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Committee Workshop

July 11-15, 2010
Marriott Albuquerque Pyramid N
Albuquerque, NM

July 17-20, 2011
Amelia Island Plantation
Amelia Island, FL

Annual Conference

February 6-10, 2011
Westin Riverwalk
San Antonio, TX

February 5-9, 2012
Hilton Hotel
Houston, TX

Press Release

Contact: Chairman, CTI Multi-Agency Testing Committee
Houston, Texas 2-November-2009

Cooling Technology Institute, PO Box 73383, Houston, Texas 77273 - 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, 2010, at the CTI address listed.
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EDITORIAL: MODERNIZATION OF CTI

I want to bring you a glimpse of what the Future of CTI holds. The current economic trends seem to be against “Technical Organizations.” The old question of “what’s in it for us” is asked more and more by corporate managers.

The answer to these questions is very simple. The value of a Technical Organization is INFORMATION. We live in the age of quick available information acquisition. Everyday, we seek information on many different subjects via the internet. The Cooling Technology Institute is all about providing information to our membership and general public. We have no other product. It is with this thought in mind that the Board of Directors along with many of our member volunteers and CTI staff are developing plans for improvements in the way CTI provides access to the information that has been accumulated over the last 60 years.

In the future, we plan to improve our website so that our membership can have better access to the wealth of information that exists in CTI Standards, Guidelines Technical Papers and Technical Experts.

We are exploring ways to bring our Annual Conference to a worldwide audience via video conferencing and webinars. We hope that these new features will be of benefit to our membership and cooling tower industry as a whole.

We are assembling the most “Frequently Asked Questions” that are sent to CTI’s “Ask The Expert” website so they can be included available on-line.

Our technical committee’s agendas, meeting minutes and master document lists will be made available on-line; so that, everyone can see what CTI technical committees and tasks groups are working on. We hope to encourage as many technical experts as possible to become new members who can assist in the work of improving existing standards and developing new standards and guidelines.

Technology is changing everyday; your CTI is changing to meet the needs of the membership. We invite you to send all email inquires or suggestions to Virginia Manser, CTI Administrator at vmanser@cti.org. The CTI Administrator will make sure that your emails get to the appropriate person.

I wish to thank the CTI Staff, Board of Directors and CTI Membership for my two years as your President. I hope that I can continue to be of service to CTI in future.

Yours truly,

Denny Shea
CTI President 2008-2009

CTI’s President Elect for 2010 & 2011

Jess Seawell’s career spans over a 29 year period in the cooling tower industry. He has over 32 years engineering and manufacturing experience with composite structures. He was one of the founding partners of Composite Cooling Solutions and held the position of President and CEO from its beginning until his semi-retirement in mid 2008. Seawell remains with the company as a partner and consulting capacity.

He has held positions at the executive level in engineering, operations, and marketing while at the former Ceramic Cooling Tower Corporation. Seawell holds multiple patents in the structural and mechanical design of cooling towers. Seawell is considered an industry technical expert on composite materials and their application to cooling towers as well as the leading industry consultant for FM Approval as applied to cooling tower design. Seawell has presented numerous articles and related technical publications to the cooling tower and power industries.

Jess Seawell is presently Vice President of the Cooling Technologies Institute (CTI) and has held the role of Committee Chairman on “Fire Retardant Construction of Cooling Towers”, Vice Chairman of CTI Committee on “FRP Tower Structural Design”, and is a Voting Member of NFPA-214 and a Past ASME East TN Section Chairman.

Mr. Seawell received a Bachelor of Science degree in Mechanical Engineering from Vanderbilt University and is a licensed Professional Engineer in the State of Texas. Seawell presently resides in Granbury Texas.
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Dear Reader,

As this letter is being written, a great deal of change is in the air. The major changes in the global picture are beyond the scope of this letter (and the grasp of this writer). In our corner of global industry, and in our Cooling Technology Institute organization there are some changes worthy of note.

For the millennium (remember the Y2K hoopla?), Toby Daley, a past CTI President, led the move to change the “T” in the name of CTI from tower to technology. It was a clairvoyant move. In the years since that change, the emergence of air cooled condensers for the power market has been amazing. It is an area in which the technical papers presented at CTI and the new thermal test code for ACC’s contribute an ongoing benefit to the industry.

CTI thermal certification has seen dramatic growth, transforming from a US centric program to a global program with reach across multiple Asian countries, the US and Mexico, and Europe. Cooperation with Eurovent is in process for thermal certification as well, which could introduce a new level in Europe.

Our organization has weathered, so far, the challenging economics of the last year and a half. We anticipate that this will continue. A new CTI President, Jess Seawell, will take office at the Annual Meeting in February. Jess will be the third President to hold office since the structure of the Board and the office of the President were changed to enable a 2 year term for the President. Jim Baker and Denny Shea have contributed two years each to the good of CTI as the first leaders under the new system. Most seem to agree that this has fostered stability and enhanced the ability for the President to engage in leading and sustaining progress within the organization. What do you think?

We have many challenges ahead, but a great deal of energy is evident in the leadership of the organization. We should have confidence that progress will continue as we include new generations of leaders from our industry and look to ensure the long term viability of our Cooling Technology Institute organization.

Respectfully,

Paul Lindahl
CTI Journal Editor
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An Integrated Approach to Water Reuse

Peter Elliott, Gary Geiger
GE Water & Process Technologies
4636 Somerton Road, Trevose, PA 19053

Abstract
Limited water resources combined with wastewater discharge concerns have made water reuse a growing focus of industry. Industrial cooling towers have long been seen as an ideal repository for wastewater because of the large volumes of water necessary for evaporative cooling. However, the use of wastewater as a source of cooling tower makeup water can result in significant corrosion, deposition and biological fouling issues. To address these issues at a major corn processing plant, a creative combination of mechanical and chemical approaches was employed to make a process wastewater suitable for use as cooling tower makeup water. This paper will discuss both the approach to the wastewater pretreatment and the chemical treatment used at the cooling tower.

Introduction
A major corn refining facility implemented a water reuse scheme in response to periodic drought conditions and increasing water requirements due to plant expansions. Over the past eight years the cooling tower makeup water requirements increased from 3.4 to 8.6 million gallons per day. The site utilizes three large, cross flow cooling towers to meet their process cooling needs. The total circulation rate of the towers is 295,000 gpm. All of the cooling towers have splash fill and an open distribution deck. Cooling tower blowdown is sent to a municipal waste treatment facility. The cooling tower makeup water is a combination process wastewater, well water and municipal (potable) water. The majority of the cooling tower makeup water (>80%) is composed of treated process wastewater. Table 1 provides a relative indication of the composition of the various water sources. The composition of the pond water varies with production loads and drought conditions.

Primary treatment of the process wastewater occurs in a 25-acre pond having a volume of 160-180 million gallons. The pond serves as an equilibration facility to allow particulate solids to settle and process organics to be biologically degraded. Process water entering the pond contains 200-300 ppm COD from a variety of organic materials including fructose, alcohols, amino acids and starch. Additionally, the ammonia concentration can range from 2 – 25 ppm and the inorganic phosphate level from 3-40 ppm (primarily orthophosphate). A dissolved air flotation (DAF) system is used to further reduce the organic matter and facilitate additional solids removal. Inorganic phosphate is removed by precipitation with alum (aluminum sulfate). Alum is fed manually such that a prescribed level of soluble phosphate remains for steel corrosion inhibition. The soluble phosphate is adjusted based on the corrosion program and the cycles of concentration at the cooling towers. Water exiting the pond typically contains 30-100 ppm COD and 10 ppm suspended solids.

The most significant challenge the reuse water poses to the cooling water systems is biological. The high levels of COD and the presence of ammonia and phosphate make the cycled cooling water an ideal environment for biological growth. Biological activity has been directly and indirectly responsible for corrosion failures of process heat exchangers. Microbiologically influenced corrosion (MIC) has contributed to stainless steel plate and frame heat exchanger failures and extensive deterioration of mild steel distribution piping. The high organic loading and biological activity at the cooling systems, combined with additional organic and ammonia contamination from process leaks, require the use of significant levels of a chlorine-based oxidizing agent. This has contributed to high chloride concentrations that have resulted in chloride-induced pitting of stainless steel.

The process coolers of all three cooling water systems are primarily plate and frame exchangers with 316L stainless steel plates. The exit water temperature of critical equipment can reach 160°F. Very little carbon steel or copper alloys are present in the systems.

The composition of the makeup water varies with production loads and fresh water availability.

Evolution of the Water Reuse Scheme

Phase 1 - Initial Approach

Makeup Water Treatment

Cooling tower makeup water was primarily composed of pond water and of city water. The makeup water was treated with up to 400 pounds per day of ozone and a bleach/sodium bromide combination that provided 8-9 ppm mixed oxidant (HOCl/HOBr), as ppm Cl₂. The ozone/halogen combination was used to reduce the COD loading at the cooling towers and achieve some level of biological control. Ozone was chosen because it is a strong oxidizing agent capable of rapidly destroying organic compounds. However, the ozone was only capable of oxidizing a small percentage of the 900+ pounds per day of COD entering the cooling system with the makeup water. Bromine chemistry was included because of the presence of ammonia in the pond water. Unlike chlorine, bromine retains it biological control capabilities in the presence of ammonia. The ozone, bleach, sodium bromide program was able to achieve 0.2 – 0.5 ppm total oxidant, as Cl₂, in the cooling tower makeup water.
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Cooling Tower Treatment Program

Two biological approaches were employed at the cooling towers. The smallest of the cooling towers (60,000 gpm recirculation rate) used a combination of ozone, up to 200 pounds per day, and a bleach/sodium bromide combination. The mole ratio of the combination was such that 25% of the total halogen was HOBr. The control range for the total oxidant was 0.5 – 1.0 ppm, as Cl₂. The microbiological treatment program for the remaining two cooling tower systems consisted exclusively of chlorine dioxide (ClO₂). Originally, chlorine dioxide was generated using chlorine gas and a 25% solution of sodium chloride as precursors. This later evolved into using the three-precursor combination of liquid bleach (10-12% NaOCl), and sulfuric acid (98%) and 25% sodium chloride solution. In either case, the plant required chlorine dioxide generation systems capable of supplying 900,000 lbs per year (~103 lbs per hour) to the cooling water systems. Excess chlorine (bleach or gas) was fed to ensure a high ClO₂ yield. The total halogen control range was >0.5 ppm, as Cl₂. During upset conditions (COD values exceeding 250 ppm) supplemental chlorine bleach and non-oxidizing biocide were added. The pH of the cooling systems was controlled in the 6.8 – 7.4 range to maximize the oxidizing power of the free chlorine. Additionally, neutral pH operation, in combination with a calcium phosphate polymer dispersant, allowed high levels of inorganic phosphate and zinc to be utilized for steel corrosion control.

The use of bleach or chlorine gas in the generation of bromine and chlorine dioxide introduces considerable levels of chloride; especially when used to respond to process leaks. Bleach is an equal molar combination of chloride ion (present as NaCl) and hypochlorite (present as NaOCl). Chlorine gas dissociates to an equal molar combination of hydrochloric acid (HCl) and hypochlorous acid (HOCI).

The chloride concentration of the cooling water is critical when stainless steel alloys are present. Rapid failure of process equipment can occur from chloride-induced pitting. The chloride ion is capable of penetrating and destroying the naturally occurring protective passive oxide film on stainless steel surfaces. Once a void in the film occurs, corrosion will proceed, unless the film reestablishes itself. The most significant factors affecting the pitting potential are the chloride concentration and surface temperature. As with any noble metal, the surface must be kept free of deposits to prevent the formation of oxygen differential cells. Deposits restrict the access of oxygen to the metal surface, which is necessary to preserve the naturally occurring passive oxide. As corrosion begins, the oxygen-rich area adjacent to the deposit serves as the cathode generating hydroxide ions resulting from the reaction of oxygen and electrons. As corrosion proceeds, metal ions are generated under the deposit (at the anode), creating a net positive electrical charge. The coulombic attractions cause chloride ions to preferentially migrate through the deposit to neutralize the charge. As the chloride ions accumulate under the deposit, acidic metal chlorides are formed that further accelerate corrosion.

Performance/Results

The microbiological control program at all three cooling towers was not sufficient to prevent biofouling of heat transfer surfaces or MIC of carbon steel distribution piping. High levels of supplemental chlorine were applied during process leaks, but were not sufficient to prevent biological growth. Slime deposits retarded the heat transfer efficiency of process equipment, making frequent cleanings necessary. Algae mats formed on the cooling tower decks, which served as a constant source of anaerobic bacteria. The failure of the programs was attributed to the high organic matter (COD) of the cycled makeup water and the additional organic contaminants encountered during process leaks. The organic matter provided the food source for microbial growth and consumed halogen, particularly chlorine.

Numerous corrosion failures of the 316L stainless steel plate and frame exchangers occurred due to chloride-induced pitting, under-deposit corrosion and manganese induced corrosion. Chloride levels in excess of 700 ppm could be encountered during upset conditions. The high chloride levels were a result of the halogen programs and the supplemental chlorine (bleach) added during process leaks. Cycles of concentration were maintained at 3 to minimize the chloride contribution from the makeup water. Under-deposit corrosion was primarily due to biological fouling and accumulations of particulate matter. Manganese induced corrosion was attributed to low levels of soluble manganese (Mn²⁺) in the makeup water that was not oxidized by ozone or halogen. The source of the manganese was the well water that is added to the makeup water stream. Stainless steel catalyzes the air oxidation of Mn²⁺ to insoluble MnO₂ at the metal surface. In the presence of chlorine, MnO₂ can oxidize to form permanganate that will pit stainless steel.

Phase 2 - Improvement in Makeup Water Pretreatment

Makeup Water Treatment

The use of hollow fiber ultrafiltration (UF) was employed to reduce the COD of the makeup water and hence the oxidant demand at the cooling towers. Reducing the COD would diminish the demand for chlorine and chlorine dioxide. This in turn would improve microbiological control at the cooling tower and reduce the chloride level in the cooling water.

With the development of submerged hollow fiber membranes, the next generation of advanced purification technologies in water and wastewater treatment became a reality. Instead of clarification ponds to settle solids from the purified water stream and relying on gravity for solids/liquid separation—a technology that was developed more than 100 years ago to ensure safe drinking water treatment and proper sanitation—today’s membranes ensure that all contaminants of a specific diameter (0.04 mm) or larger, are removed from the purified effluent.

Membranes are based on filtration methods found throughout nature. The membranes employed at this facility consist of hollow polymer fibers with billions of microscopic pores on the surface. The pores are much smaller in size than common contaminants, like bacteria and viruses. This physical barrier only allows visibly clean water to pass through while rejecting multiple impurities—guaranteeing an exceptional water quality and clarity on a continuous basis. In this application, a slight vacuum is applied, drawing water into the membrane fiber and consequently filtering out the vast majority of impurities. The working principle is demonstrated in Figures 1 and 2.

The advanced hollow fiber UF membrane in use at this facility was extremely effective at removing all of the visible impurities con-
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tained in the process-generated wastewater. COD levels were reduced from greater than 50 ppm in the pond water to 10 ppm. The improvement in water clarity is clearly evident in Figure 3.

The UF filtration system is downstream of the alum injection point. Permeate is collected in a makeup storage tank along with raw pond water, well water and city water. The inclusion of raw pond water was necessary because the UF system was not large enough to meet the cooling makeup water demands. The use of raw pond water as partial cooling tower makeup causes the blended water to have COD levels greater than 10 ppm. The water blend was subsequently treated with ozone and bleach/sodium bromide as detailed in Phase 1 before going to the cooling towers.

**Cooling Tower Treatment**

The corrosion and biological control programs did not change after inclusion of the UF permeate. The small cooling tower continued to use ozone and bleach/NaBr and the other two towers continued with chlorine dioxide. Supplemental bleach and non-oxidizing biocide were added during upset conditions when process leaks caused the COD to exceed 250 ppm. The pH of the cooling water was controlled at 6.8 – 7.4, and zinc/phosphate was applied for carbon steel corrosion protection. For the most part, cycles were maintained at 3, unless the chloride concentration exceeded 400 ppm. A chloride maximum of 400 ppm was chosen in an attempt to minimize pitting of stainless steel.

**Performance/Results**

Reducing the COD at the cooling towers greatly improved biological control. Biological fouling diminished along with MIC. High levels of halogen were still required when process leaks occurred. This increased the chloride levels above the 400 ppm limit and required a reduction in cycles of concentration. During periods of high process contamination the 400 ppm chloride limit was exceeded. Chloride concentrations of 650-800 ppm were recorded in each cooling tower at various isolated times.

Although biological control improved and fouling greatly diminished, chloride-induced pitting of stainless steel was not reduced. The failure rate of the stainless steel plate and frame exchangers remained virtually unchanged.

**Phase 3 - Chloride Reduction**

**Makeup Water Treatment**

The cooling tower supply water disinfection program was changed from bleach/sodium bromide to chlorine dioxide in an effort to reduce the chloride level at the cooling towers. Ozonation was discontinued because of cost/maintenance issues. The main source of organic contamination at the cooling towers was from process leaks. Chlorine dioxide was chosen because of its relative inactivity with organic components, and because its disinfection properties are not compromised by the presence of ammonia.

Chlorine dioxide was generated electrochemically with a highly concentrated sodium chlorite solution. The electrochemical method eliminated the need to adjust multiple chlorine dioxide precursors to ensure maximum yield. The chemical reaction proceeds according to:

\[ 2\text{NaClO}_2 + 2\text{H}_2\text{O} \rightarrow \text{Cl}_2 + \text{NaCl} + 2\text{H}_2\text{O} \]  

The key to this strategy is the dosing point in the system. The high capacity electrochemical chlorine dioxide generator was able to produce up to 100 lbs. of chlorine dioxide per day. The chlorine dioxide was injected directly into the pond water makeup/reuse header supplying the process cooling towers. This was reasoned as a way to effectively disinfect the makeup water stream that was inoculating the cooling water. Ultimately, this would reduce the halogen requirements and the chloride levels at the cooling towers. The feed point was later relocated to the makeup water tank, which is the repository for the hollow-fiber UF permeate, direct pond water bypass, well, and city water. This dosing point change provided for a greater contact time with the composite makeup water prior to entry into the cooling water system. Typical ClO₂ residual range in the makeup water was 0.2-1.0 ppm. The entire wastewater pretreatment and cooling water systems appear as Figures 4(a) and 4(b), respectively.

**Cooling Tower Treatment**

For years, the standard method of chlorine dioxide generation required the use of precursor combinations of either chlorine gas reacted with sodium chlorite, or using liquid bleach, and reacting it with a strong acid (hydrochloric or sulfuric) and then taking that intermediate product and reacting it with sodium chlorite in the confines of the chlorine dioxide generator. (See equations 1-3 below.)

\[ \text{Cl}_2 (\text{gas}) + 2\text{NaClO}_2 \rightarrow 2\text{ClO}_2 (\text{gas}) + 2\text{NaCl} \]  
\[ -\text{Or-} \]

\[ \text{NaOCl} + 2\text{HCl} \rightarrow \text{Cl}_2 + \text{NaCl} + \text{H}_2\text{O} \]  

(2)

\[ 2\text{NaClO}_2 + \text{Cl}_2 \rightarrow 2\text{ClO}_2 + 2\text{NaCl} \]  

(3)

(4)

In an effort to eliminate as many hazardous precursors as possible and reduce the chloride contribution from the chlorine source, a significantly different means of chlorine dioxide generation was implemented. This method employs the use of a unique set of precursor chemicals that essentially eliminates one of the needs for chlorine (gas/bleach).

One set of generators is the main source of chlorine dioxide feed to the process cooling towers. This generation system employs a sodium chlorate/hydrogen peroxide solution in combination with sulfuric acid. This unique chlorine dioxide generation chemistry is shown by the following reaction:

\[ [\text{NaClO}_3 + \text{H}_2\text{O}_2] + \text{H}_2\text{SO}_4 \rightarrow \text{ClO}_2 + \text{O}_2 + \text{Na}_2\text{SO}_4 + \text{H}_2\text{O} \]  

(5)

Figure 5 is a schematic of this system that currently acts as the principal source of chlorine dioxide to each of the process cooling towers.

In attempting to maintain the new, higher level of performance with respect to cooling system surface cleanliness, the new generation method was set to produce higher levels of chlorine dioxide. The chlorine dioxide generator serving two of the cooling towers was set to produce 30-110 lbs/hour. The unit dedicated to the third cooling tower had its output increased to 40-130 lbs/hour. The new generators increased the average chlorine dioxide capability from 103 lbs./hour to 155 lbs./hour. The target residual range for ClO₂ in the cooling towers was set at 0.5-1.0 ppm. The use of ozone and bleach/sodium bromide at the small cooling tower was discontinued. Supplemental sodium hypochlorite is fed on a relatively infrequent basis, during process upsets as previously discussed.
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Performance/Results

The change in the disinfection method and the new chemistry employed for generating chlorine dioxide reduced the chloride levels at the cooling towers (Figure 6), without sacrificing microbiological control. The lower chloride concentration allowed the cooling water cycles of concentration to be increased from 3 to 4 without negatively impacting the integrity of the stainless steel process equipment. Figure 7 summarizes the two years of operation with the new treatment protocol. The frequency of corrosion failures has declined since the new treatment protocol was implemented. However, the success of the program cannot be conclusively assessed until the life (failure rate) of newly installed equipment is determined. Many of the failures currently encountered may be a result of the condition that existed in the past.

Total water savings associated with increasing cycles of concentration by one (from 3 to 4) amounted to almost 358 million gallons per year (980,000 gallons/day), significantly reducing the municipal water treatment charges. See Figure 8 for the relationship between cycles of concentration and blowdown rate.

Corrosion and Scale Control

In addition to the microbiological treatment involving chlorine dioxide, the areas of corrosion and deposition must also be addressed to ensure full asset protection and operational efficiency is maintained. In order to fully complement the mechanical pretreatment of the reuse water employed as cooling tower makeup, a strong chemical water treatment strategy would be required to meet the high stress condition posed by the reuse water. To preclude serious scaling conditions associated with calcium carbonate and calcium phosphate, the cooling water was maintained at a relatively neutral pH of 6.8-7.5. High pH conditions coupled with the elevated skin temperatures present in the system’s process heat exchangers, would pose a serious scaling threat, in light of the retrograde solubility associated with calcium carbonate and calcium phosphate. As is the case many times in industrial water treatment, when the risks in one direction are minimized, different risks can, and normally do surface in the other direction. High temperature, neutral pH water, high conductivity and chlorides, increase the potential for corrosion, both general and localized (pitting/crevice corrosion). Therefore, it was imperative to design a chemical treatment program to address this potentially high corrosion potential using a combination of effective agents.

In consideration of this stressful water environment, the following operating parameter ranges were set for the process cooling systems:

- Calcium hardness: 400-800 ppm, as CaCO₃
- pH: 6.8 – 7.5
- Chloride: 400 ppm, as Cl⁻ (maximum)
- Conductivity: 4,000 – 5,500 mmhos/cm
- Ortho-PO₄: 15 - 40 ppm, as PO₄
- LSI: 0.15 – 1.0

Orthophosphate was used for carbon steel corrosion protection and dosed at such a rate to induce the formation of a passive oxide film. There already was a ready supply of phosphate present in the makeup/reuse water generated as process wastewater. The challenge in this case was to dose the proper amount of alum prior to the UF hollow-fiber membrane inlet in order to precipitate a portion, but have some remain soluble. The soluble phosphate would then cycle at the cooling towers, providing a sufficient concentration for carbon steel corrosion protection. The filtered orthophosphate levels charted over the past 2.5 years appear as Figure 9. Additionally, a complete phosphate profile is routinely performed across the entire system (Reuse Water Collection Tank, to the Process Wastewater Settling Pond, to the inlet and outlet of the UF hollow fiber membrane, and finally the discharge of the cooling tower makeup tank). This practice helps to accurately monitor phosphate levels throughout the entire system, in order to properly control alum feed, which is ultimately regulating orthophosphate levels in the cooling towers. Wide variation in soluble phosphate in the treated reuse water was experienced because alum feed was not automated. To complete the mild steel corrosion package, and provide the additional protection of cathodic corrosion inhibition for mild steel, zinc was fed at a low concentration 1-2 ppm. Just recently, zinc has been removed from the chemical treatment program due to discharge limitations imposed by the municipal water treatment plant. With a relatively high concentration of phosphate and additional zinc (when used), maintaining inhibitor solubility becomes crucial to maintaining both corrosion and deposition control. A halogen stable, sulfonated copolymer was applied for scale control. The polymer dosage was adjusted based on the calcium phosphate saturation of the cooling water. Therefore, the key component of this particular treatment regimen becomes the polymeric dispersant. The copolymer effectively prevented scaling of hot process equipment even when the inorganic phosphate concentration reached 40 ppm. The results of the corrosion treatment program are evidenced by the mild steel corrosion rates from each cooling tower. These results are highly respectable considering the elevated conductivity levels encountered with the increase in cycles of concentration achieved. This corrosion data is charted and shown as Figure 10. Corrosion rates of 316L stainless steel were essentially zero and did not give any indication of the pitting corrosion experienced with the process equipment.

Conclusions

1. Proper pretreatment of process water is essential to the successful use as cooling tower makeup water.
2. Hollow fiber ultrafiltration is capable of removing particulate matter, microbiological organisms, and most organics components that contribute to COD, but not inorganic ions such as orthophosphate and manganese.
3. Chloride ions are extremely detrimental to the integrity of heat exchanger components, principally 316L stainless steel plates. When critical levels are exceeded, severe pitting and crevice corrosion of these plates will occur.
4. Chlorine dioxide, produced with the sodium chlorate/hydrogen peroxide combination will limit chloride inventory, compared to conventional methods using chlorine gas or bleach with acid.
5. Chlorine dioxide is a very effective biocide in waters contaminated with process organics and/or ammonia, as it is a selective oxidant and will not react with these types of contaminants.
6. Effective deposition control requires a polymeric dispersant capable of preventing calcium phosphate formation over a wide range of supersaturations.

References

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Table 1. Cooling Tower Makeup Water Composition Profile

<table>
<thead>
<tr>
<th></th>
<th>Well</th>
<th>City</th>
<th>Pond Influent</th>
<th>Pond Effluent</th>
<th>UF Permeate</th>
<th>Composite Cooling Tower Makeup</th>
</tr>
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<td>7.9</td>
<td>7.7</td>
<td>8.2</td>
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<td>Specific Conductance, at 25°C, μmhos/cm</td>
<td>940</td>
<td>315</td>
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<td>18.6</td>
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<td>4.0</td>
<td>4.9</td>
<td>4.7</td>
<td>4.9</td>
</tr>
</tbody>
</table>

Membrane Fiber: Electron microscope view of membrane surface

Figure 1: Hollow Fiber Membrane Method of Operation with electron microscope view of membrane surface

Figure 2: Cutaway View of a Single Hollow Fiber
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Figure 3: Hollow Fiber Membrane System
Influent and Effluent

Waste Water Effluent Processing to Reuse Water for Cooling Tower Makeup

Figure 4(a): Process Wastewater Pretreatment System
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Figure 4(b): Open Evaporative Cooling System
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Figure 5: Sodium Chlorate/Hydrogen Peroxide Chlorine Dioxide Generator in Basic Schematic Form (Courtesy of PureLine Treatment Systems)

Figure 6: Conductivity and Chloride Levels for the Three Cooling Towers
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Figure 7: Conductivity and Chlorides – A Closer Look at Cooling Tower C

Figure 8: Relative Water Savings Achieved by Increasing Cooling Tower Cycles of Concentration from 3.0 to 4.0

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Wednesday 12:00 p.m. - 7:00 p.m.
Thursday  9:30 a.m. - 12:00 p.m.
Figure 9: Cooling Tower Filtered Orthophosphate Residuals
Figure 10: Cooling Tower General Corrosion Rates (Carbon Steel)
Cooling Tower Components

- Wood Replacement Shapes
- Deck Board
- Wall Panels
- Angles
- Beams
- Channels
- Square Tube
- Ladders and Handrail
- Molded and Pultruded Grating
- Stairs and Walkways
- Platform Fabrication
- Custom Layed-Up Parts

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ABSTRACT
By itself, the presence of legionellae in a cooling tower is insufficient to predict the potential for disease transmission because other factors are involved. This paper will describe details about one of the important factors, cooling tower air emissions, by providing a comprehensive technical understanding of drift quantity, droplet distribution, and plume dispersion. By understanding these air emission details, ranges of Legionella bacteria concentration at distances from the tower can be estimated as a function of legionellae concentration in the tower water.

This paper will also describe the ecology of the bacteria in cooling towers and the epidemiology of outbreaks attributed to cooling towers. Most importantly, the paper will discuss the correlation of the bacteria-exposure model described in this paper with the incidents of disease from previously studied outbreaks.

The quantity of bacteria required to cause disease depends on several factors including the health of the individual and the exposure. A hypothetical example would be a situation where an individual could inhale 1 bacterium a week for fifty weeks with no ill effects, but develops disease when he inhales 50 bacteria in an hour. There is likely some exposure rate (inhalation of X bacteria / time) where the risk of disease may occur; the higher the exposure rate, the more likely the occurrence of disease. The inhalation rate (inhalation is the only means of transmission from cooling towers) depends strongly on two factors: 1) the concentration of bacteria in the ambient air in a particular area and 2) the time spent in that area.

INTRODUCTION
Legionellosis is a form of pneumonia caused from Legionella bacteria being inhaled or aspirated deeply into the lungs. Legionella is quite common in the environment and there are many steps from ‘present in the environment’ to ‘disease’.

The accepted prerequisite for infection is the bacteria must be contained in droplets of water less than 5 microns in diameter. Larger droplets would not penetrate deeply enough into the lungs to cause infection. While there is no known infectious dose or alternatively safe level for the bacteria, because of its ubiquity in nature, most researchers believe that an infection requires the inhalation of tens if not hundreds of bacteria.

As might be expected with the widespread distribution of Legionella bacteria, there is a ‘normal’, low incidence of random cases of Legionellosis. With the low background rate, a cluster of disease would be statistically rare. When a cluster has occurred, there is often a specific source identified as the cause of the outbreak.

Outbreaks of community-acquired Legionella have been attributed to specific spas, fountains, cooling towers, metal working fluids, misters and other sources. With all of these sources except cooling towers, a very close proximity to the source was required for exposure. With cooling towers, exposures have been reported several kilometers away from the purported source.

The exposure to disease connection is not fully understood. There are likely at least two competing processes occurring in the host: bacteria germination and host immune system response. In a healthy, non-smoking individual, an exposure of thousands of bacteria is likely necessary before the immune system is overwhelmed; in others the exposure of a few bacteria may be sufficient.

It is not the norm for a cooling tower to cause an outbreak of Legionnaires’ disease. There are hundreds of thousands of cooling towers in the US, many if not most containing some level of Legionella bacteria, yet there are only a handful of cooling-tower implicated outbreaks. A person’s exposure to Legionella bacteria from a cooling tower is based on a variety of factors:

1) The drift rate of the tower. Drift is the mechanically aspirated droplets of circulating water that are entrained into the effluent air stream.
2) The volume of air passing through the tower.
3) The dispersal of the exhaust air with ambient air (plume dilution).
4) The time spent in plume/air mix
5) The concentration of Legionella bacteria in the circulating water.

This paper will explore these factors and the effect they have on risk of exposure.

COOLING TOWER DRIFT
Most tests on a specific tower design show a linear relationship between circulating water flow and drift within normal cooling tower operating air flow. Air flow rate will significantly affect tower drift only at the extremes of the design. Because of this, drift is typically described as a percentage of circulating water rate.

All modern cooling towers are or should be equipped with drift eliminators (DE). The DE force the exhaust air to make sharp turns before exiting. The momentum of entrained droplets carries the droplets to the DE surfaces where they coalesce and drip back into the tower. Cooling towers or drift eliminators may be evaluated for
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drift rates under controlled conditions. The standard test is the “Heated Bead Isokinetic (HBIK) Drift Test Procedure” described in the Cooling Technology Institute code ATC 140. A portion of the exit air stream is drawn at the same speed and direction (isokinetically) into a collection device. The collection device consists of heated beads. Any drift that is pulled into the tower is dried on the beads. The tower water has a specific concentration of a tracer element and by measuring the quantity recovered from the beads, the quantity of drift can be determined.

Less modern designs for drift eliminators are not as efficient as newer equipment. While an older design might result in drift rates up to 0.02%, all towers constructed in the last few years by the major manufacturers are much better. Typically, for cross-flow designs the drift rate will be less than 0.005% while because of use of higher efficiency eliminators, counterflow designs routinely achieve 0.001%.

The newer cellular drift eliminators started being used in the late 1980’s with particular model lines changing over about a 15-year period. Around the early 1990’s the 0.005% drift rate for crossflow towers became standard. The 0.001% drift rate for induced-draft counterflow became standard also around 1990. For forced-draft counterflow units, 0.001% didn’t become standard until just a few years ago. Prior to the change, cooling tower drifts were typically in the 0.02% or higher range.

A typical 1,000-ton HVAC cooling tower nominally circulates 3,000 gpm water. At nominal conditions, the drift from a 1,000-ton crossflow tower would be less than 0.15 gpm while the drift from a 1,000-ton counterflow tower would be less than 0.03 gpm. These values should be routinely achieved by units as they are shipped from the factory. With a well maintained tower, these rates can be sustained for many years. However, there are things that happen in the field which can degrade the eliminators effectiveness. A partial list of these problems follows:

1) Damaged drift eliminators. UV, hail, and improper handling can all damage drift eliminators. Damaged drift eliminators interfere with exhaust air flow. If there are gaps or holes in the eliminator, then more air will pass through the open area at high velocity carrying significantly more entrained water.

2) Clogged drift eliminators. In highly cycled water the entrained droplets contain a high quantity of dissolved solids. This can result in a gradual build up of minerals on the DE. As the minerals build up, the air is blocked in some areas and the air velocity increases in the open areas. As this velocity gets high enough, the amount of entrained water carried from the tower increases.

3) Misaligned or missing drift eliminators. If there are gaps in the eliminators, their effectiveness is severely reduced.

4) Damaged fill. While not as obvious as damaged drift eliminators, damaged or partially clogged fill will change the airflow to the DE and affect their efficiency.

5) Obstructed inlet air. For the same reason as in #4, changing the airflow in the tower affects DE efficiency.

6) Water distribution. Improper water distribution may put too much water in one area resulting in very high drift from that part of the tower. Misaligned or over-pressured spray nozzles can also increase the amount of drift.

7) Use of surfactants in the chemical water treatment. By lowering the surface tension of the recirculating water, surfactants can cause water to form very small droplets. These small droplets are more easily carried by the air stream and are less effectively removed by the drift eliminators.

The drift that leaves the tower is in the form of small droplets. The larger the droplet the more momentum it carries and the more effective the DE. The distribution of water drop sizes in the drift can be measured by water sensitive paper. The paper is treated so that a droplet impinging on the paper will generate a well defined mark. The size of the stain is related to drop size. This is a less exact method than the HBIK test but provides some information about droplet size distribution. This test is not effective for droplets less than 30 microns in size.

Many studies have been performed on the size of drift particles from a tower. Figure 1 shows the results from nine separate tests on drift eliminators performed by the manufacturer. The cumulative volume of drops is plotted as a function of the diameter of the drop in microns. Below each label on the X-axis is the number of droplets of that specific diameter per milliliter of water. The drops per ml information is useful to see that, absent clumping, it would be very unusual for a single droplet to contain more than 1 Legionella bacterium even in a heavily contaminated system with a Legionella count per ml of 1,000. Because of this, parametric statistical analysis is valid for considering Legionella dispersion in the plume.
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In 1988 there was a Legionella outbreak at a Los Angeles retirement home. The investigation of that outbreak identified a below-ground forced-draft evaporative condenser as the source of the outbreak. While the specifics of the condenser were not included in the paper, Table 1 contains calculations using a typical evaporative condenser with 1988-style drift eliminators. The investigation measured Legionella in the tower basin of 9,000 CFU/ml. The investigation also used impinger sampling data to estimate that there were 2.3 CFU/liter of air of Legionella in the condenser exhaust vent. That 2.3 CFU/liter agrees very closely to the 2.8 CFU/liter that was calculated using the approach of Table 1.

**PLUME DILUTION**

Only a very small percentage (on the order of 1%) of the drift as it leaves the cooling tower is of respirable size, and hence able to cause an infection. The remainder of drift and contained Legionella consists of droplets greater than 5 microns. Thus a person breathing undiluted exhaust air from a well-maintained cooling tower with what might be considered a moderate concentration (100 CFU/ml) of Legionella would need to be in the exhaust much longer (possibly 99 times longer) than the times indicated in Table 1 before he statistically would inhale a single Legionella bacterium deeply into his lungs. The droplets can evaporate to respirable size once they travel a distance from the tower.

When exhaust air leaves a cooling tower it forms a plume. The characteristics of this plume depend on a complex interaction of, amongst others, the following:

1. wind speed and direction
2. buildings and structures downwash
3. buoyant/dense plume behavior
4. gravitational settling
5. droplet evaporation and humidity condensation (phase changes)
6. surrounding terrain
7. ambient temperature and humidity

Because of the complexity of the flows around the cooling equipment we will not focus on the ‘near-field’ plume. In addition, the water droplets in this area are likely too large to inhale deeply into the lungs. We are defining this near-field to extend 20 fan diameters from the base of a tower. This is the approximate distance that the plume from a ground-level tower would reach the ground under the simplified plume dispersion model shown below.

There are several computational fluid dynamic programs that attempt to model plume behavior with varying success. Beyond some generalizations, the detailed prediction of cooling tower plume is beyond the scope of this paper.

With the previous caveat, there are some generalities that can be stated. For the basic condition we will assume that people are all located at ground level. The worst case scenario would then be a tower installed on or near the ground.

One of three things can happen as the ambient air mixes with the cooling tower exhaust air:

1. If the air is very still, the exhaust may climb very high and be dispersed over a very large area before it reaches ground level.
2. If the ambient air is very turbulent, winds greater than 20 mph, the plume will be rapidly diluted and dispersed.
3. The third condition is a steady mild breeze of 5 to 10 mph. This condition is sufficient to bend the plume over and bring it to ground level, yet the plume will maintain some cohesiveness. This is the condition that will most likely bring a person in contact with contaminants from the cooling tower and is the condition that we will discuss in the remainder of this section.

**CONCENTRATION OF LEGIONELLA IN COOLING TOWER EXHAUST**

Cooling towers cool water by evaporation, thereby exchanging both heat and humidity to the air. The amount of air passing through a tower per gallon of water depends on both the design of the tower and often on the heat load on the tower for towers equipped with multispeed fans.

The design mass flow rate of circulating water to cooling air is usually given as an l/g ratio with the both the liquid and gas amounts given in pounds. A quick review of manufacturer catalogs shows that induced-draft counterflow towers are designed with l/g ratio between 1.43 and 2.23. Induced-draft crossflow towers are designed with a lower l/g ratio of between 1.34 and 1.50. Both designs produce an equivalent amount of cooled water per fan HP, the counterflow run lower air volumes at slightly higher pressure than crossflow towers. Forced-draft counterflow towers typically run at range of l/g ratios between 1.10 and 1.65. Using a nominal specific volume of air of 14 cubic feet per pound, Table 1 shows the min and max concentration of drift in the exhaust air at the referenced drift rates. This value is then extrapolated to a nominal time that an individual would need to breathe undiluted cooling tower exhaust to, on average, inhale a single Legionella bacterium. The values in Table 1 are based on full fan power. It is assumed that the drift rate as a percentage of the circulating water rate does not fall appreciably until the fan rate drops below 50%. Thus for low fan speeds, the concentration of drift, and hence Legionella bacteria, could be up to twice as high as is shown in the table.

In 1988 there was a Legionella outbreak at a Los Angeles retirement home. The investigation of that outbreak identified a below-ground forced-draft evaporative condenser as the source of the outbreak. While the specifics of the condenser were not included in the paper, Table 1 contains calculations using a typical evaporative condenser with 1988-style drift eliminators. The investigation...
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that charge characteristic dimension squared ($F^2$). As the plume spreads, dilution independent of cooling tower size. multiples of this distance as a simplified way to describe plume tower. We are calling this of the plume will be $(5 \times F^2)$, 25 times the area as the plume left the tower.

The characteristic distance, $D_o$, that the plume travels before it touches the ground is a function of the discharge dimension. Larger units exhaust higher off the ground and the near-field of the plume extends for a greater distance. Table 2 lists this distance for some common sized units used in factory-assembled towers as well as some multiples of this distance.

### Table 2 – Characteristic Distance ($D_o$) as a Function of Common HVAC Fan Diameters

<table>
<thead>
<tr>
<th>Fan Dia.</th>
<th>$D_o/25/1$ dilution</th>
<th>$2x \ D_o/63/1$ dilution</th>
<th>$3x \ D_o/117/1$ dilution</th>
<th>$4x \ D_o/187/1$ dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-foot fan</td>
<td>0.02 miles</td>
<td>0.05 miles</td>
<td>0.07 miles</td>
<td>0.09 miles</td>
</tr>
<tr>
<td>8-foot fan</td>
<td>0.03 miles</td>
<td>0.06 miles</td>
<td>0.09 miles</td>
<td>0.12 miles</td>
</tr>
<tr>
<td>10-foot fan</td>
<td>0.04 miles</td>
<td>0.08 miles</td>
<td>0.11 miles</td>
<td>0.15 miles</td>
</tr>
<tr>
<td>12-foot fan</td>
<td>0.05 miles</td>
<td>0.09 miles</td>
<td>0.14 miles</td>
<td>0.18 miles</td>
</tr>
</tbody>
</table>

### Figure 3 – Near-Field Plume Dispersion Model. ‘$F$’ = Characteristic Discharge Dimension

Figure 3 details the near-field plume dispersion of the simplified model. With this model, the plume touches the ground at a distance $D_o = 2F^2 \tan (6°) = 20F$. At this point the cross-sectional area of the plume will be $(5F^2)^2$, 25 times the area as the plume left the tower. We are calling this $D_o$ the characteristic distance and using multiples of this distance as a simplified way to describe plume dilution independent of cooling tower size.
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in this paper. Data was input for ground level pollutant dilution from two cooling towers, one with a 12-foot diameter fan and operating at ½ fan speed; the other with an 8-foot diameter fan operating at full speed. The program automatically chooses the wind and atmospheric conditions that produce the highest concentration at a given distance. From these worst-case concentration values, the plume dilution was calculated. The values of the SCREEN3 worst-case dilutions are plotted against the simplified model dilutions in Figure 5. There is very good agreement between the two models. Both these models assume no other structures in the immediate area. The close agreement of the simplified model with the EPA model helps to validate the reasonableness of this simplified approach.

The simplified model allows a quick consideration, independent of tower size, of the plume dilution at a distance from the tower. The model fails at very short distances (less than 20 fan diameters the simplified model assumes zero ground-level concentration) and at very long distances. For the intermediate distance in an open area it has some use.

5. Fans operating at ½ speed (worst-case doubling the drift concentration from full fan speed).
6. All of the *Legionella* bacteria that leave the tower become respirable (worst-case).

Table 3 indicates that in a modern tower that was acceptably maintained there is little chance of inhaling multiple *Legionella* bacteria unless one spent extensive time close to the tower under a worst-case scenario wind condition or if the cooling tower were sited very near a building fresh air intake.

<table>
<thead>
<tr>
<th>Tower type</th>
<th>l/g Fan at full speed</th>
<th>Fan at ½ speed</th>
<th>At 2 x Dg</th>
<th>At 3 x Dg</th>
<th>At 4 x Dg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counterflow max. l/g</td>
<td>2.23</td>
<td>52.2 min</td>
<td>26.1 min</td>
<td>10.9 hrs</td>
<td>27.4 hrs</td>
</tr>
<tr>
<td>Crossflow max. l/g</td>
<td>1.50</td>
<td>15.8 min</td>
<td>7.8 min</td>
<td>3.2 hrs</td>
<td>9.1 hrs</td>
</tr>
</tbody>
</table>

Table 3 – Average Time to Inhale 1 *Legionella* Bacterium

**LEGIONELLA IN COOLING TOWER WATER**

THE ECOLOGY OF *LEGIONELLA* – *Legionella* have a unique ecology compared with other bacteria that live in water. It is now well understood that *Legionella* in the environment grow as intracellular parasites of free-living amoebae and other protozoa. Rowbotham first demonstrated the ability of *Legionella* to replicate within freshwater and soil amoebae as early as 1980, and since then this phenomenon has been confirmed by many investigators using *Acanthamoeba*, *Naegleria*, and *Hartmanella* amoebae, and the ciliated protozoan *Tetrahymena*. Most authorities agree that this intracellular replication not only plays a vital role in the amplification of *Legionella* in the environment, but is also the unique pathogenic ability that enables *Legionella* to infect humans via the intracellular replication with monocytes and macrophages.

In an environmental habitat such as a cooling tower, most of the amoebae reside as part of the biofilm on the solid surfaces, rather than free in the water. This complex ecosystem contains a wide variety of slime-producing bacteria that colonize the surfaces, along with higher organisms such as amoebae and other protozoa that graze on the bacteria as a food source. *Legionella* interact with the amoebae in the biofilm, blocking the killing and digestion process of the amoebae, and replicating to large numbers within the food vacuole or vesicle inside of the amoebae. Eventually the amoeba is killed and the *Legionella* are released to find new hosts. Some of the bacteria (including *Legionella*) and amoebae in the biofilm migrate from the surface into the free-flowing water and are distributed to other biofilm locations. It is these water-borne (referred to as planktonic) *Legionella*, along with other bacteria and amoebae, that are released into the air from the cooling tower in the drift.

Rowbotham has described the replication cycle of *Legionella* within the amoebae and first noticed the release of small vesicles.
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full of \textit{Legionella} at certain stages. He hypothesized that, while intact amoeba (10-40 im diameter) are generally too large to be inhaled into the lungs, the inhalation of small (<5 im) vesicles packed with \textit{Legionella} could provide an infectious dose in a single inhaleable particle\textsuperscript{16}. More recently, Berk and colleagues\textsuperscript{12} have more convincingly demonstrated the production of respirable vesicles (2-6 im in diameter) containing live \textit{Legionella} from \textit{Acanthamoeba}. Berk\textsuperscript{11} estimated that each vesicle could contain between 20 and 200 bacteria, while Rowbotham\textsuperscript{4} calculated numbers in the range of 365-1,483 \textit{Legionella} for a 5 im diameter vesicle. These membrane-bound vesicles would also protect the \textit{Legionella} from desiccation during the airborne dissemination from the tower.

Thus, from a disease transmission perspective, the cooling tower drift that exits the tower would contain a mixture of free \textit{Legionella}, clusters of \textit{Legionella} within respirable amoeba vesicles, and intact amoeba containing \textit{Legionella}. In would seem obvious that the respirable vesicles would provide the highest risk to humans since they can be inhaled into the lungs, with a single vesicle providing a potentially infectious dose of \textit{Legionella}.

\textbf{THE STANDARD CULTURE METHOD FOR Legionella} – The gold standard for detection and quantitation of \textit{Legionella} in cooling towers or other environmental water samples is the standard culture method originally described by the CDC\textsuperscript{13}. In this procedure, samples (with and without acid treatment to reduce the other heterotrophic bacteria in the water) are diluted and portions plated on selective and non-selective agar media. Any \textit{Legionella}-like colonies that appear after appropriate incubation are confirmed as \textit{Legionella} (species and serotype) with standard confirmation procedures. Using the assumption that each colony originated from a single bacterium, the number of \textit{Legionella} in the water can be calculated and recorded as “colony forming units” (CFU) per ml or liter of original sample. To date, a number of organizations have published protocols for the culture of \textit{Legionella} from environmental samples including an international standard (ISO 11731)\textsuperscript{14}. Culture of \textit{Legionella} from environmental samples is technically demanding and successful testing requires a microbiology laboratory that is experienced in the detection of this bacterium. There are no programs to certify the proficiency of environmental laboratories for their ability to culture \textit{Legionella}. In addition, variations which can be associated with procedures such as filter concentration or acid pretreatment (to kill non-\textit{Legionella} bacteria) can dramatically affect the number of \textit{Legionella} detected by these procedures. CDC will be initiating a proficiency testing program for environmental laboratories culturing \textit{Legionella} in 2009 which should help with the standardization of these practices. Until that time, the only way to ensure accurate testing results is to rely on highly experienced laboratories.

It should be noted that other non-culture techniques are available for detection and quantitation of \textit{Legionella} in environmental samples, including antigen-antibody based methods (such as immunofluorescent microscopy) and nucleic acid detection procedures such as polymerase chain reaction (PCR). The major limitations of these other procedures is that they may cross-react with other bacteria in the water and do not distinguish between living (infectious) and dead (non-infectious) \textit{Legionella} in the sample.

\textbf{LEGIONELLA CONCENTRATION IN TOWER WATER} – Using the standard culture technique, many investigators have shown that \textit{Legionella} is a common part of the microbial ecosystem in cooling tower water, although usually at low concentrations. Results of a large survey of cooling towers (2,590 samples) over several years published by Miller and Koebel in 2006\textsuperscript{15} showed that 12% of the tower samples had detectable \textit{Legionella} above the limit of sensitivity of 10 CFU/ml and 2% of the samples had levels above 1,000 CFU/ml. A similar Spanish study presented at the European Congress of Clinical Microbiology and Infectious Diseases in 2004 by Garcia-Nunez\textsuperscript{16} found that 18 % of 554 cooling towers randomly sampled over a three-year period were culture-positive for \textit{Legionella} at their increased limit of sensitivity of 10 CFU/liter. \textit{Legionella} numbers generally constitute a small percentage of the total bacterial population in tower water (usually < 1% of the total heterotrophic bacteria). However, Miller and Knepp\textsuperscript{17} showed that (perhaps as a result of biocide selectivity), the \textit{Legionella} numbers may occasionally approach or achieve 100% of the bacterial population in the cooling tower water, often at levels exceeding 1,000 CFU/ml. Cooling towers responsible for outbreaks of Legionnaires’ disease often have high concentrations of \textit{Legionella} in their water. To the best of our knowledge, the highest concentration reported in such an outbreak investigation was in a tower which contained 10^7 CFU/ml of \textit{L. pneumophila}\textsuperscript{18}.

Analysis of cooling tower water with non-culture methodology tends to give higher percentages of samples positive for \textit{Legionella}. This is due to 1) the detection of both living and dead \textit{Legionella} in the samples, and 2) the increased sensitivity of PCR over the standard culture method (i.e. the ability to detect very low levels of \textit{Legionella} in the sample).

\textbf{UNDER ESTIMATIONS OF THE STANDARD METHOD} – While the standard culture technique is generally very reliable and reproducible in a qualified laboratory, this method may significantly under-estimate the actual number of \textit{Legionella} in a cooling tower water sample as a result of:

1. \textbf{Interference by other bacteria}. Because \textit{Legionella} is usually a minority of the total bacterial population in the cooling tower water, it is essential that the acid treatment and selective media successfully eliminate or inhibit the other bacteria so that the \textit{Legionella} can grow without interference. While occasionally encountered in all labs, interference is a problem most common in laboratories not familiar with these critical elements of the standard procedure.

2. \textbf{Viable but non-culturale (VBNC) \textit{Legionella}}. Examination of cooling tower water by non-culture techniques such as immunofluorescent microscopy or polymerase chain reaction (PCR) often reveal the presence of \textit{Legionella} in samples that were culture-negative, or higher numbers of \textit{Legionella} in samples that were culture-positive. The demonstration of a VBNC state for \textit{Legionella} has been convincingly demonstrated by several investigators using nutrient limitation\textsuperscript{18,19,20} or disinfectant exposure\textsuperscript{21,22}. These VBNC \textit{Legionella} can be resuscitated by exposure to amoeba and are potentially infectious for humans.

3. \textbf{Clusters of \textit{Legionella} bacteria}. Any clusters or clumps of \textit{Legionella} introduced onto an agar plate would form a single colony and be under-counted as a single \textit{Legionella} bacterium. Clusters containing more than one \textit{Legionella} are readily observable when water samples are examined.
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using immunofluorescence microscopy (IFM). If each cluster were counted as a single *Legionella*, the clusters may account for as much as 5–10% of the *Legionella* observed by IFM (personal observation). Additional clusters of *Legionella* within intact amoebae or amoebae vesicles may not be observed by IFM due to an inaccessibility to the anti-*Legionella* antibody used in this method, but still form single colonies when cultured onto an agar plate. Thus, the production of vesicles (each containing potentially large numbers of viable *Legionella*) by amoebae or other protozoa would be of great importance in terms of disease transmission.

**EPIDEMIOLOGY OF OUTBREAKS**

The preceding sections have discussed a semi-quantitative methodology for evaluating the risk for a Legionella infection from a cooling tower. The fundamental question is does the epidemiology data support the methodology.

The methodology assumes that the concentration of airborne bacteria is due primarily to four factors:

1. The concentration of *Legionella* bacteria in the circulating water.
2. The quantity of drift generated by the tower.
3. The quantity of air passing through the tower.
4. The dilution of the plume by ambient air.

The exposure dose and hence the risk of disease is then related to the time spent breathing in the contaminated air.

Clive Brown describes a 1994 outbreak in the area around a Delaware hospital. The paper strongly suggested a relationship to time spent near the contaminated cooling tower and risk of infection. The authors develop a variable which they call an Aerosol Exposure Unit (AEU) to describe the dose that an individual received. The AEU is proportional to the hours spent at a specific distance from the tower with a formula of:

\[
\text{AEU} = \frac{\text{time (in hours)}}{\text{distance (in miles)}}
\]

The authors performed a detailed case-control study of 22 people who came down with the disease and matched controls of similar age and health that attend the same clinic but were disease-free. This study showed a very strong correlation with high AEU and disease.

The AEU formula assumes that:

1. The dose is linear with time spent breathing contaminated air. This is exactly the assumption that we are making.
2. The contamination falls off in a linear manner the farther the distance form the tower. The AEU formula implies that contamination-concentration is proportional to 1/distance. Since contamination-concentration is proportional to 1/plume-dilution, the AEU formula assumes a linear increase between plume-dilution and distance. This is different from the model used in this paper.

Our model assumes a quadratic increase in plume dilution with distance. Although different, the result on this relatively small data base may not be noticeable. **Figure 6** is a plot of the plume dilution of a ground-based tower with a 12" fan using the model proposed in this paper. Also on this plot is a linear regression of those points that is forced through the origin. This linear regression represents the relationship used to develop the AEU variable. The difference in the two plots is not likely to be significant in the disease-AEU correlation.
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DISCUSSION

This description of Legionella concentration in a dispersed plume is only intended as an order-of-magnitude approximation. While there is no known safe levels of Legionella exposure, values that are less than 1 Legionella bacterium inhaled in 24 hours seem very low. This indicates that if current guidelines are followed – good drift eliminators, good mechanical repair of the tower, sound tower sitting practice, reasonable microbiological control, etc. – the risk of Legionella infection can be quite low.

The basic plume dispersion model is a very simplified case. Buildings in the area of the tower as well as other structures will dramatically affect how the plume is diluted. The simplified model is only intended as a visualization and order-of-magnitude approximation that bacteria concentration, in general, decreases as distance from the tower increases.

There are well-documented cases of Legionellosis associated with cooling tower exposure – how does this analysis help understand those cases? In general, two or more of the basic assumptions of this analysis were not followed. It is useful to review the basic assumptions of this analysis because they certainly do not apply in many situations. The assumptions of this analysis are:

1. That modern drift eliminators (0.005% for crossflow and 0.001% for counterflow) are being used. The drift eliminators that were the standard just a few years ago were much less effective, having drift rates up to an order of magnitude higher.

2. That the tower is in good mechanical shape. Damaged or missing drift eliminators will greatly increase the level of drift. While much of the drift from such a tower will be in very large, rain-drop sized drops that fall quickly to the ground, some will be entrained in the air and contribute to the respirable Legionella loading of the plume.

3. The tower is assumed sited on a clear area of ground with people below the level of the exhaust. A subterranean installation with a ground-level exhaust would be more dangerous as would locating the cooling tower such that the exhaust can be drawn into a building’s air inlet.

4. Reasonable water treatment is in effect. Although not specifically aimed for Legionella eradication as is required by some non-US regulations, water treatment that keeps good general biological control is assumed.

Another underlining assumption is that infection is caused by the inhalation of individual Legionella bacteria. As previously described in this paper, there may be vesicles in cooling towers which may contain tens if not hundreds of Legionella bacteria. The cooling towers in the outbreaks discussed in this paper all had old-style drift eliminators, high levels of Legionella in the basin, and were improperly sited. The contamination level was sufficiently high to allow an individual to inhale tens if not hundreds of Legionella bacteria by spending a relatively short time in the tower plume. These outbreaks can be explained by inhalation of sufficient individual bacteria to cause a disease. However, these outbreaks could also be explained by the inhalation of individual vesicles emitted in the drift.

There are several studies24,25,26 that implicate a cooling tower with infection that occurred at a considerable distance from the cooling tower. A vesicle-vector would help explain how an infectious dose could be inhaled at a significant distance from the tower.

If vesicles are the disease vector, and if a single vesicle contained sufficient Legionella bacteria to provide an infectious dose, then the analysis would change. A very simplified example illustrates the difference.

If we had an aerosol contamination such that there was 1 chance in 10 that a person would inhale 1 bacteria in a minute and 1000 people spent 1 minute breathing the air then 100 people would breath in 1 bacteria. A single bacteria is probably too low a dose to cause disease so nobody gets infected.

If we had an aerosol contamination such that there was 1 chance in 100 that a person would inhale 1 vesicle in a minute and 1000 people spent 1 minute breathing the air then 10 people would inhale a vesicle. If every vesicle contained a large quantity of bacteria then some of the 10 could become infected, depending on the health of the individual.

Current epidemiological data has not been able to distinguish between the alternative vectors and it is possible that both vectors are involved in infections. Reduction or elimination of vesicles in tower water could require a different water treatment approach than reduction of Legionella bacteria.

CONCLUSION

There are many excellent guidelines for minimizing the risk of Legionella infection from cooling towers. These guidelines all recommend proper maintenance, good drift eliminators, proper siting, and good biological control among many other recommendations; however, none of these guidelines attempts to describe the relative importance of these recommendations.

Because of the quantitative nature of biological control, that aspect is often emphasized over other aspects of control. A 1990-genre cooling tower with drift eliminators that reduce drift to 0.02% and a Legionella count of 50 CFU/ml might be thought of being a low risk of infection while a 2000-genre cooling tower with drift eliminators that reduce drift to 0.001% and a Legionella count of 1000 CFU/ml would require immediate disinfection. Using the approach in this paper, the 2000-genre cooling tower presents a similar risk for a community-acquired infection than the less contaminated, older tower. One way to reduce the risk of Legionella exposure from older equipment is to upgrade the drift eliminators to the modern, high-efficiency designs.

Further studies of the transmission vector for cooling-tower infection (bacteria, vesicles, or both) are needed. The control of amoebae and vesicles in the cooling water may require different water treatment than the control of planktonic Legionella bacteria. The factor that vesicles may play in disease transmission needs to be better understood.

It has been well known that the level of Legionella bacteria in the cooling tower plays some role in the risk of infection; however, the mere presence of the bacteria is insufficient to predict the potential for disease transmission. The semi-quantitative approach to Legionella aerosol exposure level, as outlined in this paper, can be very beneficial in the management of several of the differing factors that contribute to risk of Legionnaires’ disease transmission. The importance of drift eliminator design, physical maintenance prac-
tices, and siting as well as bacteria counts can all be roughly weighed as to their contribution to the overall risk-of-infection. The authors feel that the semi-quantitative approach taken in this paper can be beneficial in evaluating the risks associated with a particular cooling tower, evaluating the benefits of proposed changes in cooling tower guidelines, evaluating the importance of equipment design modifications, and aiding in the investigation of outbreaks.

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Safely Stopping, Holding and Locking out Cooling Tower Mechanical Sets

Duane Byerly
Rexnord Industries LLC

Abstract
Safety is becoming an ever increasing factor while working around and inside of cooling towers. When a fan motor is not engaged, fans free wheel from wind and updraft in cooling towers. Entering a fan cell or removing a stack section with the fan rotating is an OSHA violation. Stopping and holding a fan to conduct maintenance operations can be dangerous to personnel. This paper presents methods for stopping and holding fans for maintenance operations and high wind conditions. It also presents various material and mounting options.

Introduction
As mechanical brakes are becoming more frequently used on cooling tower fans, it is important for owners and manufacturers to understand the brake design options available. Also it is important to understand the mathematics and have a good command of the technical requirements when specifying a brake for their application.

Throughout the course of a year, it will be necessary for maintenance personnel to enter a fan cell. CTI Chapter 10 (10.7.15.3 and 10.10.7.2) recommends semi-annual inspection of the gear reducer and coupling alignment. This will require entering a fan cell. A cooling tower fan and its connected mechanical components (gear reducer, motor, shaft) have very high inertia. Freewheeling fans contain a high level of kinetic energy. According to OSHA, an energy source like a rotating fan must be locked out prior to entry to prevent injury to personnel.

Second, fans should be stopped and locked down for high wind conditions. High winds will deflect the fan stacks enough to force them into the path of the rotating fan. In the past, hurricanes have caused considerable damage to cooling tower fans and fan stacks because the fans were not locked down and able to rotate.

The current method of stopping a fan is using a wooden 2x4 wedged up underneath the motor shaft. Unfortunately this is not safe as this could seriously injure the operator. Another method is lassoing a fan blade then hanging on to the rope before the fan stops or it pulls you over the edge of the stack not to mention the possible damage caused to the fan blades.

Safety
Prior to entering a fan cell, it is required to lock out and tag out the electric motor. A lock must be placed on the main power box to that specific fan motor. Only the owner of that lock possesses the key to that lock and can not be removed by anyone else.

Second, the fan must be stopped and locked out prior to entering a cell and the fan must be stopped and locked out prior to removing a section of the stack. Many times that fan is still rotating due to updraft in the fan cell or exterior wind. Locking out the fan involves stopping the fan if it is still coasting or rotating.

The dilemma is how to stop that fan without using a 2x4 or a rope to contact a moving piece of equipment. A coupling mounted backstop is not enough. A backstop is an anti reversing device that holds the fan from turning in the reverse direction. An anti wind milling device in the gear reducer is not adequate. This also holds the fan from turning in the reverse direction. Many times a fan will continue to freely rotate in the forward direction.

Instances of OSHA violations:

- If an individual contacts a rotating energy source like a fan or a motor shaft with their hand or foot or a piece of wood.
- If an individual uses a rope to lasso a fan blade.
- If someone removes a coupling guard or a fan stack while something is rotating.

Really the only way to stop a fan without an OSHA violation is a remotely actuated brake. This brake actuation must occur without removing a guard; without removing a stack panel; without using a rope or a 2x4 to contact a moving piece of equipment, or without putting an individual in danger.

Protect fans from wind milling
Fan wind milling is very common in our industry. When a motor is not operating, in many cases a fan will be rotating in the wind. Sometimes this is caused by the wind and other times by an updraft in the tower. The fan can turn forward and sometimes in reverse. This can be damaging to the fan and stack if the wind gusts are high enough to cause the stack to deflect and contact the fan.

When fan blade tips contact stacks, there is usually damage to the blades and the stacks. Higher winds cause more stack deflection and more deflection causes more blade contact which causes more damage.

Fans should be locked down and held stationary during high wind conditions; especially hurricanes. The best way to safely stop these fans is a braking system that can quickly lock-out the mechanical set during a plant lock-down prior to a hurricane. This lock-out system should be easy and take less than one minute per fan. The brake should be designed to not slip during high winds. It should not be capable of coming loose or disengaging during hurricane gusts.

During high wind condition when the fan is stationary, the stack may still deflect, but there is no rubbing activity causing wear which will eventually damage the blades and stacks. With a brake there will be no fan damage and no stack damage.
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Calculations

It is important for the owner/operator to understand the methodology for calculating the inertia, kinetic energy, stopping time and temperature rise in a braking system.

Calculate fan inertia reflected at the brake = \( W_{k_f} \)

\[
W_{k_f} = W_{k_{fan}} \times \left( \frac{rpm_f}{rpm_m} \right)^2
\]

where:

- \( W_{k_f} \): Rotational Inertia of fan reflected at motor (lb ft²)
- \( W_{k_{fan}} \): Rotational Inertia of fan (lb ft²)
- \( rpm_f \): Rotational velocity of fan (rpm)
- \( rpm_m \): Rotational velocity of motor (rpm)

Total rotational inertia reflected to the brake = \( W_{k_t} \)

\[
W_{k_t} = W_{k_m} + W_{k_r} + W_{k_f}
\]

where:

- \( W_{k_t} \): Total rotational reflected inertia (lb ft²)
- \( W_{k_m} \): Rotational Inertia of motor (lb ft²)
- \( W_{k_r} \): Rotational Inertia of reducer (lb ft²)
- \( W_{k_f} \): Reflected rotational Inertia of fan (lb ft²)

The time required to stop a fan can be calculated as follows:

\[
t = \frac{W_{k_t} \times rpm_m}{(T_d \times C)}
\]

where:

- \( t \): time (seconds)
- \( W_{k_t} \): Rotational reflected inertia (lb ft²)
- \( rpm_m \): Rotational velocity of motor (rpm)
- \( C \): Constant = 308
- \( T_d \): Dynamic torque (in lb)

Kinetic Energy of rotating load

\[
KE = \frac{W_{k_t} \times rpm_m^2}{5875}
\]

where:

- \( KE \): Kinetic Energy (ft lb)
- \( W_{k_t} \): Total rotational reflected inertia (lb ft²)
- \( rpm_m \): Rotational velocity of motor (rpm)

Heat generated on brake disc

Converting to Btu

\[
H = \frac{KE}{778}
\]

where:

- \( H \): Heat (Btu)
- \( KE \): Kinetic Energy (ft lb)

Temperature rise when brake is stopped

\[
\Delta T = \frac{H}{(C \times m)}
\]

where:

- \( \Delta T \): Change in temperature (°F)
- \( H \): Heat (Btu)
- \( m \): mass of rotor (lb)
- \( C \): Specific heat of stainless steel = 0.12 BTU/(lb °F)

Calculation example: What is the total inertia reflected at the brake? Time required to stop the fan? Kinetic Energy of the system? Temperature rise at the brake disc?

NOTE: This is a worst case scenario neglecting rolling resistance of fan, reducer and motor.

Assume:

- 200 Hp motor @ 1780 rpm
- Fan wind milling speed = 50 rpm
- 32’ fan \( W_{k_f} = 120,000 \) lb-ft²
- 20:1:1 gear reducer \( W_{k_r} = 30 \) lb-ft² (est)
- Motor \( W_{k_m} = 50 \) lb-ft²
- Brake rotor mass (m) = 20 lb
- Brake applied dynamic torque (T) = 200 ft lb

Calculate fan inertia reflected at the brake = \( W_{k_f} \)

\[
W_{k_f} = W_{k_{fan}} \times \left( \frac{rpm_f}{rpm_m} \right)^2
\]

\[
W_{k_f} = 120,000 \text{ lb-ft}^2 \times \left( \frac{50 \text{ rpm}}{1005 \text{ rpm}} \right)^2
\]

\[
W_{k_f} = 297 \text{ lb-ft}^2
\]

Total rotational inertia reflected to the brake = \( W_{k_t} \)

\[
W_{k_t} = W_{k_m} + W_{k_r} + W_{k_f}
\]

\[
W_{k_t} = 297 \text{ lb-ft}^2 + 50 \text{ lb-ft}^2 + 30 \text{ lb-ft}^2
\]

\[
W_{k_t} = 377 \text{ lb-ft}^2
\]

Time to stop fan \( t = \frac{W_{k_t} \times rpm_m}{(T \times C)} \)

\[
t = \frac{377 \text{ lb-ft}^2 \times (1005 \text{ rpm})}{(200 \text{ ft lb} \times 308)}
\]

\[
t = 6 \text{ seconds}
\]

Kinetic Energy (KE) =

\[
KE = \frac{377 \text{ lb-ft}^2 \times (1005)^2}{5875}
\]

\[
KE = 64,800 \text{ ft lb}
\]

Heat generated on disc

\[
H = \frac{KE}{778}
\]

\[
H = 64,800 \text{ ft lb}
\]

Temperature rise on disc (°F)

\[
\Delta T = \frac{H}{(C \times m)}
\]

\[
\Delta T = \frac{64,800 \text{ ft lb}}{(0.12 \times 20 \text{ lb})}
\]

\[
\Delta T = 35 \text{ °F}
\]

Based on the example problem, a fan wind milling under no power at half speed will take 6 seconds to stop after brake is applied and have a temperature rise on the disc of 35 °F.

Type of brakes

Caliper style brake
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- Low Noise – Where noise levels are critical, combine Vortex tips, wider chord width and increased number of blades for maximum noise reduction.
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Today, Moore Fans has some 175,000 fans in operation around the world. And with sales offices in North America and in Europe, Moore factory engineers and customer service representatives stand ready to help you analyze your air moving requirements, choose the right product, and provide reliable service and support, before and after the sale.

For more information on the Class 10000 Fans or any of the family of quality products from Moore Fans call **660-376-3575** or visit us online at **moorefans.com**.
Mechanical Brake - The caliper style brake squeezes down on disc that is attached to the hub of the drive shaft. The caliper is mounted rigidly to the frame. During installation, it will be necessary to adjust the gap of the brake pads so they do not rub against the disc during operation. The brake should be designed to have a travel range which will fully close and apply the locking torque to a wide open position allowing no pad contact during operation. The caliper brake is designed to self center so it does not apply excessive loads on the motor bearings.

Drum style brake

The drum style squeezes down on the drive shaft hub. The pads have a round curvature. One concern with this design is that not all hubs have a round cross section. Some are designed with a non-machined scalloped outer surface. This would create an interrupted braking surface and the pads would not have infinite contact with the braking surface. Centering adjustment would also be required with this method so it would not put a side bearing load on the motor bearings.

Electric Motor brake - Mechanical sets can be stopped electrically using a brake in the motor’s circuitry. This method requires a direct current (DC) running through the stator coils during the shut-down period. This will require a break-off leg to be rectified into DC current and all can be interfaced with the motor control circuit. For more information on electric brakes refer to CTI paper TP80-13.

Materials

Material selection is very important when deciding what type of brake to specify. As we all know, cooling towers are typically corrosive environments. Most cooling tower owners feel that stainless steel is the best choice. Painted carbon steel may work for a period of time, but the concern is the longevity of the paint or coating system over the life of the tower. A mechanical brake will actuate and this movement must remain free from corrosion and functional after 20-30 years. Additionally, if this brake is mounted inside the stack, in the airflow, then noncorrosive material like stainless steel is likely the best choice.

The pad should be a sintered metallic friction material and it should be corrosion resistant enough to withstand the corrosive environment. The pad backing material should also be corrosion resistant. It is also recommended that when purchasing pads that the pads have been tested to verify heat rise and durability for multiple starts. Pad material should have a high static and dynamic coefficient of friction.

Brake mounting and actuating

Should a mechanical brake be on the motor end or gear end? There are advantages and disadvantages to both. Mounting on the motor end will make actuation closer and it is not required to build linkage out to the gear. It may be possible to mount outside of the stack if on the motor end. The other advantage to motor mounting is easy access. The advantage of mounting at the gear end is that you have a way to stop the fan if you want to work on the drive shaft or motor shaft.

It is possible to mount the caliper at the 6:00 o’clock position or at the 3:00 o’clock position. A robust adapting bracket will be required to mount the brake caliper to the torque tube or motor base framework. This will require a corrosion resistant bracket made for the brake position that best fits the application.

As a cooling tower owner, you should ask if a hand lever actuation or rotational actuation will work best. Levers are solid however can come loose. Rotary actuation in which an operator can rotate a screw 1 or 2 revolutions is very desirable. This is a more natural locking feature and won’t accidentally come loose. It is very important that when the brake is actuated, it be done outside of the guard. Someone’s hand can not go under a guard to actuate a brake.

Problem is how can you see if a brake is engaged or not? Guards tend to be solid and not utilizing the mesh design. It is therefore impossible to tell if the brake is engaged from outside of the guard. It is recommended to use a proximity switch or some type of visual representation to show that the brake is engaged. This proximity switch circuit should be wired into the control room to signify to the operator that the brake must be disengaged prior to starting the motor.

Conclusion

Cooling Tower owners should understand their options when specifying brakes on their mechanical sets. Things to look for when specifying a brake:

- Remote access from outside a guard for totally safe engagement
- Noncorrosive pads, discs and structural material for the cooling tower environment
- Simple and fast engagement
- Exterior indicator verifying brake engagement
- Self centering feature to prevent motor bearing loading

A brake system can provide remote locking out of a cooling tower fan which allows personnel direct control of fans during maintenance activities. Also a brake can be used for quick lock out of fans prior to hurricane preparation and plant lock-down.
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Florida Building Code Structural Requirements for Evaporative Cooling Equipment

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SPX Cooling Technologies

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Abstract
Due to high incidences of severe weather and hurricanes to the Florida peninsula, the Florida Department of Community Affairs and the International Code Council (ICC) has issued new and more stringent regulations to the Florida Building Code.

This paper will provide an in depth examination of the Florida Building Code and recent declaratory statements issued on how the code applies to the structural design of cooling towers, fluid coolers and evaporative condensers. It will also review the benefits of following the code, how to ensure all parties involved are meeting legal requirements and the responsibilities of the engineer of record, equipment manufacturer, building code officials and owners.

Introduction
The State of Florida has issued many changes to its building code in the last 15 years. With the given number of changes and interpretations to the Florida Building Code (FBC), it is important to have a clear understanding of its intent. The following will explain past structural requirements for evaporative cooling equipment (not to be confused with an Evaporative Cooling System per the FBC), current code language, and demonstrate through actual Florida Building Commission statements how the language, by law, is to be interpreted. Lastly, an explanation of legal responsibilities will be outlined for the benefit of all parties involved.

Florida Building Code (FBC) historical requirements
The Florida Building Commission began mandating statewide building codes in the 1970s. These codes were primarily created to require local authorities to enforce one of four state minimum building codes. An example of the requirements placed on evaporative cooling equipment can be found in the Broward county code of 1994 part 6, chapter 23, section 2309.6. It states, “All exterior located plumbing, mechanical, and electrical equipment and their frames, appurtenances, components, supports and anchoring devices shall be anchored to resist the forces due to wind pressure as noted in this chapter”. [3] The key word here is ‘anchored’. This type of language has been and occasionally still is used as the minimum requirement for many Florida applications and is one of the primary differences between the previous codes and the current FBC.

After a series of natural disasters in the early 1990s the state building codes were reviewed. The study revealed that code adoption and enforcement was inconsistent as well as inadequate [1]. The end result occurred in the Florida State legislature in 1998 when chapter 553, Florida Statutes, Building Construction Standards was amended to create one state building code to be enforced by local governments. As of March 1, 2002, the Florida Building Code (FBC) became active and by law supercedes ALL local building codes in the state. [1]

Below is a brief chronology of the changes pertaining to the evaporative cooling industry [2]

- July 1996 – Governor Chiles establishes the FBC Study Commission.
- August 1999 – The Commission adopts draft II of the FBC covering windload design, roofing, and code enforcement for addressing the concerns of South Florida.
- November 1999 – The Commission adopts the wind design option from the International Building Code (IBC) including American Society of Civil Engineers ASCE 7-98.
- March 2002 - the Florida Building Code (FBC) becomes active and by law supercedes all local building codes in the state. All new construction from this point must follow the FBC.

There are many points of debate shared by manufacturers, building design engineers, building inspector/local code officials, and customers as to what the actual interpretation should be. First, where are the structural requirements for evaporative cooling equipment and does the code apply to equipment anchorage, structure or both? Second, what is the responsibility of each party involved and is a structural review by a Florida State PE required?

Current FBC 2004 requirements for evaporative cooling equipment
One of the primary sources of confusion for evaporative cooling equipment is the location of the structural requirements in the code. Few realize that the structural requirement is actually in the mechanical code. Even more confusing, the structural code (FBC-Building) has a cooling tower section (section 1509.4) that does not mention any structural requirements. Since structural engineers may not read the mechanical code, it is very easy for them to miss
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the structural requirements. In addition, many mechanical engineers and contractors do not understand the references in FBC-Mechanical to FBC-Building and fail to investigate.

So where are the structural requirements for evaporative cooling equipment? For new mechanical construction, the first place to start is FBC 2004–Mechanical, sections 301 and 908 [1].

**301.12 Wind resistance.**

> Mechanical equipment, appliances and supports that are exposed to wind shall be designed and installed to resist the wind pressures on the equipment and the supports as determined in accordance with the Florida Building Code, Building ...

Here the code clearly states that the mechanical equipment shall be designed and installed to resist the wind pressure on the equipment and supports. So the answer is that both structure and anchorage are required.

In addition to section 301.12, the mechanical code also states the following in section 908.1 [1]:

**908.1 General.**

> A cooling tower used in conjunction with an air-conditioning appliance shall be installed in accordance with the manufacturer’s installation instructions. The design of such cooling towers shall be in accordance with the requirements of the Florida Building Code, Building for a structure.

Here again, the code reinforces that the equipment must be designed per the FBC Building ‘for a structure’. And lastly section 908.4 specifically addresses the supports and anchorage [1].

**908.4 Support and anchorage.**

> Supports for cooling towers, evaporative condensers and fluid coolers shall be designed in accordance with the Florida Building Code, Building.

As a final confirmation, SPX Cooling Technologies submitted for ruling two cases to the State of Florida Building Commission; one for new construction and one for a level one alteration of an existing building. The following was confirmed by Conclusion of Law for new construction [9]:

- The Florida Building Commission has the authority to interpret the FBC.
- Section 301.13, Florida Building Code, Mechanical states that mechanical equipment exposed to wind shall be designed and installed to resist the wind on equipment and supports per Florida Building Code, Building.
- Section 908.1, Florida Building Code, Mechanical states that cooling towers used in conjunction with air-condition appliance shall be designed per the Florida Building Code, Building for a structure.
- Construction documents shall have all pertinent information per section 1604.5 of FBC, Building.
- Section 1609.1 states that structures shall be designed to withstand the minimum wind load prescribed and that decreases shall not be made for the effect of shielding by other structures.
- The code requires the structure and anchorage of exterior mounted cooling towers to be designed to withstand the applied wind force and the design must be included with the construction documents.

The following was confirmed by Conclusion of Law for existing construction [4]:

- The Florida Building Commission has the authority to interpret the FBC.
- Section 407.1.2 of the FBC states the wind design of existing buildings shall be in accordance with the building codes that were in effect when the building was permitted. This applies to repairs not Level 1 alterations.
- Section 503.3 of the FBC states all new work shall comply with materials and methods in the FBC.
- Section 507.1 of the FBC states where work includes replacement of equipment that is supported by the building the structural provisions of this section apply.
- Where replacement of equipment results in additional dead loads, structural requirements shall comply with the vertical load requirements of the FBC Building.
- The Code requires the structure and anchorage of exterior mounted cooling towers that are subject to the forces of wind to be designed to withstand the applied wind force.
- Mechanical equipment structure and support anchorage being replaced during a level 1 alteration shall meet the wind design criteria of the current code, not the code in effect when the building was originally constructed or permitted.

Level 1 alterations are covered in Section 303.1 of FBC-Existing Building [6]. See excerpt below:

**303.1 Scope**

Level 1 alterations include the removal and replacement or the covering of existing materials, elements, equipment, or fixtures using new materials, elements, equipment, or fixtures that serve the same purpose. Level 1 alterations shall not include any removal, replacement or covering of existing materials, elements, equipment or fixtures undertaken for purpose of repair...

To summarize, minor repairs (not Level 1 alterations) must adhere to the code in use when the building was permitted. Level 1 alterations and new buildings must adhere to the current FBC. All cooling towers must be designed to meet the FBC wind load requirements for both structure and anchorage.

From the above, it is clear that FBC-Building structural wind load criteria are required for cooling towers, fluid coolers and evaporative condensers. It will be left to the FBC and ASCE documents to demonstrate the calculations that provide the lb per sq. ft. (PSF) wind load requirement. More detail can be obtained by referencing the following sections of FBC-Building [6].

1609.1 Applications
1609.3 Basic Wind Speed
1609.4 Exposure Category
1609.5 Importance Factor

In addition, high velocity hurricane zones are defined as Broward and Dade counties. For these regions consult the following: Sections 1612.1.3, 1620 and 1621. As a side note, on March 1, 2009, FBC 2007 will become effective. In this new version there will be some
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changes to the exposure categories as well as references and associated changes from ASCE 7-02 to 7-05. If you are involved in the design of new buildings in Florida, make sure your design engineers are aware of the new code and its requirements.

Exception – The FBC does not have jurisdiction and does not apply to Federal installations

Responsibilities

The engineer, contractor, code officials, owner and equipment manufacturer all have a responsibility to comply with the FBC. However, it all starts with the building design engineer or Project Engineer of Record. It is the engineer of record’s responsibility to manage the construction documents relating to the structural calculations as indicated in FBC-Building Section 1603.1, and provide the required information per Section 1603.1.4 [6]. The requirements of 1603.1.4 are shown below [6]. In addition to this, per FBC-Building Section 106.1, all construction documents are to be prepared by design professionals and in the case of engineers, must be a licensed professional engineer[1]. See the supporting documentation below:

106.1 Submittal documents.

The construction documents shall be prepared by a design professional where required by the statutes.

If the design professional is an architect or engineer legally registered under the laws of this state regulating the practice of architecture as provided for in Chapter 481, Florida Statutes, Part I, or engineering as provided for in Chapter 471, Florida Statutes, then he or she shall affix his or her official seal to said drawings, specifications and accompanying data, as required by Florida Statute.

Chapter 471 [5]

...All final drawings, specifications, plans, reports, or documents prepared or issued by the licensee and being filed for public record and all final documents provided to the owner or the owner’s representative shall be signed by the licensee, dated, and sealed...

1603.1.4 Wind design data.

The following information related to wind loads shall be shown, regardless of whether wind loads govern the design of the lateral-force-resisting system of the building:

1. Basic wind speed (3-second gust), miles per hour (km/hr).
2. Wind importance factor, I W and building classification from Table 1604.5 or Table 6-1, ASCE 7 and building classification in Table 1-1, ASCE 7.
3. Wind exposure, if more than one wind exposure is utilized, the wind exposure and applicable wind direction shall be indicated.
4. The applicable enclosure classifications and, if designing with ASCE 7, internal pressure coefficient.
5. Components and cladding. The design wind pressures in terms of psf (kN/m²) to be used for the design of exterior component and cladding materials not specifically designed by the registered design professional.

At this point it is the project engineer of record who is responsible for the structural design of the evaporative cooling equipment. However, once the engineer of record obtains the above information, he or she can perform the final equipment structural review (if so qualified) or delegate the analysis to a qualified engineer. The Florida Board of Professional Engineers Statutes and Rules defines this relationship and responsibility [5].

Chapter 61G15-30

Delegated Engineer. A Florida professional engineer…the delegated engineer is the engineer of record for that portion of the project.

Chapter 61G15-23

...A professional engineer may only seal an engineering report, plan, print or specification if that engineer was in responsible charge of the preparation and production of the engineering document and the professional engineer has the expertise in the engineering discipline used in producing the engineering document in question.

In most instances the final structural analysis for the equipment is sent to the manufacturer. If this is the case, the manufacturer can be responsible for the following:

- Conform to anchorage and structural requirements outlined by the project engineer of record.
- Provide support reactions.
- Provide anchorage attachment details.
- Provide certification of the equipment wind load capability (PSF).

If the manufacturer cannot provide certification by a qualified Florida State structural P.E., then the burden of responsibility still remains on the project’s engineer of record or his delegated engineer. It should be pointed out that if the cooling equipment structural review is delegated to the manufacturer, the manufacturer is NOT responsible for defining the building criteria in Section 1603.1.4.

Even though clearly stated, there are challenges with these requirements. For example, project engineers of record must find capable structural engineers to perform the analysis or do the equipment review themselves if qualified. This is highly unlikely considering the time involved in analyzing an unfamiliar product.

To remedy this and simplify the process, some manufacturers have started providing the structural design review and Florida State PE seal or “Certification”. Certification is defined in the Florida PE Statutes in chapter 61G15-18 [5].

Chapter 61G15-18.011

“Certification” shall mean a statement signed and/or sealed by a professional engineer representing that the engineering services addressed therein…have been performed by the professional engineer, and based upon the professional engineer’s knowledge, information, belief, and in accordance with commonly accepted procedures [are] consistent with applicable standards of practice…

This allows the Engineer of Record, the contractor or anyone designing or modifying a building the simplicity of having the manufacturer provide the necessary documentation with regard to the PSF wind load capability of the equipment. It also ensures it is designed by a qualified licensed engineer.

As for the local building department, the Florida Department of Community Affairs does a good job of summarizing the responsibilities by all current possible titles [7]. They are as follows:
Over 30 years of cooling tower experience will satisfy your specific requirements in performance, durability and appearance. We manufacture district cooling towers, factory assembled towers, large industrial towers and special purpose towers such as plume abatement towers.
“Building code administrator or building official – directly responsible for plan review, enforcement, and inspection of construction, repairs, additions, alterations, remodeling…requiring a permit to show compliance with construction codes as specified by state law...”

“Building code inspector – responsible for construction regulations and inspection of projects that require a permit to show compliance with construction codes.”

“Plans examiner – person qualified to determine whether building or other plans submitted comply with applicable construction codes.”

“Building code enforcement official or enforcement official – licensed building code administrator, building code inspector, or plans examiner whose responsibilities are spelled out in section 468.604, Florida Statutes.”

Regardless of the title, the expectation of responsibility is clear. The local code officials are responsible for reviewing the construction documents and making sure they follow FBC requirements. They are also responsible for enforcement.

**Summary**

- The Florida Building Code takes precedence over all local Florida codes.
- FBC-Mechanical 908.1/908.4 must be followed for evaporative cooling equipment (cooling towers, evaporative condensers, and fluid coolers).
- Evaporative cooling equipment must be designed as a structure per the Mechanical code (FBC-Mechanical).
- The structural code (FBC-Building) defines the lbs per sq. ft. (PSF) the equipment must meet.

The building design engineer (project engineer of record) or contractor responsibilities:

- Adhere to FBC-Building 1603.1.4
- Provide site specific wind load (PSF) requirement
- Provide wind speed (three second gust)
- Provide Wind Importance Factor
- Provide Wind Exposure
- Provide Elevation to Base of Tower
- Ensure the structural capabilities of the evaporative cooling equipment has been reviewed by a qualified licensed Florida State professional engineer unless he passes that responsibility to a Delegated Engineer per Florida State rules and guidelines.

**Manufacturer**

- Ensure the evaporative cooling equipment conforms to the anchorage and structural requirements provided by the Building Design Engineer
- Provide support reactions
- Provide anchorage attachment details
- Provide certification of evaporative cooling equipment wind load structural and anchorage capability.

**Local Florida Code Official**

- Understand the FBC requirements
- Understand that FBC-Mechanical refers to FBC-Building and that FBC-Building is used to determine the PSF requirement for evaporative cooling equipment.
- Review construction documents
- Ensure all parties adhere to the FBC
- Ensure that the structural design has been reviewed and sealed by a licensed Florida structural PE.
- Enforce non-compliance

**Owner**

- Is ultimately responsible for the building and the safety of those who use it. Not only is it the law, but it is also in their best interest and the public’s to make sure their project is designed correctly.

**References**

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A Digital Method for Analyzing Droplets on Sensitive Paper

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Abstract
Sensitive paper has long been used to detect droplet impingement in several processes, including drift measurement. Identifying, counting, and measuring the individual droplet stains has been a tedious, labor-intensive task involving microscopic examination and statistical extrapolation; because, counting all the stains has previously been impractical. Digital techniques now in common use, however, can reduce this previously labor-intensive task to a rather simple one of graphical data screening. Furthermore, all the stains are counted, reducing the uncertainty of the results. The conventional (manual/optical) and digital methods are compared for actual samples as well as the effort and equipment involved.

Introduction
The sensitive paper method of measuring droplet count and size distribution was developed by J. D. Womack in the 1970s at the Environmental Systems Corporation. The sensitive paper is prepared by first soaking it in a solution of Potassium Ferricyanide \([K_3Fe(CN)_6]\) and allowing it to dry. Then the paper is dusted with Ferrous Ammonium Sulfate \([Fe(NH_4)_2(SO_4)_2\cdot6H_2O]\) powder. The resulting surface is ferric yellow in color. When any moisture, such as a droplet, comes in contact with the paper, it produces a deep ammonium blue stain. The relationship between droplet and stain size was determined by a series of experiments using precision-generated drops as described in the Appendix. Frequently, 47 mm diameter filter papers are used for convenience and consistency.

Traditionally, the stains are examined with a microscope and the size, shape, and number are used to infer the count and size distribution of the impinging droplets. As there may be hundreds, even thousands of stains on a single paper, a statistical approximation has traditionally been used rather than an exhaustive examination. In this practice, a series of precision grids are overlaid on the paper and the stains fitting within several grid cells are counted. The counting continues from cell-to-cell until some statistical measure of sample significance is met. The examination can be facilitated by using a magnifying projection device, a digitizing tablet, computer software, and an audible signal.

This process has been successfully carried-out for decades and has provided a reliable and accurate way of measuring airborne transport of droplets. Still, it is very labor-intensive. Tests often require dozens and may require hundreds of papers. Considering the limited equipment and trained technicians required for this task—not to mention the individual endurance for such tedium—it can take quite a while to complete the processing of samples from a single test. This process has been known to take weeks to complete and is done away from the site of the measurements. Returning for more data was also not considered practical. This is the motivation for developing the current digital processing.

Digital Processing of the Sensitive Papers
Precision digital color scanners are now readily available. These units are surprisingly inexpensive, quickly installed, easy to use, and come with powerful software. While their intended purpose is primarily photographic, they can be used for a variety of other tasks. One such purpose would be eliminating the microscope and projector from this sensitive paper examination. The same manual counting methodology and statistical sampling could be applied to the scanned papers. This would at least preserve them digitally from any degradation or contamination with moisture during storage while they await processing. Given the ubiquitous availability of computing power, the logical next step is digital processing.

Several scan resolutions were tested and 4800 dpi (dots per inch) was found to be adequate. At this resolution a 47 mm sensitive paper results in an 8800x8800 pixel image. With default JPEG compression each scan produces a file of approximately 4 MB in size.

In order to digitally determine the size and quantity of the droplets, it is essential to delineate what is and is not a droplet-formed stain and to distinguish one stain from another. Ultimately, the stains must be converted to individual closed polygons. A single polygon may represent more than one overlapping droplet; but this situation exists whether the processing is optical/human or digital/automated. Once the stains are reduced to polygons, a variety of statistical tests can be performed. Additionally, the papers can be examined exhaustively. Approximation by statistical sampling of part of the paper is no longer necessary.

The ammonium blue on ferric yellow of the sensitive paper technique is particularly well-suited to digital analysis, as this color combination provides excellent contrast; because ferric yellow and ammonium blue are almost color counterparts. Simple black-and-white rendering does not adequately reveal just how fortuitous this color combination is. Gray shade discrimination is inherently a matter of degrees: How light is white? How dark is black? Ferric yellow/ammonium blue discrimination is much easier.

All Color Separations are Equal
As children we were taught that the three primary colors are: red, yellow, and blue. As well-intentioned as they might have been, our teachers were misinformed. In fact, one set of primary colors is: magenta, yellow, and cyan. Another set of primary colors is: red,
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green, and blue. Except that, if this green is the color of grass, the corresponding red isn’t the color of fire trucks and the other isn’t the color of the deep blue sea. [Realization of this foundational misconception can be quite disturbing for some people!]

The fact is, that there are an infinite number of primary colors, in that all other colors can be made from an infinite number of sets of three. The only requirement is that the colors comprising a set of three (triad) bear a certain relationship to each other. All color separations are equally valid, provided they are based on a proper triad. A CMY (cyan, magenta, yellow) color separation is just as valid as an RGB (red, green, blue) separation. Some color separations are more useful than others depending on the availability of ink or the desire to assure that the grass is always green on television.

This is where the definitions of hue, saturation, and luminosity become useful. The position of a color in HSL-space is defined in spherical coordinates. Hue is what we ordinarily think of as color. The hue axis is basically that of the rainbow and varies from 0 to 360°. In spherical coordinates hue is analogous to longitude. Saturation is what we ordinarily think of as the purity of a color and varies from 0 to 100%. The saturation axis is analogous to the radius: 0% being the center and 100% being the surface. Luminosity, which is what we ordinarily think of as brilliance, varies from -180° to +180°. The luminosity axis is analogous to latitude.

The color sphere shown in Figure 1 was developed by Philipp Otto Runge (1810). Any simple, non-metallic color can be represented by its HSL coordinate triad. [Note: In computer systems it is common to use a scale of 0255 for hue, saturation, and luminosity.] There is also an equivalent RGB coordinate triad for the same color as well as a CMY coordinate triad. Simple relationships are readily available for converting from one coordinate triad to the other. Most graphics programs provide the common color coordinate transformations internally. The formulae are available from many sources, including Wikipedia (2008).

The essential requirement for a valid color separation triad is that the three primary colors have 100% saturation, 0° luminosity, and be 120° apart in hue. If you choose one color the other two are automatically defined. Color television transmission is based on green so that the grass in a football field always looks good; because it’s generated by the green color “gun,” which never requires hue adjustment. Red and blue naturally follow from the selection of green. Color ink cartridges are based on CMY; because yellow is the most difficult color to produce with blended ink, although some very old or specialized printers use RGB ink. Interestingly, the yellow pigment used in ink cartridges is ferric-based, just like the sensitive papers.

By transforming the color triad from one coordinate system to another, any desired color separation can be easily achieved. This is particularly convenient for 24bit or 3byte color, which is the most common storage format for digitized images. If a custom color separation is performed, based on a triad, one color of which exactly matches the ferric yellow of the unstained sensitive paper, the distinction between stained and unstained areas will be maximal. The ferric yellow has a hue of 56° (RGB: 255, 240, 1). Banana yellow has a hue of 60° (RGB: 255, 255, 0). The other two colors in this sensitive paper-tailored color separation triad are turquoise at 176° (RGB: 1, 255, 240) and lavender at 296° (RGB: 240, 255, 1). Ammonium blue has a hue of 190° (RGB: 1, 210, 255); whereas cyan has a hue of 180° (RGB: 128, 255, 128). The difference in hues between ferric yellow and ammonium blue is then 134°. [Exact color counterparts are 120° apart.]

The effect of this custom color separation can be achieved digitally by several means. Custom software is one method and is the obvious choice considering the subsequent identification and analysis of the polygons. The same effect can be achieved using the photograph manipulation software that comes with most scanners by rotating the hue of the scanned image by +4° and performing a CMY color separation or by rotating it -56° and performing an RGB separation.
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color separation. [Rotation is accomplished using the “hue adjustment” feature.] The advantage of performing this specialized color separation can be seen by comparing the relative contrast available in a gray-scale vs. the three color separations as shown in Figures 3 through 6.

Figure 3. Ferric Yellow Separation

Figure 4. Turquoise Separation

Figure 5. Lavender Separation

For this particular paper the degree of unadjusted contrast between the ferric yellow and turquoise (unstained and stained) images obtained by custom color separation is 1.8 times that of the contrast between white and black (unstained and stained) in the gray-scale image (c.f., Figures 2 and 5). For the papers analyzed this contrast enhancement varied from 1.6 to 2.3 with an average of 1.9. Recognizing and utilizing the fortuitous contrast between the ferric yellow and ammonium blue colors basically doubles the distinction between unstained and stained areas. [The degree of contrast is typically displayed on the luminance histogram and varies from 0 to 100%.

Reduction to Polylines

The next step in the process of digital analysis is reducing the stained areas to closed, continuous polygons (polylines). This is accomplished by the color transformation known as “solarization” followed by taking the negative of solarized image and performing a logical NOT operation on the two images (solarized and non-solarized). The solarization transformation is defined by a threshold value: pixels having a luminosity above the threshold value are changed to black while those below the threshold are changed to white. Either the ferric yellow or turquoise separated images can be used. The turquoise image is preferable, as it always has less noise. Stray marks, fingerprints, and dust on the scanner are much less likely to have a predominantly ammonium blue color component than is an actual stain (c.f., Figures 3 and 5). [There is little useful information in the lavender image; so it is discarded.]

While this process doesn’t necessarily require custom software, it can be very helpful and greatly speed the process. Selection of the threshold value is critical, as exposure varies from one scanned paper to the next. Photographic manipulation software, such as that which typically comes with the scanner, can perform these steps sequentially and the optimum threshold value can be selected by trial-and-error in a multi-step process. Custom software developed by the author allows a technician to quickly select the threshold value with a slider and see the results immediately in enhanced color rather than black-and-white. The unstained areas
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are displayed as pure ferric yellow (below the user-defined threshold luminosity) and the stained areas are displayed as pure ammonium blue (above the threshold) with black borders separating the two (equal to the threshold). The black borders become the polylines. A simple contour collection algorithm is then used to concatenate the contiguous black pixels into digital line segments. A typical processed image is shown in Figure 6 with a close-up in Figure 7.

Dealing with Anomalies

If all of the stains were circular and non-overlapping, the rest of the process would be quite simple: compute the diameters and count the stains. There are, however, several common anomalies which must be addressed, including: irregularly-shaped stains and overlapping stains. These must be considered, regardless of the methodology, whether optical/manual or digital/automated.

Streaked or elongated stains as identified in Figure 7 were investigated experimentally by the Environmental Systems Corporation (Webb and Culver 1979). These experiments indicated that the minor diameter should be used, as the extent of elongation was indicative of impingement rather than size.

Overlapping stains are also identified in Figure 7. These can be handled numerically and can optionally be highlighted for attention by a technician. A non-overlapping, elongated stain (e.g., one shaped like a zucchini squash) will have an area closely equal to that of an ellipse: the product of the major and minor diameters times $\pi/4$; however, an overlapping stain (e.g., one shaped like a peanut or Mickey Mouse ears) will not; because the elongated stain is convex; whereas, the overlapping stain is not. The location of the stains on the paper is not of interest; therefore, the polygons can be sorted and re-displayed in order of increasing size or convexity. Two common types of anomalies are shown in Figures 8 and 9.

Of the 2249 polyline objects shown in Figure 6, only 13 (0.6%) are degenerate. Upon examination these appeared to be scratches, streaks, or hairlines, rather than stains formed by droplets, and were discarded as irrelevant artifacts. These degenerate objects were easily identified; because they have an eccentricity (ratio of the minor to major diameters) much less than 1. [Eccentricity ranges from 0 to 1. Almost all of the objects have an eccentricity significantly greater than 0.1.]

Convexity is the ratio of the polygonal area to the area of the inscribed circle. If the polygon were a circle, the value would be 1. If the polygon were a square, the value would be $4/\pi$. Convexity ranges from 0 to $4/\pi$. Of the 2249 polyline objects shown in Figure...
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- Drift
- Plume Abatement
- Sound
- Flow Measurement
- Heat Rejection Cycle Analysis
6, only 28 (1.2%) exhibit the type of anomalous behavior illustrated in Figures 8 and 9. These all have a convexity less than 0.5. Almost all of the other objects have a convexity significantly greater than 0.5; so these are also easily identified computationally. If the anomalies are sufficiently few, they could simply be discarded.

There are several ways to interpret the anomalies shown in Figures 8 and 9. One possible interpretation is to speculate as to the round stains which might coalesce to form the resultant complex stain, then subdivide the polygon accordingly. This could be done manually or possibly automated, provided some sufficiently accurate algorithm could be developed. For the current analysis this was done manually using a polygon editor developed by the Author.

**Size Distribution**

Once the equivalent stain diameters have been determined, the size distribution is determined by first dividing the range of diameters into equal intervals (or “bins”) based on the logarithm, then counting the number of stains that fall into each interval. More bins result in greater resolution along the log(diameter) axis, but less resolution along the count-per-bin axis, as the total number remains constant. The number of bins is a trade-off, especially when the total number of stains is small. The stain diameter distribution for the paper shown in Figure 6 is given in Figure 10.

Two bin sizes are illustrated in Figure 10: 25 and 50. The actual (times 1) count is shown for the 25 bin curve. The count is doubled (times 2) for the 50 bin curve. The total number of stains is constant; so this makes the two lines have the same order of magnitude. This completes the digital analysis of the sensitive paper.

**Summary**

In summary, a digital method has been presented for analyzing water droplet stains on sensitive paper. This method begins by scanning the paper at a resolution of approximately 4800 dpi. A color separation is then performed in order to maximize the contrast between the paper and the stains. A solarization filter is applied along with a logical pixel operation which eliminates everything but the borders surrounding the stains. The borders are concatenated to form continuous, closed polygons. The eccentricity and convexity of the polygons is used to eliminate extraneous objects and identify anomalies such as incomplete and overlapping stains. The anomalous polygons are corrected or discarded. The equivalent diameters are divided into statistical bins and counted in order to determine the size distribution.

**Conclusions**

The digital method described herein is straight-forward and easily implemented using readily available, inexpensive equipment—at least when compared to the traditional method, which involves a microscope, projector, digitizing tablet, and much tedium. The software that comes with most scanners can be used to accomplish the graphical tasks. Customized software can streamline this process and further reduce time and effort. Anomalous stains are relatively few and must be handled regardless of the method, whether traditional or digital. Digital analysis of droplets on sensitive paper is the logical next step for this measurement technique.

**Recommendations**

The digital method described herein should be implemented and become the standard approach to analyzing sensitive paper data. Tests should be performed comparing this method to the traditional one. This could be accomplished as part of a future data collection effort or be based on a past effort, provided the sensitive papers (or photographs) are available and in good condition. A computational algorithm should be developed to handle the anomalous stains, possibly eliminating this manual step.

**References**


Appendix: Drop vs. Stain Size

As mentioned previously, experiments were performed by Womack, Culver, Webb, and others in order to quantify various aspects of the droplet/sensitive paper interactions. A key relationship is that between initial droplet size and stain size. This is essential in order for the sensitive paper results to be useful. Precision droplet generators were used to create drops which were captured on sensitive papers and the stains measured. Webb and Culver (1979) provided the following figure summarizing these data.

Figure 11. Droplet vs. Stain Size
A Systematic Review of Biocides Used in Cooling Towers for the Prevention and Control of *Legionella* spp. Contamination

Kelly Rangel
University of Texas Health and Science Center

Abstract

Introduction: The use of biocides is very important for controlling *Legionella* contamination in evaporative cooling systems. This study is a systematic review of research studies that evaluated the effectiveness of biocides in evaporative cooling systems for *Legionella* control.

Methods: Published journal articles, dating from 1980-2008, were included if these studies were field test of biocides against *Legionella* in operating cooling systems or tests preformed in a model cooling system that was spiked with *Legionella* spp. or used actual cooling water collected from an operating cooling system.

Results: Of the 52 journals produced from the systematic review, 20 articles meet the inclusion criteria. The types of biocide studies included 9 articles that tested only chemical biocides, 3 articles that tested only non-chemical biocides, and 8 articles that compared chemical and non-chemical biocides.

Discussion: The common endpoint for most of these studies was the measured reduction in the *Legionella* count in the cooling water after the addition of the biocide. There were not many studies conducted on the same kinds of biocides. When the same biocides were tested in more than one study, the results rarely agreed. Also, scientific statistics were rarely applied to the outcomes in many of these studies.

Future Research: Biocides need more field testing in order to generate better scientific evidence as to their effectiveness against *Legionella* spp. in evaporating cooling systems.

Introduction

*Legionella* is a family of bacteria that causes Legionnaires’ disease and Pontiac fever, collectively known as legionellosis. Many outbreaks of legionellosis have been attributed to infected evaporative cooling systems including the first recorded outbreak at the Bellevue-Stratford hotel in Philadelphia, PA in 1979 (Respiratory infection- Pennsylvania.1997). The Center for Disease Control and Prevention estimates 10,000 to more than 100,000 cases occur each year with a case-fatality rate of 8% (Hicks et al., 2007; Sheldon, Kerbel, Witherall, & Millar, 2000). Since the first recorded outbreak of legionellosis, an effort has been made to establish the best maintenance practices in evaporative cooling systems to control *Legionella* contamination and prevent further legionellosis outbreaks. Evaporative cooling systems operate at a pH range of 6.8 to 9.2, a temperature range of 25°C to 45°C which provides optimal growing conditions for *Legionella* species (spp.) (Bartram, Chartier, Lee, Pond, & Surman-Lee, 2007). Biocides are only one small part of controlling the *Legionella* contamination. The objective of this study was to do a systematic review of journal articles that investigated the efficiency of biocides to reduce the *Legionella* population in evaporative cooling systems.

Results

The journal search produced 489 papers. Of these, only 52 were relevant to *Legionella* control in evaporative cooling systems. Applying the inclusion criteria produced 20 papers. The study types of these papers incorporated 16 experimental studies, 3 cross-sectional studies and one cost-effectiveness analysis. The types of biocides studied were as follows: 9 articles that tested only chemical biocides, 3 articles that tested only non-chemical biocides, and 8 articles that compared chemical versus non-chemical biocides.

Table 1 through 3 provide a brief summary of each article by displaying the study design, sample size and description, the location where the study was conducted, the type of biocides studied, and the results of each study.
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Chemical Biocides

Table 1 describes the articles that only studied chemical biocides. The majority of these studies were conducted in the US, 2 were conducted in the UK, one in South Australia, and one in Spain. Three of these studies were conducted in a lab setting. One of these lab studies used *Legionella* species isolated from cooling water and tested 8 different biocides, both alone and in combination (Garcia & Pelaz, 2008). The other two used *Legionella* species from ATCC in water samples collected from cooling towers and tested one biocide each (McCoy, Wireman, & Lashen, 1986; McCoy & Wireman, 1989). The endpoints of these studies were the fastest and most significant bacterial count reduction at different concentrations of biocide and pH. Four of the chemical biocide studies were long term field trials of biocides in cooling towers (Bentham & Broadbent, 1995; Fliermans & Harvey, 1984; Prince et al., 2002). Two of these studies collected water samples before biocide treatment within a 2 week to 5 month period, and then collected water samples after the biocide treatment for an additional 4-5 months. The other two studies randomly selected 14 or 16 cooling towers to treatment or control groups. Both trials lasted for 4 weeks with water samples taken from twice a week to every 2 weeks. The remaining two studies were cross-sectional studies. The first study gathered 2590 water samples from 1000 cooling towers in nine US states and reviewed the prevalence of *Legionella* and high *Legionella* counts in cooling towers utilizing eight different biocides both singly and in combination (Miller & Koebel, 2006). The other cross-sectional study simply reviewed the prevalence of biocide use among refinery and power plant cooling systems (Veil, Rice, & Raivel, 1997).

Non-Chemical Biocides

Table 2 describes the articles that only tested non-chemical biocides. Non-chemical biocide studies were reported in 3 articles. Two of them used an experimental study design and one was a cross-sectional study. Among these studies, one was conducted in the US, one in Finland, and one in South Australia. Two of these articles were long term field trials: one testing the e-disinfector (electrolytic disinfection) and the other testing ultra-violet irradiation (Forstmeier, Wozny, Buss, & Tolle, 2005; Kusnetsov et al., 1994). The UV-lamp field trial lasted for 33 days while the e-disinfector field trial lasted for 7 weeks. In both of these trials, before treatment and after treatment water samples were taken and the *Legionella* counts were compared. The remaining article was a cross-sectional study that collected 13 water samples from a single cooling tower over an unspecified period of months. The goal of this study was to establish correlations between *Legionella* growth and one or more of the following variables: alkalinity, pH and certain dissolved minerals.

Chemical versus Non-Chemical

The last category of articles includes studies that compared chemical biocides to non-chemical biocides in controlling *Legionella* populations (See Table 3). The majority of these studies were conducted in the US, but one was conducted in Finland and another in Japan. Five of these studies were side-by-side field trials comparing conventional chemical treatments to the non-chemical treatments where the cooling towers were randomized to one treatment per tower (Bisbee, 2003; Kitzman, Mazaara, Padgett, Blumenschein, & Smith, 2003; Kusnetsov, Tulkki, Ahonen, & Martikainen, 1997; Pope, Eichler, Coates, Kramer, & Soracco, 1984; Yamamoto, Ezaki, Ikedo, & Yabuuchi, 1991). The study time frames for these field trials ranged from 4 months to 2 years. The water samples were taken from as little as once per month to as much as 5 times per week. Two other studies gave one treatment for a length of time and then began the second treatment for another period of time (Gilpin et al., 1985; McGrane & Ditzler, 1994). Each study time frame for the alternating treatments ranged from 2 hr to 2 months per treatment. Gilpin et al. also conducted a cross-sectional study on one cooling tower where water samples were collected every 2-3 days for 2 months. The goal of this survey was to monitor the *Legionella* population in this cooling tower which was under chemical treatment (Gilpin et al., 1985). The remaining article was a cost-effectiveness analysis for chemical and non-chemical treatments (Envirometrics Staff, 2004). The goal of this article was to identify the most useful and cost-effective biocides used in cooling towers.

General Results

For some biocides, a consensus on their overall effectiveness against *Legionella* and other heterotrophic species simply does not exist. Bromo-chloro-dimethylhydantoin (BCD) was used in three studies, however there is a not consensus among these studies for BCD (Bentham & Broadbent, 1995; Fliermans & Harvey, 1984; McCoy & Wireman, 1989). Two studies reported that BCD is effective and one reported that it is not effective in reducing *Legionella* counts. 2-bromo-2-nitro-propane-1,3-diol (BNPD) was used in three studies (Bentham & Broadbent, 1995; Kusnetsov et al., 1997; Yamamoto et al., 1991). One study reported BNPD to be ineffective, one reported that it is only temporary effective, and a third study reported that it was effective at reducing *Legionella* in cooling water. Chlorine was used in four studies as a comparison group in the form of sodium hypochlorite or calcium hypochlorite although Veil et al. found it to be the most prevalent among biocides used in power plants and refineries (Envirometrics Staff, 2004; Garcia & Pelaz, 2008; Gilpin et al., 1985; McGrane & Ditzler, 1994; Veil et al., 1997). These studies found that chlorine was effective in reducing the *Legionella* count to 1000CFU/mL or less, but it was ineffective in reducing the total bacterial count. Five studies used the non-oxidizing biocide iosthiozolone in which two of these studies claim that it is effective and three which claim that iosthiozolone is ineffective for controlling *Legionella* and THC (Garcia & Pelaz, 2008; Kitzman et al., 2003; McCoy et al., 1986; Prince et al., 2002; Yamamoto et al., 1991). Pulse-power system disinfection and ozone were used in five studies each. PPS and ozone were individually compared to chemical treatments and found to be more effective than the chemical biocides (Bisbee, 2003; Kitzman et al., 2003; McGrane & Ditzler, 1994; Pope et al., 1984). However, the UV irradiation was found to be effective in one study and ineffective in three studies due to the fact that the basin was not subjected to the UV-light and thus was able to harbor the proliferating *Legionella* (Kusnetsov et al., 1994; Yamamoto et al., 1991). Miller et al. reported that all of the cooling towers included in their study harbored *Legionella* regardless of the type of chemical biocides used (Miller & Koebel, 2006). The most consistent feature of all the articles was that they all used the standard *Legionella* culture test.

Discussion

The studies included in this review revealed many different study designs and study lengths. The common endpoint was basically
the reduction of Legionella species and, for some, total heterotrophic species counts (THC) during the time allowed. The study designs varied from laboratory experiments to randomized field trials to cross-sectional studies. For the laboratory studies, the study length ranged from 1hr to 24hrs. Also the number of biocides studied ranged from one, at varying pH levels, to 8, including all combinations of the 8 biocides. The randomized field trials also varied in length, frequency of sampling, and the use of different biocides. The frequency of the sampling has recently been proven to be a critical issue. Bentham and Broadbent in 2000 showed that the sampling of 28 cooling towers twice a week for sixteen weeks yielded means of less than 100 CFU/mL for most of the cooling towers, but the standard deviations were typically three times the means. These results show that the level of Legionella in cooling water is constantly in flux (Bentham, 2000). These data question the accuracy of sampling for Legionella once a week as a measure of the effectiveness of the biocides.

Of the articles included in this study, only a few of them used any actual statistics to report their data and instead reported only observational data. The “before and after” studies could have used a paired t-test to evaluate whether or not the reduction in the Legionella counts was truly significant.

The studies also varied types of biocides used. Very few of the articles incorporated the same biocides and the results often varied greatly. Many variables in the field can affect the efficiency of the various types of biocides. Some of these include: the turbidity of the make-up water, the pH must be in the correct range, the use of other chemicals (i.e. anti-corrosion agents and biodispersants), the total amount of dissolved solids, the amounts of dissolved organic chemicals, and even the season (Prince et al., 2002). Other factors for controlling Legionella growth include removal of organic and inorganic materials and deposits that can harbor Legionella as well as other bacterium and promote their growth (Cooling Technology Institute, 2008). Legionella spp. have the virus-like ability to reproduce inside of protozoa and amoebae (Atlas, 1999; Barbaree, Fields, Feeley, Gorman, & Martin, 1986). So biocides that did not significantly reduce the THC, allow for the rapid re-colonization of Legionella. Most of these studies only focused on the Legionella count but not the THC. Srikanth and Berk have found that some non-oxidizing biocides actually stimulate the growth of amoebae in cooling towers, and amoebae containing Legionella may adapt to these biocides (Atlas, 1999; Srikanth & Berk, 1993; Srikanth & Berk, 1994). Moreover, most of these studies included an initial cleaning phase followed by either continuous or slug doses of biocide without any additional treatments.

**Future Research**

Although Legionella species are ubiquitous in evaporative cooling systems and nearly impossible to eliminate totally, the level of contamination can be controlled to a benign state (Bentham, 2000). Deciding which biocides are well suited to this task is difficult since there is limited field research available. There are many biocides that are commercially available, but few of them have been field tested by unbiased parties or compared to other biocides to assess their efficiency. Some biocides, such as chlorine dioxide, have been found to be effective in potable water systems, but this system has not been fully applied or studied in cooling towers (Envirometrics Staff, 2004). According to Yu, many cooling system guidelines recommend conscientious maintenance to prevent Legionella proliferation, yet there is little data to support “the claim that maintenance minimizes colonization by Legionella and that control measures are useful in preventing outbreaks of Legionnaires’ disease from cooling towers” (Yu, 2008). Clearly, this field of research is still wide open. Science has only begun to understand the best practices for Legionella control and prevention. More scientific evidence is needed to back up claims that one water treatment program is better than another. In the future, well designed scientific studies need to be conducted in order to establish what the best practices for Legionella control truly are.
Table 1: Chemical Biocides, continued

<table>
<thead>
<tr>
<th>Author/ Date</th>
<th>Study Design</th>
<th>Biocides/dosage</th>
<th>Sample Description/Location</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bentham and Broadbent (1995) (Bentham &amp; Broadbent, 1995)</td>
<td>Experimental</td>
<td>CPTE and BNPD at 200ppm, BCD at 350g – slug dose</td>
<td>16 cooling towers in-maintained to ‘s Standard, 15-300kW</td>
<td>1. Mean time to non-detection±SD days 2. Mean time to redetection±SD days CPTE: un-detection:5.4±4.1d, redetection:13.8±13.0d BCD: un-detection:5.5±5.3d, redetection:19.0±11.0d BNPD: <em>Legionella</em> count not reduced</td>
</tr>
<tr>
<td>Garcia &amp; Pelaz (2008) (Garcia &amp; Pelaz, 2008)</td>
<td>Experimental</td>
<td>A. sodium hypochlorite  B. Hydrogen peroxide/silver nitrate  C. Dicyclohexylammonium chloride  D. Benzalkonium chloride  E. Ammonium salts  F. Tributyltetradecylphosphonium chloride  G. DPH 4  H. Heterocyclic ketone chloromethylisothiazole</td>
<td><em>Legionella</em> from cooling towers (6), hotels (2), spa (1), &amp; cruise ship (1) associated w/ outbreaks. Cultures were suspended in hard water and biocides added singly and in combination. Conducted in.</td>
<td>G at 1pm, A at 1pm, H at 4pm, and F at 6pm induced MBE. A and G produced the best FBE. <em>Legionella</em> showed resistance to A, B, D, and F after 7 days. H and B were dose dependent. All of the disinfectants showed a bactericidal effect.</td>
</tr>
<tr>
<td>Flenman and Harvie (1984) (Flenman &amp; Harvie, 1984)</td>
<td>Experimental</td>
<td>No treatment for 4 months BCD0.2-0.5ppm continuous for 4 months Sampling once per month</td>
<td>One cooling tower: cooled 1000gal/min, pH6-7.5, temperature 27.5°C in.</td>
<td>No effect at 0.2-0.5ppm, 1.5-2.1ppm continuous feed did not reduce the <em>Legionella</em> counts either.</td>
</tr>
<tr>
<td>Kurz, J. et al. (1982) (Kutz, Burtlett, Newton, White, &amp; Jones, 1982)</td>
<td>Experimental</td>
<td>1. Quaternary ammonium compound dimethyl-diacetyl ammonium chloride (QAC/TBTO)  2. CPTE  3. sodium di-chloro-isocyanurate (SCL) All biocides to maintain a free chlorine level of 0.5-5.0ppm for at least 4hr.</td>
<td>14 cooling towers randomly selected to one of 3 treatment groups or 2 control groups in.</td>
<td>The doses and frequency used for QAC/TBTO and SCL were ineffective in reducing <em>Legionella</em> counts. CPTE only temporarily reduce the <em>Legionella</em> count below the detectable level.</td>
</tr>
<tr>
<td>McCoy, Wireman, and Lashem (1986) (McCoy et al., 1986)</td>
<td>Experimental</td>
<td>Methylchloro-ethyl/isothiazolone various dosages</td>
<td>Cooling tower water w/ biocide present, pure <em>Legionella</em> cultures. Conducted in.</td>
<td>99% killed 6hr at 1.07ppm and 3hr at 3.13ppm at pH 6 99% killed 6hr at 2.23ppm and 3hr at 9.43ppm at pH 6.7 4x reduction w/ 24hr at 0.35ppm at any pH.</td>
</tr>
</tbody>
</table>

1 Chlorinated phenolic thioether (CPTE), 2-bromo-2-nitro-propane-1,3-diol (BNPD), bromo-chloro-dimethylhydantoin (BCD)
2 Minimal bactericidal effect (MBE): The lowest concentration of the disinfectant able to induce bactericidal effect in all of the strains within 24 hours.
3 Fastest bactericidal effect (FBE): The lowest concentration of the disinfectant able to induce bactericidal effect in all of the strains within 1 hour.
4 2,2-dibromo-3-nitropropionamide (DBNPA), tetra-(hydroxymethyl)phosphonium sulfate (THPS)
5 Free residual chlorine

---

Table 2: Non-chemical biocides Only

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<th>Author/ Date</th>
<th>Study Design</th>
<th>Biocides/dosage</th>
<th>Sample Description/Location</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forsterneier, M. et al. (2005) (Forsterneier et al., 2005)</td>
<td>Experimental</td>
<td>E-disinfect: disinfects by hydroxyl radicals and produces a controlled free chlorine level without the additional of chemicals Fig 762</td>
<td>One cooling tower over 2 months in.</td>
<td>Free chloramine level was maintained at 1.9mg/L so corrosion is reduced at this free chloramine level. TBC were maintained &lt;10 CFU/mL, and <em>Legionella</em> counts were &lt;10 CFU/mL.</td>
</tr>
<tr>
<td>Kuznetsov, J.M. et al. (1994) (Kuznetsov et al., 1994)</td>
<td>Experimental</td>
<td>Ultra violet irradiation 13.8W per lamp (2 lamps total) at 253nm wavelength for 33 days. Sampling occurred before and after the UV lamps.</td>
<td>A cooling system for telecommunication appliances. Conducted in.</td>
<td>Field test of UV-radiator was not as efficient as in lab tests due to the stable concentration in the reservoir water, biofilm and sediment in the basin and the recalcitrant of damaged cells. Also build up of debris to the UV-lamp surfaces.</td>
</tr>
<tr>
<td>States, S. et al. (1987) (States et al., 1987)</td>
<td>Cross-sectional</td>
<td>Alkalinity pH Dissolved minerals (particularly Mn)</td>
<td>13 Water samples collected from a cooling tower basin in.</td>
<td>Alkalinity (P&lt;0.005) and pH (≤ 0.01) were positively correlated with <em>Legionella</em> growth. Mn (P&lt;0.01) was positively correlated with <em>Legionella</em> growth but less than alkalinity and pH.</td>
</tr>
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1 Total bacteria count (TBC)
2 *Legionella* counts <10 CFU/mL are below the detectable amount for the test.
### Table 3: Chemical versus non-chemical biocides

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<th>Author/ Date</th>
<th>Study Design</th>
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<th>Sample Description/ Location</th>
<th>Results</th>
</tr>
</thead>
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<tr>
<td>Bisbee, D (2003)</td>
<td>Experimental</td>
<td>Pulse-powered system (PPS) vs. chemical treatment</td>
<td>Two 239-ton cooling towers one with each biocide for one year in</td>
<td>PPS produced total bacterial levels of 1,000 CFU/mL, reduced water usage by 68% over the chemically treated system.</td>
</tr>
<tr>
<td>Gilpin, RW et al. (1985) (Gilpin et al., 1985)</td>
<td>Experimental</td>
<td>Calcium hypochlorite Ultraviolet light Dodecyldimethylamine hypochloride and calcium hypochlorite treatments used the surveyed cooling tower. Added on different days weekly</td>
<td>Evaporative condenser: First treated with chlorine for 10 weeks then treated with UV-light for 5 weeks with water samples taken 5 times per week. Cooling tower survey: sampled at 2-3 day intervals for 2 months. In.</td>
<td>Evaporative Condenser: Before UV = 1.1 x 10^6 CFU/mL, Legionella After UV = 0.2 x 10^6 CFU/mL, Legionella Reduction F = 0.001 Cooling Tower survey (n=27) count ± SD TBC from pool water = 3.0 x 10^6 ± 2.5 x 10^6 CFU/mL TBC form flat surface = 5.7 x 10^6 ± 5.5 x 10^6 CFU/mL Legionella count = 5.9 ± 6.8 CFU/mL</td>
</tr>
<tr>
<td>Kitzman, KA et al. (2003) (Kitzman et al., 2003)</td>
<td>Experimental</td>
<td>Chemical treatment (CT): alternating ethionylzole and glutaraldehyde Pulse power system (PPS) Hydrodynamic Cavitation (HDC)</td>
<td>3 side-by-side but independent cooling towers in, one tower per treatment for 6 months.</td>
<td>Mann Flankonic bacterial count: (max level &lt;1 x 10^5) CT = 1.7 x 10^6 CFU/mL PPS = 6.5 x 10^5 CFU/mL HDC = 9.5 x 10^5 CFU/mL Mann Susiptal bacterial count: (max level &lt; 2 x 10^6 CFU/cm^2) CT = 2.5 x 10^6 CFU/cm^2 PPS = 5.9 x 10^6 CFU/cm^2 HDC = 1.9 x 10^6 CFU/cm^2</td>
</tr>
<tr>
<td>Kusnetsov, JM et al. (1997) (Kusnetsov et al., 1997)</td>
<td>Experimental</td>
<td>Lower Temperature (~20°C) Improved Water Quality using tap water PHMB at 45mg/L BNPD at 65-190mg/L</td>
<td>5 cooling systems: A and B lowered temperature, C with improved water quality, D with PHMB and E with BNPD. Conducted in for 2 years.</td>
<td>Lowering of the water temperature did decrease the Legionella counts below 1,000 CFU/L, but not TBC. Changing to tap water was only temporarily effective in reducing the Legionella count. Both BNPD and PHMB lowered both the Legionella and the TBC for only 2 weeks.</td>
</tr>
<tr>
<td>McGreane, WK et al. (1994) (McGreane &amp; Ditzler, 1994)</td>
<td>Experimental</td>
<td>Sodium Hypochlorite: 1.0 ppm free chlorine for 2hr. Ozone: 0.1ppm for 2hr. Samples taken at 0, 1, and 2hrs.</td>
<td>Model cooling tower with the known bacterial and amoeba asp. added to the model system including Legionella pneumophilia sp. 1. In.</td>
<td>TBC: Chlorine = from 4.65 x 10^5 CFU/mL at 0hr to 3.4 x 10^5 CFU/mL at 2hr Ozone = from 1.3 x 10^6 CFU/mL at 0hr to 6 x 10^5 at 2hr. Legionella: Chlorine = from 5.6 x 10^5 CFU/mL at 0hr to 2.6 x 10^5 CFU/mL at 2hr Ozone = from 2.9 x 10^6 CFU/mL at 0hr to 0 CFU/mL at 1 and 2hr.</td>
</tr>
<tr>
<td>Pope, DH et al. (1984) (Pope et al., 1984)</td>
<td>Experimental</td>
<td>Ozone (0.333 Bq/day, conc. 0.6-1.8 mg/L) Chemical treatment = 1.38 ppm once / week of disodiumnvanadithionico carbonate and potassium N-methyl dithiocarbamate.</td>
<td>2 cooling towers in NY. Tower A was the control (chemical treatment), and Tower B treated with ozone. Treatments were reversed after 2 months.</td>
<td>TBC&lt;sup&gt;2&lt;/sup&gt; Means: 1.7 x 10^5 cells/mL control and 4.4 x 10^5 cells/mL for the ozone tower, P = 0.0001. Legionella Mean counts: P &lt; 0.001 reduction, 63% fewer in the ozone tower than the control tower.</td>
</tr>
<tr>
<td>Yamamoto, H. et al. (Yamamoto et al., 1991)</td>
<td>Experimental</td>
<td>1. Initially cleaned w/ 3% hydrogen peroxide only, no additional biocides added 2. glutaraldehyde added once at 0.1% 3. continuous bronopol (BNPD) 4. continuous ethionylzole 5. UV lamp 110W w/ flow rate of 2.5 m^3/h 6. UV lamp 60W w/ flow rate of 4 m^3/h 7. UV lamp 40W w/ flow rate of 1.5 m^3/h</td>
<td>7 cooling towers (CT) &lt; 100 capacit y ion with initial Legionella counts of 10^5-10^6 CFU/mL in 1 treatment per tower for 3-4 months.</td>
<td>CT 1: In 2 weeks, THC&lt;sup&gt;2&lt;/sup&gt; increase from 10^4 to 10^5 CFU/mL &amp; Legionella count 10^4 CFU/mL CT 2: THC &amp; Legionella levels decreased when added but increase to initial level after 2 weeks. CT 3 &amp; 4: THC results were similar to control (1) but Legionella growth was suppressed during 4 month study. CT 5, 6, &amp; 7: THC decreased from 1/10 to 1/100 of control (1) but Legionella counts reached 10^5 CFU/mL in 5 weeks. UV-sterilization did not include the basin area which allowed Legionella growth in the basin.</td>
</tr>
</tbody>
</table>

1 Polyhexmethylene-biguanidechloride (PHMB)
2 Total Bacterial Count (TBC)
3 Total Heterotrophic bacterial Count (THC)
References


The best sheaves for the worst environments!

Ideally suited for the most aggressive atmospheres, unusual conditions, such as weight requirements and installation problems, Bailisco lightweight all-aluminum cast V-belt sheaves have been in the field for over 15 years. Full range of sizes available up to 38" diameter, larger sizes available upon request. Special designs to meet OEM requirements. Design, molding, casting, machining, heat treating and balancing are all done "in-house".

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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 insure 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>Address</th>
<th>Contact Person</th>
<th>Telephone</th>
<th>Fax</th>
</tr>
</thead>
<tbody>
<tr>
<td>A,B</td>
<td>Clean Air Engineering</td>
<td>7936 Conner Rd, Powell, TN 37849</td>
<td>Kenneth Hennon</td>
<td>800.208.6162</td>
<td>865.938.7569</td>
</tr>
<tr>
<td>A,B</td>
<td>Cooling Tower Technologies Pty Ltd</td>
<td>PO Box N157, Bexley North, NSW 2207, AUSTRALIA</td>
<td>Ronald Rayner</td>
<td>612 9789 5900</td>
<td>612 9789 5922</td>
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<tr>
<td>A,B</td>
<td>Cooling Tower Test Associates, Inc.</td>
<td>15325 Melrose Dr, Stanley, KS 66221-9720</td>
<td>Thomas E. Weast</td>
<td>913.681.0027</td>
<td>913.681.0039</td>
</tr>
<tr>
<td>A,B</td>
<td>McHale &amp; Associates, Inc</td>
<td>6430 Baum Drive, Knoxville, TN 37919</td>
<td>Thomas Wheelock</td>
<td>865.588.2654</td>
<td>425.557.8377</td>
</tr>
</tbody>
</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

<table>
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<th>Agency Name</th>
<th>Address</th>
<th>Contact Person</th>
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<tr>
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<td>McHale &amp; Associates, Inc</td>
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<td>Thomas Wheelock</td>
<td>865.588.2654</td>
<td>425.557.8377</td>
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</tbody>
</table>
As stated in its opening paragraph, CTI Standard 201... “sets forth a program whereby the Cooling Technology Institute will certify that all models of a line of water cooling towers offered for sale by a specific Manufacturer will perform thermally in accordance with the Manufacturer’s published ratings...” By the purchase of a “certified” model, the User has assurance that 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 with entering wet bulb temperatures between 12.8°C and 32.2°C (55°F to 90°F), a maximum process fluid temperature of 51.7°C (125°F), a cooling 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 or publish less restrictive limits if the CTI limits are clearly defined and noted in the publication.

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.; Aggreko Cooling Tower Services; Amcot Cooling Tower Corporation; AONE E&C Corporation Ltd; Baltimore Aircoil Company, Inc.; Delta Cooling Towers, Inc.; Evapco, Inc.; Fabrica Mexicana De Torres, S.A.; HVAC/R International, Inc.; KIMCO (Kyung In Machinery Company, Ltd.); King Sun Industry Company, Ltd.; Liang Chi Industry Company, Ltd.; Mesan Cooling Tower, Ltd.; Nihon Spindle Manufacturing Company, Ltd.; Polacel b.v.; Protec Cooling Towers; RSD Cooling Towers; Ryowo (Holding) Company, Ltd.; SPX Cooling Technologies; Ta Shin F.R.P. Company, Ltd.; The Cooling Tower Company, L.C.; The Trane Company; Tower Tech, Inc; Waltco Systems Limited; and Zhejiang Jinling Refrigeration Engineering Company who are committed to the manufacture and installation of full-performance towers. In competition with each other, these manufacturers benefit from knowing that they each achieve their published performance capability. They are, therefore, free to 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.

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