwanda Cooling Towers, Repair or Replace?

Robert Fulkerson
Fulkerson & Associates, Inc.

ABSTRACT
This paper discusses the structural problems and structural failures associated with the 43 year old cooling towers located at Reliant Energy’s Etiwanda Power Plant located in Rancho Cucamonga California. It describes the decision analysis procedure used to determine if the cooling towers should be repaired or replaced with new cooling towers. It also describes the necessary modifications required to improve the soundness and reliability of the structure.

DISCUSSION
Reliant Energy operates the Etiwanda Generating Station which is located in Rancho Cucamonga, California. At one time there were 5 generating units operating at the Etiwanda Station. Units 1, 2, and 5 have been shut down leaving only Units 3 and 4 now operating. These two generating units are 320 MW gas fired units. The condenser cooling water for these two units is supplied by two cooling towers. Each cooling tower has eight cells. The cooling towers are doubleflow crossflow towers which were originally designed to cool 136,000 gpm from 100.6° F to 80° F at a 69.2° F wet bulb temperature. The original fill material used in the towers was redwood lathe installed perpendicular to the airflow. This fill was similar to Marley’s G-480 fill. At some time in the past the wood fill was replaced with PVC “T” bar installed parallel to the air flow. Thermal capacity has never been a problem so the design point remained the same after the fill replacement.

The structure of the towers was fabricated from pressure treated clear heart redwood lumber. There have been some repairs in the past where pressure treated douglas fir lumber was used. Originally, the fan stacks and the hot water headers were also fabricated from redwood. Both the fan stacks and the water headers have been replaced with fiberglass components. Over the life of the towers they received regular inspections and repairs from three or four of the major cooling tower manufacturers.

The hot water header on the Unit 4 tower starts out at 54 inch diameter and is supported on 4 X 6 columns. The 54 inch pipes run for 180 feet where they reduce to 36 inch diameter. The 36 inch diameter pipes are supported on 4 X 4 columns. The horizontal ties are on 6 foot vertical spacing with the longitudinal ties offset 3 foot from the transverse ties.

On July 21st, 2005 the Unit 4 cooling tower experienced a partial collapse in an area right after the reduction in pipe diameter. Some of the 4 X 4 columns which supported the 36 inch diameter hot water header buckled and failed allowing the header to fall down.
about 2 feet. A blind flange was installed to isolate the water flow to the damaged cell so emergency repairs could be made. It was apparent that, at 43 years of age, the towers were near the end of their service life.

Fulkerson & Associates, Inc. was contracted by Reliant Energy to assist in the initial cooling tower inspection, make recommendations for repair and provide the necessary engineering for the cooling tower upgrade. A project team was assembled which consisted of Tim Brunette as the Reliant Energy Project Manager, Robert Fulkerson and Don Carter from Fulkerson & Associates. There was also input from several plant people.

**Partial collapse from failed columns**

**THE DILEMMA:**

Reliant Energy would like to operate the cooling towers for an additional 10 years. The cooling towers are beginning to suffer structural failures. Additional and more serious failures in the future are a certainty. Reliant Energy has three options:

1. Do nothing and continue to have failures resulting in capacity derates, then repair the failures as they occur.
2. Repair the structure of the towers to a point where they will operate safely for another ten years.
3. Remove and replace the towers with new cooling towers.

If Reliant Energy decides to do nothing and repair the towers as failures occur for the next ten years, there is the probability of a catastrophic collapse which could result in lost revenue that would exceed the cost of installing new cooling towers.

If Reliant Energy decides to repair the existing cooling towers’ structure, does the wood in the structures have enough life to last another ten years?

If Reliant Energy decides to remove and replace the cooling towers with new towers, new douglas fir towers may have a life of 25 to 35 years before major repairs will be necessary. Only 10 more years is desired. Is this a waste of money?

**CONDITION OF EXISTING WOOD:**

In order to be able to choose one of the three options the condition of the existing wood in the cooling towers has to be determined. The project team first looked at the wood that had been removed from the fill area of the towers during repairs. There were bowed and bent columns, broken columns and some rotted members. Some horizontal members had a great deal of surface erosion and some members looked good on the surface. When cutting through some of the columns, close grained clear heart redwood was found which looked very good even when the outside surface looked rough.

**Bent and broken columns removed from tower**

**Horizontal 2 X 6 removed from tower**

**4 X 6 removed from tower measured 3 ¼ X 5 ¼**

**Bent and broken columns removed from tower**

**Horizontal 2 X 6 removed from tower**

**4 X 6 removed from tower measured 3 ¼ X 5 ¼**
The surface erosion and reduction in cross sectional area was mostly found to be on the horizontal members. Some of the vertical members like the one pictured above had no surface erosion and reduction in cross sectional area.

It was decided an inspection of the structural members in the fill area was necessary. To accomplish this the fill and fill hanger wire was removed from one 6 foot wide bay in the center of several cells. Some of the inspection locations were chosen where the header pipe was 54 inch diameter and some were chosen where the pipe had reduced to 36 inch diameter. One inspection location was chosen close to the point where the failure occurred but on the opposite side of the tower. These inspection holes allowed the project team to climb down through the fill to inspect the structure. Several bowed, buckled and broken columns were found. It was not possible to see more than 12 to 18 feet through the fill, which made it impossible to thoroughly inspect a 72 foot long cell and find all of the failed columns.

**WOOD TESTING:**

Twenty one samples of wood were collected from various locations in the wet section of the towers. Some samples were columns from various locations and from several heights. Some samples were from angle braces, and one was from the support saddle under the hot water header. These samples were kept wet, wrapped in plastic and sent to EDM International, Inc., a wood testing laboratory in Fort Collins, CO. The samples were tested to determine their compressive strength and their modulus of elasticity. The samples were tested in their wet saturated condition just as they would be in use in a cooling tower.

The CTI Bulletin STD-103 (For The Design of Cooling Towers With Redwood Lumber) gives values of 1,758 psi for the compression strength of new clear heart structural redwood and 1.4X10^6 psi for the modulus of elasticity. After adjustments for size, temperature and moisture content, the compression strength of the new lumber was 1,261 psi and the MOE was 1.04X10^6 psi. The results of the testing by EDM indicated the compression strength had declined to 69% of new wood and the MOE declined to 79%.

By knowing the physical properties of the wood when it was new and establishing the physical properties of the wood after 43 years in an operating cooling tower, the lab was able to extrapolate the expected properties the wood would have after 10 more years in the cooling tower. (See CTI Paper TP96-11 Strength-Degradation Based Life Expectancy of Wood Cooling Towers)
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The reduced compressive capacity and modulus of elasticity were used in a structural model of the towers. The structural analysis program we used was RISA-2D Version 6.5. It calculated the stresses and deflection in all of the members in the cooling towers. It also identified the members which would fail due to bending or buckling. The program predicted failure in the exact members which were failing in the towers. The design wind load on the towers is 85 mph and the design seismic load is .2g. The analysis was done with load combinations of operating load, operating load + wind load and operating load + seismic load. The members which are colored red will fail, the pink members are close to failure and the other colors are not in danger of failure.

These towers are unusual because the columns that support the hot water distribution deck, hot water header, fill hangers and fill, and suspended water, are installed on a 13° angle. This is the same slope as the inlet louver column. The hot water headers entering the towers are 54 inches in diameter. The headers reduce in diameter as they extend down the length of the towers. The support columns under the 54 inch header are 4 X 6’s. When the header reduces to 36 inch diameter the support columns change to 4 X 4’s. The angle on the columns induces tension in the transverse horizontal ties which span across the plenum of the towers. The 2 X 6’s that support the hot water deck and continue across the plenum are in tension by over 2,000 pounds. This constant tension over the years has caused some of the splices to fail. Some have failed by splitting at the bolts and some have failed because the splice block has split and fallen out. This has allowed the hot water deck and the hot water headers to spread apart. The top 6 feet of the 4 X 4 and 4 X 6 columns have bowed outward 2 to 3 inches in some places.

**SUGGESTED MODIFICATIONS:**

1. In order to take some of the load off of the columns that are failing, a vertical helper column can be installed under the hot water header support saddle. This column should be a 4 X 6 douglas fir column that extends from the con-
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*With 45 years of fan blade production history, Hudson continues to push the limits of axial flow fan technology.*
crete basin to the bottom of the header support saddle.

2. To eliminate the tendency of the tower to spread apart a 5/16 inch stainless steel cable can be installed across the plenum tying the two headers together. These cables should be installed on all transverse bents and tensioned to 1,000 pounds.

3. The top section of all columns that are bowed more than 1 inch should be replaced with new wood.

4. All horizontal girts which are split at the bolt holes should be replaced and all splice blocks that are split should be replaced.

**REPAIR PLAN:**

One cell on both towers will be taken out of service. The inlet louvers will be removed by a contractor. The fill and fill hanger wire will be removed by the contractor to allow a complete and thorough inspection of the structure. Bad members, which should be replaced, will be identified and flagged by Reliant Energy for replacement by the contractor. After replacement of the flagged members the contractor will install new fill hangers and new fill. New inlet louvers will also be installed. It is estimated about 40% of the structure in the fill area of the towers will have to be replaced.

**THE DECISION:**

Option 1. Do nothing and repair failures as they occur.

Option 2. Repair the existing tower as outlined above.

Option 3. Remove the existing towers and install new towers

Doing nothing was not an option due to the likelihood of near term failure of the structure, and repair was half the cost of replacement. Repairing the existing structure with the added modifications was the easy choice.

**CONCLUSIONS:**

The testing of the redwood samples to determine their actual compressive strength and modulus of elasticity allowed structural modeling of the cooling towers as they actually were. This model clearly identified the members that would fail. Fulkerson & Associates, Inc. was then able to engineer a repair that would allow the towers to safely remain in service for an additional 10 years and at a cost which was about half of the cost of replacing them with new towers.

As it turned out the estimate of 40% replacement of the wood in the fill area of the towers was a low estimate. The activity of the workers dropping bad members on the existing horizontal girts and climbing and working on the old brittle horizontal girts caused some of them to break. The nailing of new fill hanger supports to the old redwood transverse girts also caused some splitting at the bolt holes. The transverse girts had to be un-bolted to allow the installation of the new vertical helper columns. The labor to remove the horizontal girts and replace them was already being expended so it made good sense not to re-install the old girts but to replace them with new lumber. Therefore most of the transverse horizontal 2 X 4 girts were replaced. Fortunately, there was enough contingency money in the budget to cover this additional cost of material.

The project was completed in mid December, 2006 on schedule and slightly under budget.
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Anionic Compatible Quat?

Sweeny, P. & Murray, D. Lonza Inc.

Abstract
Sunlight exposed cooling towers can develop significant algae-related fouling problems. Algal mats and stringers visually indicate an inefficient microbiological program and increase oxidant demand reducing the effectiveness of oxidizing biocides. In addition algal fouling will often block tower fill reducing tower efficiency.

The use of oxidizing biocides for algae control frequently requires operating at an oxidant concentration higher than desired from a corrosion perspective. In addition, most non-oxidizing biocides are designed for bacterial rather than algal slime control. Thus the use of supplemental algaecides is necessitated.

This paper shows that by optimizing the quaternary structure, excellent algaecidal efficacy can be maintained while dramatically reducing the tendency to foam as well as polyacrylate interactions. Diocetyl dimethylammonium chloride (DODMAC) was developed to bring this technology to the water treatment service industry. This paper compares the performance of DODMAC with traditional quaternaries as well as two specialty algaecides terbuthylazine (TBA) and dichloro-n-octylisothiazolin (DCOI). In addition, foaming and polyacrylate compatibility data are presented demonstrating the excellent overall performance of DODMAC.

Introduction
Cooling water systems often develop algae problems, producing algal mats and stringers in sunlight exposed towers. Such algal accumulation:

- visually indicates an inefficient microbiological control program,
- blocks fill fill reducing tower efficiency, and
- introduces and fixes high levels of reduced carbon into the cooling system increasing oxidant demand and providing nutrients for bacterial fouling.

The use of oxidizing biocides for algae control frequently requires operating at an oxidant concentration higher than desired from a corrosion perspective. In addition, adding sufficiently high levels of active bromine and chlorine to control algae results in accelerated corrosion and decomposition of scale and corrosion inhibitors. Likewise, most typical non-oxidizing biocides are generally targeted at bacterial slime control rather than algae control thus making them relatively ineffective for this application. The use of supplemental algaecides is thus typically required.

The use of quaternaries in cooling applications has been traditionally complicated by the high turbulence of these systems and the common use of various anionic inhibitors for scale and corrosion control. The high turbulence of the water caused by the recirculation pumps gives rise to a requirement for chemicals to be low foaming. Not only is foam unsightly, but it can also contribute to pump cavitation. Since traditional quats demonstrate particularly high foaming in cooling water systems, the addition of a separate defoamer is often required. In addition, when applying such older generation quaternaries to cooling systems containing anionic polymers, one must assure that the feed of the quaternaries and the corrosion/scale inhibitor packages are added remotely from each other to minimize possible interactions. Thus, while use of standard quaternaries is desirable from a cost-performance perspective, their use requires careful addition and monitoring.

The work summarized in this paper shows that by optimizing the quaternary structure, excellent algaecidal efficacy can be maintained while dramatically reducing the tendency to foam as well as polyacrylate interactions. Diocetyl dimethylammonium chloride (DODMAC) was developed to bring this technology to the water treatment service industry. This paper compares the performance of DODMAC with traditional quaternaries as well as two specialty algaecides terbuthylazine (TBA) and dichloro-n-octylisothiazolin (DCOI). In addition, foaming and polyacrylate compatibility data are presented demonstrating the excellent overall performance of DODMAC.

Background
Quaternary Composition and Structure
Quaternary ammonium compounds are tetravalent nitrogen species carrying a positive charge. The counter ion is typically chloride. Historically three classes of quaternaries have been employed in the cooling water industry for microbial control, with by far the most common being alkylidimethylbenzyl ammonium chlorides (ADBACs). The three types of quaternaries are:

A) ADBACs (e.g., benzalkonium chloride)
B) dialkyldimethyl ammonium chlorides which include materials such as diocetyl dimethylammonium chloride (DODMAC), and didecyldimethyl ammonium chloride (DDAC), and
C) polymeric quaternaries which include polyoxyethylene (dimethyliminio)ethylene(dimethyliminio)ethylene dichloride (WSCP).

Structures of DODMAC, DDAC and benzalkonium chloride are shown in Figure 1.

Polyanioinc interactions and alkyl chain length
The interaction of quaternaries with polymeric anions such as sodium polyacrylate has been studied intensively (1-3). The major relevant conclusions from this work are that interactions between quaternaries and polymeric anions:
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Algaecidal efficacy and alkyl chain length

The algaecidal efficacy of quaternary ammonium compounds is well known and commonly utilized. Perhaps the most comprehensive work on the microbiological efficacy of quaternaries was performed by Hueck et al. (4). This milestone paper describes the bactericidal, fungicidal and algaecidal efficacy of a diverse set of quaternaries and amines.

The key algaecidal efficacy data is shown in Table 1. As indicated, these materials are highly effective algaecides. DODMAC provides algae control at dosages of 0.7-7.0 ppm active. Comparison of DODMAC efficacy to the higher molecular weight DDAC and benzalkonium chloride shows that efficacy is only slightly reduced. This small decrease is far less than the 100 fold reduction in polyacrylate interaction expected from this molecular weight reduction.

The excellent algaecidal efficacy and anticipated 100 fold reduction in polyacrylate interaction suggests that DODMAC would offer idealized performance in cooling water applications.

DODMAC Technical Description

In order to apply DODMAC to cooling water and decorative fountains as an algaecide, EPA registered formulations were developed. The typical physical properties of these formulations are shown in Table 2.

Experimental

Algaecidal Efficacy:

The test protocol used was a modified version of that described in the “Pesticide Assessment Guidelines” (5) and ASTM E 645-91(6). The test materials are listed in Table 3.

Pure cultures of chlorella pyrenoidosa ATCC 30582 and scenedesmus obliquus ATCC# 14477 were utilized as specified (5). The cultures were grown in Bristol’s solution under timed 16 hours light/8 hours dark fluorescent lighting on an orbital shaker placed 12 inches below the light source. Sufficient culture was grown to provide a minimum of 3 x 10^6 cfu/ml in each 30 ml test jar. The specific initial cell counts were 4.5 x 10^6 cfu/ml for the Chlorella test matrix and 2.5x 10^6 cfu/ml for the Scenedesmus test matrix these exceeded the minimum specified concentration of 3x10^5 cfu/ml (5).

Master solutions of the indicated algaecides were prepared and added to the 30 ml jars of the inoculae/Bristols solutions in volumes no greater than 0.3 ml to minimize dilution effects.

Efficacy was rated at 5 and 14 days as specified under ASTM E 645-91. Algaecidal efficacy rating was by the visual method of the efficacy of the Pesticide Assessment Guidelines, i.e., 0 = no growth and 5= very heavy growth.

Interactions with Anionics

Quaternary anionic polymer affinity was determined through the use of a dynamic recirculation apparatus designed to maximize foaming and thus precipitation stress. The dynamic apparatus consisted of a 0.5 HP centrifugal pump attached to a clear glass reservoir holding 1.5 L of test solution. The solution was pumped to the top of the 2 ft glass reservoir and injected through an aspiration nozzle allowing the solution to impinge on the reservoir surface a distance of 18 inches from the nozzle outlet. The solution utilized was composed of distilled water to which calcium chloride and sodium carbonate were added with pH adjustment to achieve the water chemistry indicated in Table 4.

The quaternaries subjected to the dynamic polyacrylate interaction test were as listed in Table 5. Residual quaternary concentrations were measured using Hach method 8337.

Two representative scale inhibitors were examined: a) a pure polyacrylate and b) a tagged sulfate modified polyacrylate. The former was examined as it is the historical industry standard the latter was included as it allowed for rapid detection of soluble polyacrylate using the associated test kit as well as quaternary residuals.

Foaming

Foaming tendency of the test quaternaries of Table 5 were determined by measuring the foam generated using the dynamic recirculation apparatus this time in the absence of polyacrylate. The absence of polyacrylate maximizes foam potential. The absence of polyacrylate also necessitated reduced hardness, alkalinity and pH to avoid CaCO3 precipitation during the test. The specific test conditions are listed in Table 6.

Results

Algaecidal Efficacy:

DODMAC provides excellent algaecidal efficacy completely controlling Chlorella pyrenoidosa at 13 ppm product applications See Figure 2. This high level of efficacy is similar to that of standard benzalkonium chloride (ADBAC) while significantly greater than that polymeric quaternary and the alternative functionality algaecides TBA and DCOI when applied at equivalent or even higher concentrations. The results of the 14 day contact studies are also shown pictorially in Figure 3.

DODMAC algaecidal efficacy was confirmed against a second algal strain Scenedesmus obliquus with similar results. See Figures 4 and 5.

Polyacrylate Compatibility

DODMAC demonstrates significantly enhanced polyacrylate compatibility relative to the standard commercial quaternaries benzalkonium chloride (ADBAC) and polyquat. DODMAC compatibility with standard polyacrylate is shown in Figure 6. In this test quaternary residuals were measured after 15 minutes of dynamic foam stress. As indicated, dramatically higher quaternary residuals remain for DODMAC compared to standard ADBAC.
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In order to further examine the quaternary and polyacrylate interactions it was desirable to monitor not only quaternary residuals but also polyacrylate residuals and to measure these as a function of time (as opposed to a single static measurement). This was accomplished through the use of commercially available, tagged, partially sulfonated polyacrylate. As shown in Figure 7 the resulting quaternary residuals for DODMAC were high and stable as compared to the low unstable readings obtained for ADBAC and polyquat. This result is consistent with a small dynamic interaction of DODMAC with polyacrylate compared to the large increasing interaction observed for ADBAC and polyquat.

These quaternary residual results are consistent with the polyacrylate residual results shown in Figure 8. As demonstrated polyacrylate residuals remain unchanged in the presence of DODMAC while these again were low and decreasing in the case of ADBAC and polyquat.

The key function of polyacrylate in cooling applications is to inhibit scale formation. The impact of DODMAC on polyacrylate scale inhibition itself was thus examined under even more severe conditions consisting of 240 recirculation cycles of dynamic stress followed by 7 day storage at 50°C. As shown in Figure 9 the residual total hardness and final pH of the DODMAC treated samples remained similar to the untreated polyacrylate control. In contrast, the ADBAC treated sample showed a significant decrease of soluble hardness and final pH.

**Foaming**

The foaming tendency of quaternary ammonium compounds results from their surfactant nature. Possessing a water soluble positively charged nitrogen head group and a hydrophobic alkyl chain tail, see Figure 1, quaternaries can produce stable foam lamella by an analogous mechanism to micelle formation. The reduction in alkyl chain length to eight carbons in the case of DODMAC decreases the hydrophobic character of this quaternary and associated foam stabilization. The foam levels generated by 30 ppm active quaternary are shown in Figure 10. As demonstrated, the foaming propensity of DODMAC is reduced to minimal levels.

**Application**

The tendency of algae to foul cooling towers varies considerably depending on the amount of sunlight, temperature and water chemistry. Thus, the allowed application rates of DODMAC are intentionally broad. EPA label approved application rates for DODMAC algaecidal applications are from 5 to 60 ppm active. A good starting dosage program for a 1000 gallon cooling tower with minimal visible algae consists of an initial dose of 5 ounces (20 ppm active) Bardac® LF 18-50 (50% active) twice per week for two weeks followed by a maintenance regime of 3 ounces (10 ppm active) Bardac LF 18-50 twice per week thereafter. Of course, systems with lower or higher levels of algae will require lower or higher DODMAC dosages respectively.

**Monitoring**

Use concentrations of DODMAC can be monitored using Hach method 8337. As expected other standard field test kits typically do not respond to the anionic compatible DODMAC due to their use of polyanionic titrants such as polyvinylsulfate potassium salt (PVSK). Test kit response verification should be confirmed in the lab prior to field implementation.

**Conclusions**

- DODMAC provides excellent algaecidal efficacy, far surpassing both TBA and DCOI on a ppm product basis.
- DODMAC is compatible with polyacrylate based scale inhibitors.
- DODMAC is low foaming. Foaming is dramatically reduced compared to standard quaternaries such as benzalkonium chloride.

**Summary**

The unique alkyl chain composition of DODMAC allows the high algaecidal efficacy of quaternaries to be achieved in industrial cooling applications without the impediments of high foam and polyacrylate interaction. These traits show that this chemistry will demonstrate improved cost performance over alternate commercial algaecides when used in cooling water system. Accordingly it should be considered:

- As a cost-effective way to prevent algae formation or recover systems where algae has become established.
- In conjunction with oxidizing biocide programs to provide algal control without the excessive application of oxidant and associated corrosion.
- In conjunction with stabilized oxidizing biocide programs to provide algal control without the excessive application of stabilizer and associated efficacy loss and elevated cost.
- As a complimentary algaecide for non-oxidizing programs.

**References**


**Table 1. Algaecidal Efficacy of Quaternary Ammonium Compounds (4)**

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Total Carbons</th>
<th>MN</th>
<th>Algaecidal Efficiency ppm active</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chlorella</td>
</tr>
<tr>
<td>DODMAC</td>
<td>16</td>
<td>312</td>
<td>7</td>
</tr>
<tr>
<td>DGAC</td>
<td>22</td>
<td>367</td>
<td>2</td>
</tr>
<tr>
<td>Benzalkonium chloride</td>
<td>22</td>
<td>361</td>
<td>1</td>
</tr>
</tbody>
</table>
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Table 2. Typical Properties of DODMAC EPA Registered Formulations

<table>
<thead>
<tr>
<th>Property</th>
<th>Bardac® LF 18-00 WT</th>
<th>Bardac® LF 18-10 WT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active DODMAC</td>
<td>50 %</td>
<td>10 %</td>
</tr>
<tr>
<td>Form</td>
<td>Aqueous solution</td>
<td>Aqueous solution</td>
</tr>
<tr>
<td>Flash Point, °F</td>
<td>&gt; 200</td>
<td>&gt; 200</td>
</tr>
<tr>
<td>Freeze Point, °C</td>
<td>-12</td>
<td>-8</td>
</tr>
<tr>
<td>Appearance</td>
<td>Clear to pale yellow</td>
<td>Clear to pale yellow</td>
</tr>
<tr>
<td>pH 10% solution</td>
<td>6.5 – 9.0</td>
<td>6.5 – 9.0</td>
</tr>
<tr>
<td>Density g/cm³</td>
<td>0.960</td>
<td>0.988</td>
</tr>
<tr>
<td>Viscosity, cps @ 25°C</td>
<td>30</td>
<td>7.5</td>
</tr>
<tr>
<td>Solubility</td>
<td>Water soluble in all proportions</td>
<td>Water soluble in all proportions</td>
</tr>
</tbody>
</table>

Table 3. Material List

<table>
<thead>
<tr>
<th>Material</th>
<th>% Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diocetyl(dimethylammonium chloride (DODMAC))</td>
<td>50.0</td>
</tr>
<tr>
<td>4,6-Dichlor-2-n-octyl-3(2H)-isothiazolone (DCOI)</td>
<td>4.25</td>
</tr>
<tr>
<td>6-(tert-butyramino)-4-chloro-6(ethylamino)-3-triazine (TBA)</td>
<td>4.0</td>
</tr>
<tr>
<td>Benzalkonium chloride (an ADBAC)</td>
<td>50.0</td>
</tr>
<tr>
<td>Poly(oxethylene(dimethylimino)ethylenedimethylimino) dichloride (WSCP)</td>
<td>60.0</td>
</tr>
</tbody>
</table>

Table 4. Dynamic Polyacrylate Interaction Test Conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additives</td>
<td></td>
</tr>
<tr>
<td>Quaternary</td>
<td>15 ppm Al</td>
</tr>
<tr>
<td>Polyacrylate*</td>
<td>10 ppm Al</td>
</tr>
<tr>
<td>Water Chemistry</td>
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<tr>
<td>pH</td>
<td>10</td>
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<tr>
<td>Total alkalinity</td>
<td>200 ppm as CaCO₃</td>
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<tr>
<td>Total hardness</td>
<td>600 ppm as CaCO₃</td>
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<tr>
<td>Temperature</td>
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</tr>
<tr>
<td>Conditions</td>
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<tr>
<td>Flow rate</td>
<td>1.5 GPM</td>
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<tr>
<td>Time</td>
<td>15 min</td>
</tr>
<tr>
<td>Cycles/turnovers</td>
<td>60</td>
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*tagged, sulfate-modified polyacrylate

Table 5. Material List

<table>
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<tr>
<th>Material</th>
<th>% Al</th>
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<tr>
<td>Diocetyl(dimethylammonium chloride (DODMAC))</td>
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<tr>
<td>Benzalkonium chloride (an ADBAC)</td>
<td>50.0</td>
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<tr>
<td>Poly(oxethylene(dimethylimino)ethylenedimethylimino) dichloride (WSCP)</td>
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Table 6. Dynamic Foam Test

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<th>Parameter</th>
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<td>Quaternary</td>
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<td>pH</td>
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<td>Total alkalinity</td>
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<td>Total hardness</td>
<td>260 ppm as CaCO₃</td>
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<td>Temperature</td>
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</tr>
<tr>
<td>Time</td>
<td>15 min</td>
</tr>
<tr>
<td>Cycles/turnovers</td>
<td>60</td>
</tr>
</tbody>
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Figure 1. Standard Water Treatment Quaternaries

1. **DODMAC (Bardac® LF)**
   - Total carbons = 18;
   - MW = 312
   - ![DODMAC Structure](image)

2. **ADBAC (Benzalkonium chloride)**
   - Total carbons = ~22;
   - MW = 357
   - ![ADBAC Structure](image)

3. **DDAC**
   - Total carbons = 22;
   - MW = 361
   - ![DDAC Structure](image)

Figure 2. *Chlorella pyrenoidosa* Efficacy

Algal Growth at Comparable Product Additions

*Chlorella pyrenoidosa*, 14 day contact

Algae Growth:

- 0 = None
- 5 = Heavy Growth

![Algae Growth Graph](image)
Figure 3. *Chlorella pyrenoidosa* Efficacy (Visual)

**Relative Efficacy:**

*Chlorella pyrenoidosa*, 14 day contact

![Image of Chlorella pyrenoidosa efficacy](image)

- **TBA**: 25 ppm prod.
- **DODMAC**: 13 ppm prod.
- **DCOI**: 12 ppm prod.

Figure 4. *Scenedesmus obliquus* Efficacy

**Algal Growth at Comparable Loadings**

*Scenedesmus obliquus*, 14 day contact

![Image of Scenedesmus obliquus efficacy](image)

- **Algae Growth**
  - Scale: 0 = No growth, 5 = Heavy growth
  - **DODMAC**: 13 ppm Prod.
  - **TBA**: 25 ppm Prod.
  - **DCOI**: 12 ppm Prod.
  - **Control**

Figure 5. *Scenedesmus obliquus* Efficacy (Visual)

**Algal Growth at Comparable Applications**

*Scenedesmus obliquus* 14 day contact

![Image of Scenedesmus obliquus efficacy visual](image)

- **TBA**: 25 ppm prod.
- **DODMAC**: 13 ppm prod.
- **DCOI**: 12 ppm prod.

Figure 6. Dynamic Quaternary/Polyacrylate Compatibility

(Quaternary Residuals)

![Graph of Dynamic Quaternary/Polyacrylate Compatibility](image)

- **Residual Active Quaternary (%)**
- **DODMAC**
- **ADBAC**
- **Polyquat**

Figure 7. Dynamic Quaternary/Sulfonated Polyacrylate Compatibility

(Quaternary Residuals)

![Graph of Dynamic Quaternary/Sulfonated Polyacrylate Compatibility](image)

- **Residual Active Quaternary (%)**
- **DODMAC**
- **ADBAC**
- **Polyquat**

Figure 8. Dynamic Quaternary/Sulfonated Polyacrylate Compatibility

(Polyacrylate Residuals)

![Graph of Dynamic Quaternary/Sulfonated Polyacrylate Compatibility](image)

- **Residual Polyacrylate (%)**
- **DODMAC**
- **ADBAC**
- **Polyquat**
Figure 9. Dynamic Scale Inhibition Testing (maximized stress)

Figure 10. Comparative Dynamic Foam Levels (maximized foam stress)

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Evaptech, Inc
Aggreko Cooling Tower Services
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Composite Cooling Solutions, LP
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Tables Still Available. Contact Virginia Manser at 281-583-4087 or vmanser@cti.org for Information.
For nearly thirty years, the Cooling Technology Institute has provided a truly independent, third party, thermal performance testing service to the cooling tower industry. In 1995, the CTI also began providing an independent, third party, drift performance testing service as well. Both these services are administered through the CTI Multi-Agency Tower Performance Test Program and provide comparisons of the actual operating performance of a specific tower installation to the design performance. By providing such information on a specific tower installation, the CTI Multi-Agency Testing Program stands in contrast to the CTI Cooling Tower Certification Program which certifies all models of a specific manufacturer's line of cooling towers perform in accordance with their published thermal ratings.

To be licensed as a CTI Cooling Tower Performance Test Agency, the agency must pass a rigorous screening process and demonstrate a high level of technical expertise. Additionally, it must have a sufficient number of test instruments, all meeting rigid requirements for accuracy and calibration.

Once licensed, the Test Agencies for both thermal and drift testing must operate in full compliance with the provisions of the CTI License Agreements and Testing Manuals which were developed by a panel of testing experts specifically for this program. Included in these requirements are strict guidelines regarding conflict of interest to ensure CTI Tests are conducted in a fair, unbiased manner.

Cooling tower owners and manufacturers are strongly encouraged to utilize the services of the licensed CTI Cooling Tower Performance Test Agencies. The currently licensed agencies are listed below.

### Licensed CTI Thermal Testing Agencies

<table>
<thead>
<tr>
<th>License Type*</th>
<th>Agency Name</th>
<th>Contact Person</th>
<th>Telephone</th>
<th>Fax</th>
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<tr>
<td>A,B</td>
<td>Clean Air Engineering</td>
<td>Kenneth Hennon</td>
<td>800.208.6162</td>
<td>865.938.7569</td>
</tr>
<tr>
<td></td>
<td>7936 Conner Rd Powell, TN 37849</td>
<td><a href="http://www.cleanair.com">www.cleanair.com</a></td>
<td>612 9789 5900</td>
<td>612 9789 5922</td>
</tr>
<tr>
<td>A, B</td>
<td>Cooling Tower Technologies Pty Ltd</td>
<td>Ronald Rayner</td>
<td>913.681.0027</td>
<td>913.681.0039</td>
</tr>
<tr>
<td></td>
<td>PO Box N157 Bexley North, NSW 2207 AUSTRALIA</td>
<td><a href="mailto:coolingtwrtech@bigpond.com">coolingtwrtech@bigpond.com</a></td>
<td>865.588.2654</td>
<td>425.557.8377</td>
</tr>
<tr>
<td>A,B</td>
<td>Cooling Tower Test Associates, Inc.</td>
<td>Thomas E. Weast</td>
<td>800.208.6162</td>
<td>865.938.7569</td>
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<tr>
<td></td>
<td>15325 Melrose Dr. Stanley, KS 66221-9720</td>
<td><a href="http://www.cttai.com">www.cttai.com</a></td>
<td>865.588.2654</td>
<td>425.557.8377</td>
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<tr>
<td>A, B</td>
<td>McHale &amp; Associates, Inc</td>
<td>Thomas Wheelock</td>
<td>800.208.6162</td>
<td>865.938.7569</td>
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<tr>
<td></td>
<td>6430 Baum Drive Knoxville, TN 37919</td>
<td><a href="http://www.mchale.org">www.mchale.org</a></td>
<td>865.588.2654</td>
<td>425.557.8377</td>
</tr>
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</table>

* Type A license is for the use of mercury in glass thermometers typically used for smaller towers.
Type B license is for the use of remote data acquisition devices which can accommodate multiple measurement locations required by larger towers.

### Licensed CTI Drift Testing Agencies

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<th>Fax</th>
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<td>Kenneth Hennon</td>
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<td>865.938.7569</td>
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<td><a href="http://www.cleanair.com">www.cleanair.com</a></td>
<td>865.588.2654</td>
<td>425.557.8377</td>
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<td>McHale &amp; Associates, Inc</td>
<td>Thomas Wheelock</td>
<td>800.208.6162</td>
<td>865.938.7569</td>
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<tr>
<td>6430 Baum Drive Knoxville, TN 37919</td>
<td><a href="http://www.mchale.org">www.mchale.org</a></td>
<td>865.588.2654</td>
<td>425.557.8377</td>
</tr>
</tbody>
</table>
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- All without picking up a pencil!

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Card No.: ___________________ Expiration Date: ___________________
Signature: ___________________ CVV; CVC; CID Code: ___________________

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<th>Unit Price</th>
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<td>CTI ToolKit Version 3.0 (single user license)</td>
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<td>CTI Member</td>
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<td>CTI ToolKit Version 3.0 (Upgrade from V1.0 and V2.0)</td>
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<td>CTI Member</td>
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<tr>
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<td>PerfCurv 3.0 (Stand alone Performance Curve application)</td>
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<tr>
<td>CTI Member</td>
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<td>$240</td>
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<td>Any of the above applications with original hard copy of the CTI Performance Curve (3-Ring Binder)</td>
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<td>CTI Member (add)</td>
<td>$140</td>
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<tr>
<td>Non-member (add)</td>
<td>$180</td>
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Shipping for CD-Rom (from Texas):
- Priority mail $6; 2nd Day Air $16; Overnight Domestic $26; / US Priority International $30

Shipping for BlueBook 3-Ring Binder (from Texas):
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gram whereby the Cooling Technology Institute will certify that all models 
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will perform thermally in accordance with the Manufacturer’s published rat-
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the tower will perform as specified, provided that its circulating water is no 
more than acceptably contaminated-and that its air supply is ample and 
unobstructed. Either that model, or one of its close design family members, 
will have been thoroughly tested by the single CTI-licensed testing agency 
for Certification and found to perform as claimed by the Manufacturer. 
CTI Certification under STD-201 is limited to thermal operating conditions 
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range of 2.2°C (4°F) or greater, and a cooling approach of 2.8°C (5°F) or greater. The manufacturer may set more restrictive limits if desired 
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Following is a list of cooling tower models currently certified under STD-201. They are part of product lines offered by Advance GRP 
(Advance) Cooling Towers, Pvt., Ltd.; Amcot Cooling Tower Corporation; AONE E&C Corporation, Ltd; Baltimore Aircoil Company, Inc.; 
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div of York International; Ltd; KIMCO (Kyung In Machinery Company, Ltd.); Liang Chi Industry Company, Ltd.; Mesan Cooling Tower, 
Ltd; Polacel b.v.; Protec Cooling Towers; Ryowo (Holding) Company, Ltd; SPX (Marley) Cooling Technologies; Supraflux Cooling 
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distinguish themselves through design excellence and concern for the User’s operational safety and convenience.

Those Manufacturers who have not yet chosen to certify their product lines are invited to do so at the earliest opportunity. You can 
contact Virginia A. Manser, Cooling Technology Institute, PO Box 73383, Houston, TX 77273 for further information.
## Cooling Towers Certified by CTI Under STD-201

<table>
<thead>
<tr>
<th>Company</th>
<th>Model Line</th>
<th>CTI Certification Validation Number</th>
<th>Certification Date (Revision)</th>
<th>Models</th>
<th>CTI Model Listing</th>
<th>Information</th>
<th>Selection</th>
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Baltimore Aircoil Company, Inc. – PT2 Series Cooling Tower Line
CTI Certification Validation Number 07-11-11 – May 5, 2007 (Revision 0)
(214 counter-flow, induced-draft models)

Baltimore Aircoil Company, Inc. – Series V Closed Circuit Cooling Tower Line
CTI Certification Validation Number 00-11-10 – September 15, 2000 (Revision 0)
(265 VF1 & 103 VFL closed-circuit, forced-draft models)

Baltimore Aircoil Company, Inc. – Series V Open Cooling Tower Line
CTI Certification Validation Number 92-11-02 – April 12, 1995 (Revision 3)
(34 VT0 counter-flow, forced-draft models)
CTI Certification Validation Number 92-11-04 – April 12, 1995 (Revision 1)
(81 VT1 counter-flow, forced-draft models)
CTI Certification Validation Number 92-11-03 – October 31, 2003 (Revision 2)
(61 VTL counter-flow, forced-draft models)

Baltimore Aircoil Company, Inc. – Series 1500 Cooling Tower Line
CTI Certification Validation Number 98-11-08 – June 30, 2006 (Revision 6)
(29 cross-flow, induced-draft models)

Baltimore Aircoil Company, Inc. – Series 3000A, C, & D Cooling Tower Line
CTI Certification Validation Number 92-11-06 – November 2, 2007 (Revision 8)
(183 cross-flow, induced-draft models)
Delta Cooling Towers, Inc. – TM Series Cooling Tower Line
CTI Certification Validation Number 02-24-01 – October 10, 2002 (Revision 0)
(96 counter-flow, induced-draft models)
Information: http://www.deltacooling.com/tm.html
Selection: www.deltacooling.com/tmtable.html

Evapco, Inc. – AT Series Cooling Tower Line
CTI Certification Validation Number 99-13-01 – May 15, 2007 (Revision 7)
(453 AT, USS/UAT, UT + 36 REP + 100 UBT counter-flow, induced-draft models)
Selection All Models: www.evapco.com/evapspec/welcome.asp

Evapco, Inc. – ESWA Line of Closed Circuit Coolers
CTI Certification Validation Number 06-13-05 – November 19, 2007 (Revision 3)
(400 closed-circuit, induced-draft models)
Information: http://www.evapco.com/esw_brochures.asp
Selection: http://www.evapco.com/evapspec/welcome.asp

Evapco, Inc. – LPT Cooling Tower Line
CTI Certification Validation Number 05-13-04 – January 3, 2005 (Revision 0)
(43 counter-flow, forced-draft models)
CTI Model Listing: http://www.cti.org/towers/Evapco-LPT.pdf
Information: http://www.evapco.com/lptcooling.asp
Selection: http://www.evapco.com/evapspec/welcome.asp

Evapco, Inc. – LSTB Cooling Tower Line
CTI Certification Validation Number 05-13-03 – January 3, 2005 (Revision 0)
(57 counter-flow, forced-draft models)
CTI Model Listing: http://www.cti.org/towers/Evapco-LSTB.pdf
Information: http://www.evapco.com/lstbcooling.asp
Selection: http://www.evapco.com/evapspec/welcome.asp

Fabrica Mexicana De Torres, S. A., Reymsa Cooling Towers – GHR Cooling Tower Line
CTI Certification Validation Number 00-22-02 – July 5, 2000 (Revision 1)
(168 counter-flow, induced-draft models)
CTI Model Listing: http://www.cti.org/towers/Fabrica-GHR.pdf
Fabrica Mexicana De Torres, S. A., Reymsa Cooling Towers — HR Cooling Tower Line
CTI Certification Validation Number 04-22-03 — October 3, 2004 (Revision 0)
(40 counter-flow, induced-draft models)
CTI Model Listing: http://www.cti.org/towers/Fabrica-HR.pdf

HVAC/R International, Inc. — Therflow Series Cooling Tower Line
CTI Certification Validation Number 05-28-01 — September 29, 2006 (Revision 1)
(27 cross-flow, forced-draft models)
CTI Model Listing: http://www.cti.org/towers/HVACR.pdf

Imeco, Div. of York International — IMC Cooling Tower Line
CTI Certification Validation Number 05-21-01 — August 28, 2005 (Revision 0)
(87 counter-flow, induced-draft models)
Information: http://www.frickcold.com/products.asp
Selection: http://www.frickcold.com/products.asp

KIMCO (Kyung In Machinery Company, Ltd.) — CKL Line of Closed Circuit Cooling Towers
CTI Certification Validation Number 05-18-02 — June 22, 2007 (Revision 1)
(10 closed-circuit, induced-draft models)
CTI Model Listing: http://www.cti.org/towers/KIMCO-CKL.pdf
Information: http://www.kyunginct.co.kr/eng/prod1.htm
Selection: http://www.kyunginct.co.kr/eng/webcal1.htm

KIMCO (Kyung In Machinery Company, Ltd.) — EnduraCool Cooling Tower Line
CTI Certification Validation Number 93-18-01 — May 17, 2007 (Revision 6)
(33 cross-flow, induced-draft models)
Information: http://www.kyunginct.co.kr/eng/prod1.htm
Selection: http://www.kyunginct.co.kr/eng/webcal1.htm

Liang Chi Industry Company, Ltd. — LC Cooling Tower Line
CTI Certification Validation Number 96-20-01 — September 8, 2007 (Revision 2)
(8 cross-flow, induced-draft models)
CTI Model Listing: http://www.cti.org/towers/LiangChi.pdf
Mesan Cooling Tower, Ltd. – MCR Series Cooling Tower Line
CTI Certification Validation Number 05-26-02 – October 5, 2005 (Revision 0)
56 counter-flow, induced-draft models
CTI Model Listing: http://www.cti.org/towers/Mesan-MCR.pdf

Mesan Cooling Tower, Ltd. – MXR Series Cooling Tower Line
CTI Certification Validation Number 05-26-01 – May 23, 2007 (Revision 2)
58 cross-flow, induced-draft models
CTI Model Listing: http://www.cti.org/towers/Mesan-MXR.pdf

Polacel, b. v. – CR Series Cooling Tower Line
CTI Certification Validation Number 04-25-01 – July 16, 2004 (Revision 0)
78 CMC + 180 CMDR counter-flow, induced-draft models
CTI Model Listing: http://www.cti.org/towers/Polacel-CR.pdf
Information: http://www.polacel.com/Models.asp
Selection: http://www.polacel.com/PolaSelections/

Polacel b. v. – XR Series Cooling Tower Line
CTI Certification Validation Number 04-25-02 – July 16, 2004 (Revision 0)
4 XE +16 XL + 27 XT cross-flow, induced-draft models
CTI Model Listing: http://www.cti.org/towers/Polacel-XR.pdf
Information: http://www.polacel.com/Models.asp
Selection: http://www.polacel.com/PolaSelections/

Protec Cooling Towers, Inc. – FWS Series Cooling Tower Line
CTI Certification Validation Number 04-27-01 – June 18, 2007 (Revision 2)
55 cross-flow, induced-draft models
CTI Model Listing: http://www.cti.org/towers/Protec.pdf
Information: www.protectowers.com/pdf/crossflow/FWSbrochure%20as%20of%206-29-06.pdf
Selection: http://www.protectowers.com/pdf/crossflow/FWSbrochure%20as%20of%206-29-06.pdf

Ryowo (Holding) Company, Ltd. – FRS Series Cooling Tower Line
CTI Certification Validation Number 05-27-03 – June 27, 2007 (Revision 1)
15 counter-flow, induced-draft models
Information: http://www.ryowo.com/FRS.pdf
Ryowo (Holding) Company, Ltd. – FWS Series Cooling Tower Line
CTI Certification Validation Number 04-27-01 – June 18, 2007 (Revision 2)
(55 cross-flow, induced-draft models)
Information: http://www.ryowo.com/FWS.pdf

Ryowo (Holding) Company, Ltd. – FXS Series Cooling Tower Line
CTI Certification Validation Number 05-27-02 – October 10, 2005 (Revision 0)
(8 cross-flow, induced-draft models)
Information: http://www.ryowo.com/FXS.pdf

SPX Cooling Technologies (Marley) – Aquatower Series Cooling Tower Line
CTI Certification Validation Number 01-14-05 – December 2, 2002 (Revision 1)
(13 cross-flow, induced-draft models)
Selection: http://qtcapps.marleyct.com/update/Login.aspx

SPX Cooling Technologies (Marley) – AV Series Cooling Tower Line
CTI Certification Validation Number 98-14-04 – April 11, 2000 (Revision 1)
(38 cross-flow, induced-draft models)
CTI Model Listing: http://www.cti.org/towers/SPX-AV.pdf
Selection: http://qtcapps.marleyct.com/update/Login.aspx

SPX Cooling Technologies (Marley) – MCF Series of Closed Circuit Fluid Cooler Line
CTI Certification Validation Number 07-14-10 – May 1, 2007 (Revision 1)
(27 closed-circuit, forced-draft models)
CTI Model Listing: http://www.cti.org/towers/SPX-MCF.pdf
Selection: http://qtcapps.marleyct.com/update/Login.aspx

SPX Cooling Technologies (Marley) – MCW Series of Cooling Towers
CTI Certification Validation Number 06-14-08 – January 3, 2006 (Revision 0)
(16 counter-flow, forced-draft models)
CTI Model Listing: http://www.cti.org/towers/SPX-MCW.pdf
Selection: http://qtcapps.marleyct.com/update/Login.aspx
SPX Cooling Technologies (Marley) – MHF Series of Closed-Circuit Fluid Cooler Line
CTI Certification Validation Number 04-14-07 – October 24, 2005 (Revision 1)
(244 closed-circuit, induced-draft models)
CTI Model Listing: http://www.cti.org/towers/SPX-MHF.pdf
Selection: http://qtcapps.marleyct.com/update/Login.aspx

SPX Cooling Technologies (Marley) – NC Series Cooling Tower Line
CTI Certification Validation Number 92-14-01 – October 14, 2006 (Revision 15)
(256 NC Class + 93 NC Fiberglass cross-flow, induced-draft models)
Selection: http://qtcapps.marleyct.com/update/Login.aspx

SPX Cooling Technologies (Marley) – Quadraflow Cooling Tower Line
CTI Certification Validation Number 92-14-02 – April 11, 2000 (Revision 2)
(38 cross-flow, induced-draft models)
Selection: http://qtcapps.marleyct.com/update/Login.aspx

Supraflux Cooling Technology Co., Ltd. – SF-NG & SF-NGS Cooling Tower Line
CTI Certification Validation Number 07-30-01 – August 18, 2007 (Revision 0)
(18 cross-flow, induced-draft models)
Information: http://www.supraflux.com
Selection: http://www.supraflux.com

The Cooling Tower Company, L. C. – Series TCI Cooling Tower Line
CTI Certification Validation Number 06-29-01 – April 7, 2006 (Revision 0)
(112 counter-flow, induced-draft models)
Information: http://www.ctowers.com/tci.htm

The Trane Company – Series Quiet (TQ) Cooling Tower Line
CTI Certification Validation Number 92-14-01 – October 14, 2006 (Revision 15)
(256 cross-flow, induced-draft models)
Selection: http://qtcapps.marleyct.com/update/Login.aspx
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