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For Immediate Release
Contact: Chairman, CTI Multi-Agency Testing Committee
Houston, Texas, 3-May-2012
The Cooling Technology Institute announces its annual invitation for interested drift testing agencies to apply for potential Licensing as CTI Drift Testing Agencies. CTI provides an independent third party drift testing program to service the industry. Interested agencies are required to declare their interest by July 1, 2012, at the CTI address listed.

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As the year of 2011 comes to a close and we reflect on the uncertain economic times that both Europe and North America has been experiencing since 2007 and the resulting employment reductions and the budget cutbacks by companies that have limited non essential business travel, the CTI Organization can be thankful that it has weathered the storm well. The interest in cooling technology, both wet and dry cooling towers, continues to increase both in developed countries but also in areas of recent industrial expansion such as Eastern Europe, China and India.

CTI’s dedication to providing and maintaining high quality CTI Codes, Standards and Engineering Guidelines is well recognized as providing the technical standards that has been established for our evaporative cooling industry worldwide and the demand and interest for CTI publications, test procedures and obtaining the CTI Thermal Certification Approval and now the opportunity to certify components is in great demand.

Even in this weak and uncertain economy our membership has increased, both with new owner/operator membership and with particular growth on the International sector of manufacturers and suppliers.

The CTI Board of Directors has recognized this worldwide demand and initiated organizational changes that will allow CTI to better serve our many members and our industry. CTI is in the process of interviewing and hiring technical staff to manage the very successful existing thermal certification program and the new component certification program that has created considerable interest from suppliers to the industry. CTI looks forward to being able to provide these services to our members and subscribers worldwide.

In addition to adding technical staff to the organization, the CTI Board of Directors, with the assistance of the Past Presidents Council, is evaluating modification and expansion to the CTI governing committee organization to provide better efficiency in task completion and to provide continuity in management structure to a primarily all volunteer technical society. A number of excellent suggestions have been proposed and a well thought out re-organization plan will be devised over the next few months and presented to the Board for evaluation and approval.

CTI is expecting an excellent turnout for our Winter Annual Conference that will be held this year at the Greens Point Hilton Hotel in Houston, Texas on February, 5th through the 9th. A broad spectrum of papers will be presented as well as informative Education and Owner/Operator Seminars and Expert Panel Discussions that cover current events that affect owning and operating cooling towers. The programs that will be presented are detailed in your 2012 Annual Conference Newsletter or can be downloaded from the CTI website.

On Tuesday afternoon and evening, CTI members and suppliers will exhibit their products at the very popular “Table Top Displays” where you will be able to meet manufacturers and suppliers and discuss your questions and applications with factory representatives directly.

The amount of presentations and informative seminars that are scheduled in the 3 day period can be a bit overwhelming to a first time attendee. If you are a new or previous attendee wishing to become quickly oriented with the various programs and learning opportunities offered by CTI at the meeting, please do not hesitate to contact one of the “New Attendee Ambassadors” that will identified by their colored badges. These members are there to assist you in identifying and attending the programs of your interest.

The CTI Board of Directors consists of nine members with each member elected for a 3 year term. Each year, three board members retire and three new members are nominated to the board and will be voted on by CTI membership. The three members that are retiring from board membership, at the end of the 2009 – 2011 period, are Jon Bickford of Alliant Energy, Helen Cerra of ChemTreat, Inc and Tim Facius of BAC.

For the past three years, this board has been very active in determining the proper business direction that CTI should take to further its growth, financial stability and worldwide recognition. All three of these retiring members have been very active in board activities. Helen has served as Secretary for the past 2 years, Tim has served as Treasurer for the past 2 years and Jon has been very active in managing the Ad Hoc Procedures for codes and standards as they are brought to the board for final approval.

It has been my sincere pleasure to work with these three board members for the past 3 years. They are a true example of the quality of members that donate their time and effort for the benefit of CTI.

The three new members that have been nominated for board membership are as follows; Raul Castillo of Dow Chemical, Dean Lammering of Nalco and Tom Toth of Midwest Towers. All three of these gentlemen will make excellent CTI board members and will take an active role in governing CTI. A membership vote on these nominees is sent in December before the winter, 2012 BOD meeting.

In February of 2012, my term as President of CTI will come to end. Being president of CTI has been a very rewarding and inspiring experience. CTI is so very fortunate to have an excellent staff running the day to day operation and a large group of very experienced and dedicated volunteer members that so freely give of their time and knowledge to manage and participate on the various committees that prepare our codes and standards as well as perform and guide our expanding business functions. The members of the CTI Board of Directors that so thoroughly study the issues presented to them and offer excellent suggestions to improve the operation of CTI and the business plans submitted to them. It is truly amazing to see what such a diverse membership of owners/ operators, competitive manufacturers and suppliers can accomplish when members put their personal and company agendas aside and work for the improvement of the industry CTI serves. This speaks highly of the quality of membership we have attending CTI and the companies that they represent.

I wish to recognize all CTI membership and staff that have so faithfully supported and guided me in this position for the past 2 years. Thank you!

Respectfully submitted,

Jess Seawell PE
CTI President
2010/2011
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Jess Seawell will retire as CTI President, having stimulated a great deal of forward momentum within the CTI organization. Many thanks to Jess for all the time and energy he has invested in CTI.

We welcome Jack Bland as incoming President for a two year term. Jack has been CTI President before, and I was fortunate to serve as Vice-President at that same time - learning the ropes in CTI through Jack’s leadership.

Jack comes in as President in a year when CTI will hire a paid Certification Administrator to work with Tom Weast to bring management of Certification in-house. Secondly, after about a ten year delay, a new program is finally going to start under STD-202 to publish the results of acceptance testing by name for manufacturers of field erected cooling towers. Additionally, CTI will begin to conduct certification testing for a new set of manufacturers under the Eurovent Certification Company program.

Lastly, CTI also plans to start up a new program for certification of components and materials according to CTI Standards.

We appreciate that Tom Weast will continue in a mentoring role with the incoming Certification Administrator, to provide his guidance for a smooth transition between now and when he decides to retire as the CA. CTI and the program participants are grateful to the companies that contributed funding to enable operation with dual CA’s while we transition. To better accommodate the growth, both domestic and international, in the Thermal Certification Program, we are going to separate the CA and Certification testing roles. This will be a challenging process that will require time and patience to properly engage.

A manufacturer has been the sole participant in the STD-202 program since 2001. The program was placed on hold by the CTI Board due to having only one participant. As the ongoing Chair of the STD-202 task group since it started in the late 1990’s, it is a particularly welcome experience to see this program to evolve and finally start, and to welcome an additional manufacturer as a new participant. The aggregated results of thermal acceptance tests for the two participants will begin to be posted on the CTI website and in the Journal at the end of 2012. Additional participants are anticipated.

The Eurovent Certification Company (ECC) has completed its first year of operating its cooling tower thermal certification program in cooperation with CTI. The program has made great progress with more to come in 2012. The broadening of the number of CTI Certification testers is expected to aid in covering European tests, as well as testing for the rapidly growing number of CTI participants and product lines in Asia. ECC has successfully added the auditing of data of record on certified products in their program to the thermal certification process provided by CTI. The audits are conducted in the factory or the field.

As CTI works to develop the Component and Materials Certification program documents in 2012, the significance of this emerging discipline in the industry should add significant value.

There will undoubtedly be growing pains with the new activities, but that often goes along with change. Most certainly, our patience and energy levels will be tested as we pursue these new programs.

So, join me in welcoming Jack Bland and contributing to the nurture of these new programs for the betterment of the cooling technology industry. Respectfully,

Paul Lindahl
CTI Journal Editor
The industry's most complete line of quality cooling tower products... for the smallest HVAC towers to the largest natural draft towers... leading the way with enviro-friendly innovations like non-glue Mechanical Assembly and anti-microbial AccuShield Products.
INTRODUCTION

The water used in industrial cooling towers comes from many sources: rivers, canals, reservoirs, wells, lakes, ocean, … even sewage treatment plants. Typically the water used is seldom clean containing in varied amounts: dissolved salts, suspended solids and biological activity. During the heat exchange in the cooling tower, these constituents of the circulating water may deposit in the fill and cause fouling and/or scaling.

These deposits may not only affect the thermal performance of the cooling tower (blockage of the film fill) but also the stability and the structural integrity of the fill and its support structure. (Overloading of the fill can cause fill and beams collapse).

Fouling resistance should be taken into consideration in the selection of the fill. With the same water quality, some fills may collapse from fouling within a few months while other fills will not be affected. Generally, the most thermally efficient fills are also the most sensitive to fouling.

A water treatment program may produce water to accommodate a given fill design. Sometimes, it is economical to use a low fouling fill design that accepts a poor water quality (with light water treatment) than a thermally efficient fill needing a strong water treatment.

DEFINITIONS AND ORIGINS

Fouling

The fouling combines suspended solid concentration and quality (type and size of particles) with a biological activity. The bio film and bacteria that develop on the fill surface retain the suspended solid as a nutrient and generate a mud-like by-product which accumulates on any part of the fill surface and may block the film fill flutes.

The fouling is difficult to predict. Some fouling may occur with water having “large” biological activity and almost no suspended solids or a water having “low” biological activity and higher suspended solids.

Type and size of particles also influence the fouling. As an example, clay in water will produce more fouling than sand in water. Small particles also increase the fouling.
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The fouling increases with the fill height. The top 10 to 20 cm generally remains clean. This is due to the water distribution droplets impacting the sheets continuously and “washing” the fill.

The bottom edge is also generally clean. It is likely due to turbulence of the air entering the fill, unsettling the attachment of fouling in this bottom part of fill.

The fouling/scaling concentrates between top and bottom of the entire fill depth. Often we observe large fouling at the interface between the fill layers.

It is almost impossible to visualize fill fouling without dismantling the packing’s of the fill. Many users detected fouling of the fill by observing the crushing of the fill on the supporting beams (collapse of the fill on beams by excessive fill load). When this occurs it is unfortunately, too late to take any preventative action.

Evaluating the thermal effect by visual inspection is also difficult as it needs accurate thermal measurements to quantify the loss of thermal performance.

Scaling

Scaling is the chemical process of salt crystallisation due to the salt concentration reaching a saturation point in the water. It depends on many parameters like initial salt concentration, pH, temperature, CO₂ content, etc.

Scaling is generally related to the calcium carbonate level in the circulating water, typically relatively easy to control through a water treatment program. In Sea water cooling towers high calcium sulphate levels can result in scaling.

The knowledge of the chemical parameters allows controlling of the scaling. Adequate water treatment, mainly acid injection (Sulphuric acid or hydrochloric acid in case of sea water), allows the complete elimination of the calcium carbonate scaling.

The blow down is one of the key points of the scaling as it governs the cycles of concentration. “Cycling down” the concentration is the only way to avoid the calcium sulphate scaling. The acid injection flow is generally directly related to the blow-down flow.

An open circuit cooling tower (cycles of concentration = 1) generally doesn’t use any acid injection.

Water treatment companies also propose dispersants in the water for maintaining the scaling crystal in suspension in the water. It makes suspended solids easier to remove from the circuit with the blow down, but also increases the fouling risk.

For some cooling towers, severe limitation are imposed to the make up flow that balances the evaporation and the blow down, (regulation from authority; availability of water; tax on water rejection flow, etc) When applied, it means that the blow down will be reduced compared to the ideal value; the cycles of concentration will increase, making the fill more susceptible to scale.

Adequate water treatment must be strictly followed to avoid scaling deposits in such cases.

In addition, if the local authority regulation on water quality rejection (concentration of SO₄ for example) restricts the use of acid, the scaling cannot be avoided.

In such cases, one should initially select a low scaling fill media or replace a heavily scaled fill prior to a collapse.

The scaling also depends on the fill design. Local crystallisation may occur on some fill sheet corrugation as example due to local variation in the thickness and temperature of the water film. Some fills are designed to be less sensitive to scaling. They are generally the same as those less sensitive to the fouling.

The scaling also depends on the cooling tower design, operation and maintenance. With a given fill, high specific water flow is better than low specific water flow as the water film thickness and velocity will be higher. The local heat exchange is lower the evaporation is lower, the concentration limit moves away.

The scaling develops faster at the limit between water film and dry areas. The film of water is very thin; the evaporation is very strong, crystallisation occurs quickly. Such areas exist in cooling tower when uniform water distribution is disrupted. This could be a result of sprayers in a given area are blocked or dislodged. It also may occur at the border of a central shut off (when used for de-icing purpose) when the partition wall is missing.

The scaling develops faster at the bottom of the fill than on the top. The scaling increases from top to bottom of the fill due to the temperature decrease and the CO₂ injection. Generally scaling cannot be detected from either the top or the bottom. When scale stalactites can be observed at the bottom of the fill, it is too late.

In many cases, both fouling and scaling simultaneously occur in the fill.

FILLS DESIGN

Film type fill

On such fills, the heat exchange between water and air is achieved along the surface of water film flowing on the fill surface.

The film fills existing on the market can be classified according to the type of the flutes and the quality of the surface.
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The flutes can be sloped or vertical, with uniform or offset section. The surface can be smooth, slightly or deeply corrugated, or have a light or dense perforation. Many combinations can be used.

The following table gives the resistance to fouling/scaling according the cores and the surface type, from “Very bad”; “Bad”; “Moderate”; Good”; “Very good”.

<table>
<thead>
<tr>
<th>Flutes</th>
<th>Fouling/Scaling resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sloped</td>
<td>Very Poor</td>
</tr>
<tr>
<td>Offset</td>
<td>Poor</td>
</tr>
<tr>
<td>Vertical</td>
<td>Good</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface</th>
<th>Fouling/Scaling resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth</td>
<td>Very good for fouling; Good for scaling</td>
</tr>
<tr>
<td>Light corrugation</td>
<td>Moderate to Good</td>
</tr>
<tr>
<td>Deep corrugation</td>
<td>Poor to Moderate</td>
</tr>
<tr>
<td>Perforation</td>
<td>Good for fouling; Very good for scaling</td>
</tr>
</tbody>
</table>

The effects of flutes and surface are cumulative. For instance, the weakest fouling resistant fill will have sloped flutes with deep corrugations; the best one will have vertical flutes with smooth surface. A fill with light corrugation will have better fouling resistance than the same fill with deep corrugation.

The main problem comes from the fact that, generally, the best thermally efficient fills – those giving the smallest size and cheapest cooling tower – are the most sensitive to fouling-scaling. Cooling towers with low fouling fill are generally more expensive than with fills achieving high thermal efficiency.

The name “low fouling fill” doesn’t have the same meaning from one manufacturer to another. A given fill is considered “low fouling” by one manufacturer while “high fouling” by another one. For the same fill design, the fouling scaling resistance varies directly with the sheet pitch. Large pitch corresponds to low fouling-scaling characteristics, but also with poor thermal performance. The figures give example of several fill design.

**Mesh type fills**
The mesh type fills generally consist of vertical injected grids or extruded mesh tubes or thermoformed sheets with high perforation ratio (more than 40%) assembled together.

The heat exchange is mainly achieved at the surface of the film of water flowing along the laths. Some splashing may occur. It is however limited as the course of falling droplets is always short before hitting a lath.

Some manufacturers qualify such type of fill as “splash”. This is incorrect as most of the heat exchange is achieved at surface of the film.
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For these types of fills, the qualification of “mesh” is better appropriate, as they are neither film, neither splash.

The fouling and scaling resistance of these fills can be qualified as “Moderate to Good” depending mainly of the core size and design (tubes better than triangles). If the water contains fibers, they can be qualified “Poor” for fouling as these fibers easily deposit on the laths.

With large core design, it may be qualified “Very Good”. In such case, the thermal efficiency is poor.

The figures give examples of several mesh type designs.

**Splash type fills**

On splash type fills, the air/water heat exchange is mainly achieved at the surface of the droplets.

The splashing fills always imply relatively large vertical distance between the elements to allow droplets to fall down and break in smaller droplets.

The splashing fills can be classified in two categories: grids or laths. The splashing surface may be flat or curved; horizontal or slopped; solid or perforated.

All splashing fills can be qualified “very good” for fouling and scaling resistance.

Narrow laths are better than wide (even perforated) laths. The figures give some examples of splashing fills.

**No fills type**

Some processes imply severe scaling during the cooling. Typical examples are the towers cooling the electrolyte in the Zinc plants (electrolyte contains Calcium sulfate easily precipitating in Gypsum formation) or a zero discharge cooling tower.

For such processes, the cooling tower must be designed without any fill. The heat exchange is done between the air and small water droplets generated by high pressure sprayers. Even with no fill, these cooling towers must be regularly cleaned and the scale formed on the sprayers, the walls and the drift eliminators must be removed to avoid complete blockage.

**FOULING TEST RESULTS**

The fouling/scaling can be defined by the fill weight increase as a function of time. The best way is to measure the weight “on line” with the cooling tower in operation. The starting weight corresponds to the dead weight of the fill + the water weight. Any additional weight corresponds to fouling or/and scaling. This method has the advantage to allow a direct follow up of the fouling/scaling without handling the fill modules.

Several users remove specific pieces of packing from the cooling tower at regular intervals and measure the weight of each sample. This method has the advantage to observe the fouling/scaling development in each packing and particularly the differences between the top and bottom layers. The handling of the samples must be done carefully in order to avoid loss of fouling matter and damaging the packing.

All such methods are only qualitative and site-dependent. The results show that one fill is better than another one in a specific cooling tower using given water quality and treatment.

Nevertheless, even if the absolute value of the weight increase of a given fill is strongly site-dependent, we observe that the classification of different fills versus the weight increase, generally gives the same results in different cooling towers. The best fill in one cooling tower remains the best in another cooling tower.
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The graphs hereunder give the weight increase versus time in several cooling towers.

A way to qualify the fouling is to calculate the fouling rate coefficient of a given fill. It is the slope of the best fit line of the weight increase-vs time. The fouling rate units typically appear as: “kg/m³/day”

An intensive qualification test was done in a cooling tower operated in an open circuit to a river (large biological activity and variable suspended solid) without water treatment. This cooling tower was located in a very dusty environment. In several locations of the cooling tower, the existing grid fill was replaced with film fills of several types, each contained in a basket. The weight increase was measured on line once a week.

The fouling rate coefficients measured in these conditions vary in a ratio of 1 to about 50.

This allows for a classification of the fills and gives an idea of the improvement obtained when replacing one fill by another one.

**FOULING/SCALING CONTROL**

The fouling/scaling can be controlled with water treatment adapted to water quality and cycles of concentration.

<table>
<thead>
<tr>
<th>Langelier index</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.5</td>
</tr>
<tr>
<td>Aggressive water</td>
</tr>
<tr>
<td>Corrosion inhibitors recommended</td>
</tr>
</tbody>
</table>

As the fouling depends on both suspended solid and biological activity, both parameters may be controlled on different levels. For instance, a good sand filtration removes almost all the suspended solid. In such a case, the chlorination necessary to control the biological activity can be reduced. If the water supply is not filtered, a strong control of the biocide must be used.

For scaling by calcium carbonate, the measurement of the chemical properties of the water and the calculation of the precipitation indexes (Langelier or Ryznar) allows controlling the scaling by any method recommended by water treatment companies (acid injection, scaling inhibitors, decarbonatation etc).

For scaling by calcium sulfate, the best way is to maintain the concentration below the precipitation limit by adjusting the cycles of concentration (sufficient blow down flow)

In many cases, the make up water quality and the cooling tower operation parameters change over the year. The adjustment of the water quality to avoid fouling and scaling becomes more delicate. Putting too much additives in the water – “to be sure” – may be expensive and detrimental to the environment.
For a continuous adjustment to the water quality and to the cooling tower operation, some customers use weighing facilities in there cooling tower. Some samples of the fill equipping the tower are installed in baskets and left in their initial place in the tower. The weight of those baskets is monitored. An increasing weight clearly shows that fouling and/or scaling occur and water treatment has to be adjusted.

The following graph was obtained from such weighing facilities installed in two cooling towers using the same fill and similar water. Chlorination were made in the first tower, not in the second one. The good maintenance of the cooling tower is also an important issue to avoid the fouling or scaling. The best water treatment program is completely useless if some areas of the cooling tower are dry, for instance because of blocked nozzles: scaling will occur at the limit between dry and wet areas.

**Conclusion**

The fouling and the scaling of the fill in a cooling tower may have severe consequences, not only on the thermal performance of the cooling tower but also on its structural integrity due to fill overloading.

The design of the fill determines the thermal performance as well as the fouling/scaling resistance. Sloped flutes with corrugations film fill are the worst for fouling/scaling resistance, while smooth surface with or without holes and vertical core of film fill are favourable. The mesh type fill are often proposed as a good compromise, but can be ineffective than some film fills type. The splash type fill are the most adapted fill in case of high fouling/scaling risk.

The correct selection of the fill must consider both the water quality as well as the water treatment program. This allows optimising the overall cost of the cooling tower, including investment, operation and water treatment.

The installation and monitoring of weighting facilities allows controlling the fouling/scaling of the cooling tower.
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The Economic and Environmental Impact of Cooling Towers

Today’s society requires that we evaluate our impact on the economy and the environment in several different ways. In our attempt to define reductions in environmental impact we use such terms as “Green” or “Sustainable”. One of the problems we face is that of applying a clear definition to either of these terms. For some “Green” is a social movement that attempts to influence public policy to focus on the conservation of the ecosystem through sustainable resource management. Many environmental organizations focus on recycling, reducing or reusing materials or natural resources. For many sustainability has economic connotations that means long term financial benefits.

In the past we have focused our attention on the economic differences between air cooled and water cooled cooling systems. We have used this as the basis for determining or inferring the environmental benefits of water based cooling systems. Is that the correct approach?

In 2010, Hamilton, Bugler and Lane forwarded a unique approach to environmental impact based on a critical natural resource (CNR) approach. This approach established a metric for the comparison of two CNR’s; energy and water consumption. The paper, presented at the CTI conference in 2010, certainly does a credible job of establishing a link between measuring the impact of these two resources when making choices regarding dry versus water cooled HVAC systems.

Today we are seeing an ever increasing emphasis placed on the environmental impact of processes and technologies based on the emission of green house gases (GHG). In this paper we will take the evaluation of dry and water based cooling processes one step further and view the impact of both cooling system types as they relate to GHG emissions. In addition, we will review other environmental aspects of water cooled systems.

Let’s begin with a review of the energy requirements of both systems types, for simplicity we will focus on dry and evaporative cooling systems.

System evaluated - 400 tons of cooling operating at 20% capacity (Based on assumptions used by M.D. Pugh for CTI presentation).²

Dry cooling: requires about 1.071 million KWH annually to operate the system at the tonnage and capacity stated above.

Water Cooled: requires about 678 thousand KWH annually to meet the same cooling capacities.

According to the DOE each KWH produced generates about 1.34 pounds of green house gases.³ Taking this into account based on a 20% load factor, the air cooled system using 1.071 million KWH annually will be responsible for the release of 1.435 million pounds of greenhouse gases. By contrast the water cooled system will be responsible for the release of roughly 909 thousand pounds of GHG. The result is that the operation of the air cooled system will result in the release of an additional 526 thousand pounds of GHG emissions.

Now to stop the comparison at this point would be inappropriate since we have other factors to be considered. The dry cooling system requires minimal water for its operation while the water cooled system requires about 1.7 million gallons. The water usage for dry cooling is limited to water used for normal cleaning.

There are embedded costs, in the form of energy required to deliver water to the cooling tower. There are several aspects of energy consumption relating to supplying water to the end user. These include supply and conveyance, treatment, distribution, waste water collection and treatment and waste water discharge. The energy consumption to meet these various factors is suggested to be as high as 19% of the total electric power output of the country.⁴ However, when adjusted for residential water heating the number appears to be about 5%.⁵

As should be expected the KWH’s required to meet the needs of the distribution and treatment process varies based on the location of the water and the population concentrations served by the public utilities and companies servicing these areas. The energy cost to distribute water to the end user varies from a low of about 1.9 KWH per 1000 gallons to as high as 23.7 KWH per 1000 gallons.⁶ Energy...
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consumption in Arizona appears to approach a national average at about 4.8 KWH per 1000 gallons used. Of this total, about 25% is allocated to waste water treatment and collection. Seventy-five percent of the energy is required for the distribution portion, or 3.6 KWH/1000gal. The remaining 1.2 KWH is applied to waste water collection and treatment.

This now means that we require a total of 6,221 KWH to bring the water to the cooling tower. Of the 1.728 million gallons, required for our 400 ton tower model, the majority is evaporated. The evaporated portion should not be subjected to the additional energy cost for waste water collection and treatment. The calculated discharge for this model is about 473 thousand gallons. This portion of the water used by the tower would then consume an additional 568 KWH. The combined delivery and treatment energy charge is then 6789 KWH.

Since this additional energy usage carries with it a resulting GHG factor, we need to add 9097 pounds of GHG emissions to our total for the water cooled system. At this point the total GHG emissions for the water cooled system is 918 thousand pounds.

As we view the impact of the water cooled system for GHG emissions we have one other factor to consider. The dry system requires minimal chemical treatments, limited to those used in the cleaning process, while the water cooled system would require about 8600 lbs (water included) for its normal treatment process. According to Dow, the energy cost to produce one pound of chemical is about 1.486 KWH, this equates to 2 pounds of GHG emissions. Transportation adds another 1.45 pounds so we arrive at 3.45 pounds of GHG emissions per pound of chemical used. Based on the estimate above we add an additional 29,670 pounds of GHG emissions to the water cooled system.

The total GHG emissions for the water cooled system for direct energy used, water distribution and treatment and chemical treatments is then 948 thousand pounds. The variance between air cooled and water cooled systems is then approximately 489 thousand pounds in favor of the water cooled system.

Given that we have established a favorable variance for the water cooled system from a practical standpoint can we make any reductions to further enhance the impact of water cooled systems?

Improvements in water cooled technologies are gradual in their placement on the market and as such these changes, while no doubt forth coming, will not be immediately available. The only two areas that we can address immediately are water consumption and chemical usage.

Currently, there are several technologies that can reduce the water consumption of the average cooling tower. These same technologies can also reduce the reliance on chemical treatments for a standard HVAC cooling tower application. Let’s further explore the impact of these technologies.

The rate of evaporation for a cooling tower will not be affected by the water treatment program regardless of which methods or technologies are applied. However, the make-up water and discharge volume can be affected by raising the operational cycles of concentration (COC). The chart below reflects the water savings that can be achieved.

As has been pointed, in a number of articles and papers previously published and specifically referenced here, water savings is generated by the ability to operate at higher cycles of concentration.

The rate of change begins to decrease almost to flat line at about 10 cycles. From a practical standpoint, the percentage of decrease of make-up required drops by 20% between 2 and 6 cycles. The reduction between 2 and 8 cycles is 24%.

There is corresponding decrease in the discharge volumes between 2 and 6 cycles of 63%. The decrease between 2 and 8 cycles is 75%. This rate of decrease then has a larger impact on the environmental and energy requirements by an broader margin.

While not all enhanced technologies can operate at the higher COC’s to maximize operational and environmental benefits, many can. The next graph demonstrates their impact on total GHG emissions including power requirements for water cooled systems.

Addressing GHG emissions and water use is just two of the aspects for applying “Greener” operating practices for water cooled technologies. Many companies are now working to develop chemically based water treatment programs that can prove to have fewer environmental impacts. Unfortunately, many of the compounds used today are being found objectionable in their application. In some cases, this is the result of other uses for similar compounds. For example phosphates used for scale and corrosion control. The predominant impact of these compounds is the result of their use in agricultural applications. Because of the burden these uses have placed on waste water treatment and their impact on surface waters even the smaller quantities used for cooling water treatment is enough to create problems and concerns.
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Another consideration for enhanced water treatment programs is the ability to reuse the water for other purposes. Because most enhanced water treatment approaches do not use chemicals the discharged water from the tower can be reused as irrigation water. This not only saves a facility from using other potable water sources for irrigation but also reduces the environmental impact of water cooled systems. Now, consideration can be given to the additional reduction in GHG emissions based on the reduced requirement to deliver additional volumes of water to the facility for purposes that the discharge water could be used. While the reuse of discharge water is not yet a wide spread application in many areas of the country it is receiving increasing attention.

In a study by the Department of Natural Resources for the state of North Carolina, the benefits of water efficiency programs were set out. These benefits include reduced water demand, water and wastewater treatment savings, less environmental impact and sustained water quality. These types of studies and concerns could well lead to further regulations in the future as fresh water in general becomes a more precious commodity throughout this country.

Also requiring consideration are the compounds used for standard cooling tower water treatments and the impact of these compounds on our environment. The following table lists compounds that are commonly used for cooling water treatment, how these compounds are released to the environment and POTW’s (publically owned treatment works) (publicly owned treatment works) and the focus of their impact on the ecosystem and challenges in attempting to clean them from wastewater. These compounds are drawing the attention and concern of many regarding their continued use. Commonly used compounds for cooling tower treatment:

**Summary**

Many of us have seen the importance of environmental issues ebb and flow over the past 40 years since the first Earth Day in 1970. At that time, many thought that it was just a fringe element that eventually would go away. Concern for our impact on the environment and our use of resources has not gone away, in fact today, it impacts many of our daily business decisions and practices. It has changed the ways in which businesses, regulators and the general public view or evaluate any business entity.

As in the use of some chemical additives or our methods of using water we have not considered the laws of unintended consequences. That is while something may work well, only over time have we determined that their use creates problems, certainly unintended, in other aspects of our society. These consequences can be harmful to humans, animals, aquatic life or require additional costs and environmental impact to correct the results of their use.

So why do we need to look for and toward other improvements or technologies to enhance our environmental impact? How environmentally conscious any business is perceived can have a monumental impact on its success. We can continue with our old methods and practices but if we do, then we should not be surprised when either the public or a regulatory body makes new rules or applies pressures upon us to accept more environmentally acceptable approaches to our business or face the consequences.

Viewing the environmental impact of HVAC cooling systems does indicate that water cooled systems have a definite advantage regarding GHG emissions. This is just one aspect of monitoring and maintaining the environmental stewardship responsibilities that everyone in or directly associated with the industry must look at. While it is not the only aspect to consider, energy conservation does constitute the largest percentage of water cooled systems environmental impact.

The businesses associated with water cooled systems have much to be proud of regarding the impact of our technologies and products over competing technologies and products on the environment. But we must work to see that these advantages are effectively taught and used. In order to further exploit and optimize the environmental advantages, participants in this industry must continue to seek advances. Critical reviews must be undertaken in order to achieve better treatment results through the use of chemical, physical and mechanical processes, methods and technologies and to enter into collaborative efforts to bring such products, process and technologies to the market that will further reduce our environmental impact.

**References**

2. Benefits of Water-Cooled systems VS Air-Cooled Systems for Air-Conditioning Applications – Michael Pugh, CTI paper
6. Energy demands on water resources - report to Congress - Dec 2006, pg 25
7. The Electricity Embedded in Water, Karen Collins, Salt River Project, Mar 2010
8. Guidelines for Managing Water in Cooling Systems, San Jose Environmental Services Department, July 2002
12. JEA (Jacksonville, FL) Best management practices guide for cooling towers, August 2005
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- Thermal Performance
- Heat Rejection Cycle Analysis
- Drift Emissions
- Drift Droplet Size Distribution
- Plume Abatement
- Water Flow Rate
Information supplied by Washington State Department of Ecology.11

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<td>Molybdates</td>
<td>Corrosion Inhibitor</td>
<td>Cooling Tower Drift, System Blowdown</td>
<td>Reports to sludge in POTW then enters the biosphere in sludge used as fertilizer, has shown impact on livestock health. Voluntary ban in effect in Boston</td>
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<tr>
<td>Phosphates</td>
<td>Corrosion and scale inhibitor</td>
<td>Cooling Tower Drift, System Blowdown</td>
<td>Promotes the eutrophication of lakes and other surface waters</td>
</tr>
<tr>
<td>Zinc</td>
<td>Corrosion inhibitor</td>
<td>Cooling Tower Drift, System Blowdown</td>
<td>Aquatic toxin, generally not eliminated by POTW - Priority EPA toxic pollutant</td>
</tr>
<tr>
<td>Brine (regeneration of water softeners)</td>
<td>Scale Inhibitor</td>
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<td>Causes severe operational problems for POTW</td>
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<td>Sulfuric Acid</td>
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</tr>
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<td>Biocide</td>
<td>Cooling Tower Drift, System Blowdown</td>
<td>Aquatic and human toxin, can cause POTW problems, reaction with other organics are more toxic or carcinogenic</td>
</tr>
<tr>
<td>Bromine (Br₂)</td>
<td>Biocide</td>
<td>Cooling Tower Drift, System Blowdown</td>
<td>Aquatic and human toxin, can cause POTW problems, reaction with other organics is more toxic or carcinogenic than compound by itself.</td>
</tr>
<tr>
<td>Isothiazolones</td>
<td>Biocide</td>
<td>Cooling Tower Drift, System Blowdown</td>
<td>EH&amp;S issue, contains copper, problematic for POTW, some require special discharge permits if in use11</td>
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<tr>
<td>Copper</td>
<td>Biocide / Algaecide</td>
<td>Cooling Tower Drift, System Blowdown</td>
<td>Aquatic toxin, generally not eliminated by POTW, Priority EPA toxic pollutant</td>
</tr>
<tr>
<td>Silver</td>
<td>Biocide</td>
<td>Cooling Tower Drift, System Blowdown</td>
<td>Aquatic and human toxin, generally not eliminated by POTW</td>
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Jacksonville, FLA., prohibits the discharge of molybdates into its sanitary sewer system.12
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An Improved Method for Calculating Calcium Carbonate Deposition

Michael Coughlin
Diversey Inc.

ABSTRACT
By definition, when the actual pH of the cooling water (pHₐ) is equal to the pH beyond which CaCO₃ precipitation will occur (pHₐ), the LSI predicts no scaling. However in the special cases where pHₐ = pHₑq and the terms are greater than 6.5, the RSI predicts CaCO₃ dissolution. Conversely when the terms are equal but less than 6.5, the RSI predicts CaCO₃ deposition. Furthermore, when there is little or no calcium but ample alkalinity in the water, the conventional indices predict scaling when in fact none will occur. A new index is proposed that easily predicts the scale forming tendency of all waters without exception and is proportional to the water’s alkalinity, calcium, TDS and temperature.

INTRODUCTION
Calcium carbonate that forms on the surface of water-cooled heat transfer surfaces is likely the most common type of deposition encountered in industrial cooling systems. It is therefore little wonder that since Langelier published the first predictive model for calcium carbonate deposition, now known as the Langelier Saturation Index or LSI (1), there has been a continuing interest in refining his method and improving its accuracy.

The method used to calculate the LSI was first published by Langelier in 1936 (1) and is determined by subtracting the pH of CaCO₃ saturation (pHₑq) from the actual pH (pHₐ) of the water. Langelier provided an equation to calculate the pHₛ and it was subsequently modified by Larson and Buswell (2) who simplified it by reporting the activity coefficient of calcium and bicarbonate as a function of the Total Dissolved Solids (TDS) in the water and providing a temperature correction relationship for the expression pK₂-pK₃. Nordell (3) is credited for providing a set of tables that are still in common use today whereby entering the M alkalinity, calcium concentration, TDS and temperature into their respective columns permits the calculation of the pHₑq. Of course the accuracy of the parameters used to calculate the LSI continues to improve due to the refinements made in analytical techniques. Furthermore, what used to be a tedious task to calculate the activity coefficient can now be easily calculated with computer driven algorithms and thus eliminate the need for its approximation by using TDS (4). What this means is that we can now predict beyond a level of practical importance, the pHₑq.

Despite the overwhelming accuracy to which the pHₑq and pHₐ can be ascertained, these parameters continue to challenge water treatment professionals as to their interpretation and utility. That which follows is a proposal for an alternative index that uses the LSI equation proposed by Larson and Buswell but where the terms pHₑq and pHₐ are used in a unique way to provide an improved method and a clear understanding of how to calculate the tendency and quantity of calcium carbonate precipitation.

DISCUSSION
Conventional Calcium Carbonate Saturation Indices
The LSI is a predictive model that was initially intended to predict the formation of calcium carbonate deposits in water lines. Although the chemistry used to derive the equation can be rather complex, the parameters are easily obtained and the equation itself is simply a subtraction of the actual pH of the water less the pH of the water at which it is saturated with soluble calcium carbonate, i.e., LSI = pHₑq – pHₐ. This is a logarithmic scale and for practical purposes spans 6 log units from -3.0 to +3.0. As the LSI becomes increasingly more positive, the potential for calcium carbonate precipitation logarithmically increases. Conversely, as the LSI becomes increasingly more negative, the amount of calcium carbonate that can re-enter solution logarithmically increases. At LSI = 0.0, calcium carbonate will neither dissolve nor precipitate.

Today the LSI is also commonly used by water treatment companies to predict the scaling tendency of cooling waters on heat exchangers. Although one of the requirements in calculating the LSI of a water system is to determine the pHₑq, this becomes problematic in a cooling system. Determination of the pHₑq in a pipeline system is a relatively simple matter. However, unless a cooling water is treated with acid to maintain a predetermined pH, the pHₑq will be dependant upon deposit control agents to keep calcium carbonate from precipitating. If precipitation of calcium carbonate occurs, then measuring the pHₑq is of limited value since precipitation of calcium carbonate will lower the pH. Therefore, rather than determine the pHₑq of a cooling system it is preferred to calculate the theoretical pHₑq of a cooling water before it cycles-up.

Puckorius (5) was the first to document the need for predicting the pHₑq of a cooling water. He chose to use the term pHₑq to replace the pHₑq. The pHₑq is a theoretically derived pHₑq and is calculated based on the total alkalinity of the make-up water. Instead of using the LSI, Puckorius substituted his new term pHₑq for pHₑq in the in the Ryznar Stability Index (RSI) equation, 2pHₑq – pHₑq (6) and thereby created a new calcium carbonate scaling index called the Practical Scaling Index or PSI. For both RSI and PSI, the scale ranges from 3-13. Any water with an RSI less than 6.5 will form progressively more calcium carbonate and waters with an RSI greater than 6.5, progressively more calcium carbonate will dissolve. At RSI = 6.5 the water is equilibrium relative to calcium carbonate saturation. Not only does the PSI differ from the RSI in that the PSI uses a predicted pHₑq instead of the actual pHₑq, Puckorius also assigned the value 6.0 rather than 6.5 to indicate a water in equilibrium with calcium carbonate saturation.
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Puckorius could have also used the term pH\textsubscript{eq} to modify the LSI equation. Had he done so, the LSI and the PSI would have ranked the five waters that he referenced equally for their ability to generate CaCO\textsubscript{3} deposition. Puckorius chose to use the PSI because like Ryznar, the empirically derived formula more closely matched the results observed in the field. Langelier on the other hand derived his equation solely on the equilibrium equation of calcium carbonate saturation and made little attempt to correlate it with scaling observations in the field or laboratory. The LSI is in fact an index that intends to provide guidance as to the “driving force” of a water to form or dissolve calcium carbonate whereas the RSI is an empirically derived formula that attempts to predict the amount of calcium carbonate dissolution or precipitation. Hence a divergence of opinion occurs to this day as to which index is the more useful.

As can be seen from Figure 1, the pH\textsubscript{eq} provided by Puckorius is very similar to those also derived empirically by Kunz et al (7) and Caplan (4). The most recent attempt to determine the pH of a cooling water was proposed by Vanderpool (8). Unlike the other models, Vanderpool used regression analysis to determine the pH\textsubscript{eq} of a cooling water that is in equilibrium with the CO\textsubscript{2} in the atmosphere and not treated with acid. The term used by Vanderpool to describe this situation is “atmospheric equilibrium pH” and is not empirically derived. Although Vanderpool provided regression models of increasing complexity to calculate the atmospheric equilibrium, a simple equation was also provided that comes remarkably close to providing similar results when compared to the regression models. This theoretically derived value is called pH\textsubscript{T} and is described in equation 1.

\[ \text{Equation 1: } \text{pH}_T = 0.92 \log M \text{ alkalinity as mg/L CaCO}_3 + 6.6 \]

It is apparent from observing the plots of the commonly used equations to predict the pH\textsubscript{eq} that the Vanderpool equation is notably different from the others. The difference between the empirically derived formulas versus Vanderpool’s theoretical derivation may result from the former depending upon cooling waters that have their pH maintained with acid or conversely, incurred a drop in pH when calcium carbonate is precipitated. Therefore, when attempting to predict the pH\textsubscript{eq} of a cooling water prior to any cycling-up or acid addition, the Vanderpool equation is preferred. It has also been a personal observation that most ground and surface waters incur a rapid and substantial increase in pH when they become fully aerated in the absence of heat and evaporation. Water circulating in a cooling tower also becomes rapidly and fully aerated before any cycling occurs. This aeration process will drive off excess CO\textsubscript{2} and consequently results in an increased pH of the cooling water.

Regardless of how the pH\textsubscript{eq} is calculated or whether it is simply obtained by direct measurement, there remain two basic methods for determining if calcium carbonate precipitation will occur. One is based on the RSI equation and the other on the LSI equation. Because both resulting indices use the same parameters to predict the extent of calcium carbonate saturation, one might reasonably expect to deduce equations of equivalency that relate one to the other. In fact, simple substitution and rearrangement of terms reveal that LSI = pH\textsubscript{eq} - RSI. In reality, the only time the equations of LSI and RSI predict equivalent degrees of calcium carbonate saturation is for the special case when pH\textsubscript{eq} and pH\textsubscript{T} = 6.5. When this occurs, the predicted saturation indices differ from the equilibrium condition (RSI = 6.5 and LSI = 0.0) by the same number of saturation units. Other than this special case, there is no factor or equation to convert one index to another. If indeed the two saturation indices always predicted the same outcome for all pH\textsubscript{eq} values, there would be no need to have more than one calcium carbonate saturation index. Because the RSI and PSI formulas are in part empirically derived, they avail themselves to erroneous predictions in exceptional situations. When pH\textsubscript{T} = pH\textsubscript{eq} by definition the system is in equilibrium, regardless of the actual values. However, when pH\textsubscript{eq} = pH\textsubscript{eq} > 6.5, RSI predicts calcium carbonate dissolution and when pH\textsubscript{eq} = pH\textsubscript{eq} < 6.5, the RSI predicts calcium carbonate super saturation. Obviously neither situation is correct.

### An Alternative Saturation Index

Admittedly, cases where pH\textsubscript{eq} = pH\textsubscript{eq} are exceptional but it is the exception that begs for new rules to be made when the predictive models fails. In attempting to overcome the limitations of the two conventional saturation indices, another index has been derived for which there is no need to make exceptions. The term TSI (Total Saturation Index) has been coined to describe this index. It too relies on calculating the pH\textsubscript{eq} and pH\textsubscript{T} for its predictive ability and of course will only be as accurate as the data used in these calculations. Other than eliminating errors obtained from anomalous data, perhaps the biggest contribution made by the TSI is that like the LSI it does not rely upon empirically derived data but like the RSI, quantifies the amount of calcium carbonate dissolved or precipitated.

The key to calculating the amount of calcium carbonate dissolved or formed is to use the Larson, Buswell modified Langelier equation to solve for the amount of calcium carbonate in equilibrium with the pH\textsubscript{eq} of the system. The pH\textsubscript{eq} of a water is calculated by the simplified method reported by Vanderpool. In doing so, one can determine the actual solubility limits for calcium and M alkalinity. The generalized equation for determining the pH\textsubscript{eq} of a cooling water was provided by Heffer (9) who successfully organized the tabulated data provide by Nordell to calculate the pH\textsubscript{T}. The Heffer equation is reduced to

\[ \text{Equation 2b was determined by plotting the Nordell tabulated temperature correction in an Excel spreadsheet and obtaining the equation with the best fit. Heffer on the other hand provided several equations that reflected different temperature spans (due to the non linearity of the data) but unfortunately made some computational errors in the process. When the Nordell data is plotted in an Excel spreadsheet, equation 2b is obtained with a R^2 fit of 0.9993. The temperature coefficient is most correctly used when the temperature of the heat exchange surface is known. If this value is not known, an approximation is preferred to using the bulk water temperature. Beyond this point an example will better describe how the TSI is calculated.} \]

The example in Table 1 uses make-up water sample D described by Kunz et al that has been cycled 4 times at a temperature of 100 °F. Substituting pH\textsubscript{T} for pH\textsubscript{eq} in equation 2 and using equation 1 to solve for the pH\textsubscript{eq} (given that the M alkalinity is 100 mg/L as CaCO\textsubscript{3}), we see that equation 2 becomes equation 3.

\[ \text{pH}_T = 8.44 = 9.7 + F(T) - F(HCO_3^-) - F(Ca^{2+}) + F(TDS) \]

By combining the terms F(Ca\textsuperscript{2+}) + F(M alkalinity) to equal x, and given that T = 100 and the TDS is 720 mg/L, we determine that x = 3.2. There are an infinite number of values that satisfy the equation F(Ca\textsuperscript{2+}) + F(M alkalinity) = 3.2, but there is only one combination of F(Ca\textsuperscript{2+}) + F(M alkalinity) whereby when the soluble calcium is subtracted from the total calcium, this difference is equal to that of the soluble M alkalinity subtracted from the total M alkalinity. Since the total concentration of both calcium and M
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alkalinity are known, if we determine the soluble components of both, then by simple subtraction we also know the insoluble components. Key to this method is the assumption that a stochiometric pairing of calcium and carbonate exist for insoluble species. To suitably solve the equation we must employ the quadratic equation. It is obtained in the following manner:

Equation 4: Since Log (Soluble Ca\(^{++}\)) + Log (Soluble M alkalinity) = 3.32

Equation 5: And 10 \(^{3.32}\) = 2089

Equation 6: Then 2089 = (Soluble Ca\(^{++}\)) x (Soluble M alkalinity)

Equation 7: Or, Soluble M alkalinity = 2089/ Soluble Ca\(^{++}\)

Furthermore

Equation 8: Since Insoluble M alkalinity = Insoluble Ca\(^{++}\)

Equation 9: And Insoluble M alkalinity = Total M alkalinity-Soluble M alkalinity

Equation 10: And Insoluble Ca\(^{++}\) = Total Ca\(^{++}\) - Soluble Ca\(^{++}\)

Equation 11: Then Total M alkalinity- Soluble M alkalinity = Total Ca\(^{++}\) - Soluble Ca\(^{++}\)

Equation 12: Or Total Ca\(^{++}\) - Total M alkalinity = Soluble Ca\(^{++}\) - Soluble M alkalinity

Equation 13: Since 150 = Total Ca\(^{++}\)

Equation 14: And 100 = Total M alkalinity

Equation 15: Then 50 = Soluble Ca\(^{++}\) - Soluble M alkalinity

Equations 7 and 15 can be combined to form Equation 16

Equation 16: 50 = Soluble Ca\(^{++}\) - 2089/Soluble Ca\(^{++}\)

By subtracting 50 from both sides of Equation 16 and multiplying both sides by Soluble Ca\(^{++}\), quadratic Equation 17 is obtained.

Equation 17: (Soluble Ca\(^{++}\)) - 50 x Soluble Ca\(^{++}\) - 2089 = 0

There are two results for a quadratic equation, but the correct solution to this quadratic equation is the positive value shown in equation 18.

Equation 18: Therefore Soluble Ca\(^{++}\) = 77 mg/L as CaCO\(_3\)

The amount of Soluble M alkalinity can be solved in the same manner that was used to determine the amount of Soluble Ca\(^{++}\). In doing so, and by using the positive value of the quadratic equation, 27 mg/L as CaCO\(_3\), is obtained for the amount of Soluble M alkalinity. Alternatively, the Soluble M alkalinity can be determined simply by subtracting the now established Insoluble M alkalinity (equal to the amount of Insoluble Ca\(^{++}\)) from the known amount of Total M alkalinity. The difference of these two amounts is also 27 mg/L as CaCO\(_3\). In this case the amount of insoluble Ca\(^{++}\) and M alkalinity is 73 mg/L, i.e., 73 mg/L of precipitated CaCO\(_3\). This conclusion can be confirmed by noting that the soluble and insoluble components of both calcium and M alkalinity equal their respective totals. What this problem solving exercise has accomplished is to define not a propensity for calcium carbonate deposition, but the maximum amount that can be formed. This amount is referred to as the Total Saturation Number (TSN) and can be reported as the Total Saturation Index (TSI) by simply taking the log TSN. In this case, the TSI is +1.86.

The primary value in converting the TSN into the TSI is that it provides us an opportunity to compare its veracity and utility relative to other commonly reported indices. There are few reports in the literature that provide an opportunity to compare the conventional indices with the TSI. One such data set that allows this comparison to be made is from the Kunz et al paper. In Table 1, the LSI is compared against the RSI using pH\(_A\) and the cited pH\(_A\) of all the reported waters. Whenever the LSI is calculated using the pH\(_A\), the LSI will be reported as LSI\(_A\). The waters in Table 1 have been arranged in increasing order of potential calcium carbonate formation. When the correlation coefficient R\(^2\) is calculated by comparing the different LSI values to each other, the R\(^2\) is always greater than 0.99. This is an interesting observation in that although the method for calculating the pH\(_A\) is essentially the same for all three indices, there are significant differences in the calculation of the pH\(_A\). When the correlation coefficient R\(^2\) is calculated by comparing the RSI values to all LSI values, the R\(^2\) is also greater than 0.99 in all cases. In essence, one value is as credible as the other. This is a completely expected outcome since RSI uses the same parameters as LSI except that they are used in reversed order and the pH\(_A\) is multiplied by a constant of two. Only the interpretation of the resulting value differentiates the two indices. In this regard there are some notable differences. First, the LSI scaling potential is greatest when pH\(_A\) is used to calculate the pH\(_A\). This is an expected outcome since the equation for pH\(_A\) will predict a higher pH compared to the empirically derived pH\(_A\) whenever the M alkalinity is less than 1000 mg/L as CaCO\(_3\) (see Figure 1). Secondly, unless the water is significantly prone to calcium carbonate deposition, the RSI predicts significantly less calcium carbonate deposition and often describes a situation of calcium carbonate dissolution when the other indices indicate a slight or mildly scale forming water.

In Figure 2, the RSI is not reported since it is so highly correlated with LSI to render its comparison redundant. However, when the waters are arranged in increasing order of scale forming tendency as per the LSI, the correlation of LSI and TSI ranges from R\(^2\) = +0.73 to +0.78. An examination of the data reveals that waters A2 and A4 account for the lack of good agreement between the LSI and TSI. What makes these waters different from the others is the comparatively high concentration of M alkalinity compared to the calcium. That the LSI is greater than the TSI actually reveals the essential nature of these two indices. That is, the TSI indicates the total available CaCO\(_3\) that can be generated whereas the LSI (as was originally intended by Langelier) reveals the driving force of the precipitation reaction. Therefore, in water that contains a fixed amount of calcium but increasing quantities of alkalinity, the total amount of CaCO\(_3\) that can precipitate will reach a maximum. In this situation the TSI will stabilize yet the driving force, i.e., the LSI, will continue to increase. The potential for misinterpreting the driving force value of the LSI can be further realized if one considers the anomalous situation whereby there is virtually no calcium in the presence of ample M alkalinity. In such a situation, the conventional indices predict varying degrees of calcium carbonate fouling when in fact no fouling can occur. In such water, the TSI is zero.

Although the outcomes of the LSI and RSI equations are nearly perfectly correlated, the former was intended to quantify the driving force of the precipitation reaction and the later the total amount of CaCO\(_3\) actually precipitated. Admittedly, there is more value to the RSI if it can predict the quantity CaCO\(_3\) precipitated. A review of the data found in Ryznar’s original publication suggests that this index may indeed be capable of providing this information. Table 3 is a summary of Ryznar’s water quality data. In Ryznar’s experiments, some of the samples were treated with polyphosphate to inhibit deposition and are not included in Table 3. This explains why some samples appear to be missing from Table 3. It is rightfully assumed that data presented in a published report is accurate and reproducible. When Ryznar conducted experiments, purity of reagents and accuracy of pH determinations were not comparable to today’s standards. For this reason there is no apparent correlation between the reported pH and pH calculated by using the M alkalinity. The determination of M alkalinity presents a comparatively minor source of error compared to the measurement of pH. Although the M alkalinity was determined by titrating to the end point of methyl orange, a
skilled technician can reproduce a titration within a couple of mg/L. Despite the limitations of the Ryznar experiment, the data in Table 3 show a reasonable amount of correlation between the given RSI and the amount of deposition, i.e., $R^2 = -0.77$. When the RSI is calculated using pH$_T$ instead of pH$_A$ (RSI$_T$) and the pH$_S$ is more accurately calculated, the correlation remains virtually unchanged ($R^2 = -0.75$). It was this deposition data that Ryznar used to derive and defend an empirical formula that predicted the mass of CaCO$_3$ that formed on the glass coils, especially since the LSI only yielded an $R^2$ correlation of 0.68. However the LSI correlation improves to $R^2 = 0.74$ if the pH$_T$ is more accurately calculated and pH$_S$ is used instead of pH$_A$. Therefore, the predictive power of the LSI and RSI also appears to be a function of whether the pH$_A$ or pH$_T$ is used in the respective calculation. Interestingly, equation 19 yields an $R^2$ correlation coefficient of 0.93, a substantially much better fit than either the LSI or RSI.

Equation 19: $\text{Deposition} = \frac{1}{(\text{TSI} - \text{LSI})}$

However, fit of data is not necessarily an indication of utility. Although equation 19 is able to predict the amount of deposition within the given data set, it fails to provide any level of certainty for many other situations, such as when the calcium hardness exceeds the alkalinity.

A comparison of the alkalinity and the measured pH in the Ryznar data set reveals that there is no correlation between them. Plotting the stated alkalinitities into any of the equations provided in Figure 1 shows that the measured pH does not agree with any of the predictive models. The association of alkalinity and measured pH appears to be completely random. In retrospect, it is remarkable that Ryznar derived an equation that relied upon pH measurement to correlate a set of conditions (alkalinity, temperature, calcium and TDS) with an outcome (deposition).

As might be expected, the TSI correlates poorly with the observed amount of deposition in the Ryznar data set. However, rather than discard the TSI, it remains a valuable indicator of total potential deposition. To account for the kinetics of scale formation, the LSI can be used to modify the TSI and obtain the TSI Driving Force as per equation 20.

Equation 20: $\text{TSI Driving Force} = \frac{(\text{LSI}_T - \text{TSI})}{\text{TSI}} \times 100$

Equation 20 allows differentiation to occur between samples with the same TSI. For example, in the Ryznar data set, samples 18, 19, 20, 21, 22 and 24 all have the same TSI but none share the same TSI Driving Force. It should be noted that the TSI plus the TSI Driving Force equals the LSI. The method by which the TSI Driving Force is derived is simple and intuitive. The TSI, the TSI Driving Force and LSI, are all interrelated metrics that can be used to describe the propensity for a cooling water to form CaCO$_3$ on a heat transfer surface.

CONCLUSION

New scaling metrics have been identified that take into account the driving force of the CaCO$_3$ precipitation reaction and the total available CaCO$_3$ that can be potentially formed. Novel to the calculation of these metrics is the use of the pH$_S$ equation to calculate the available CaCO$_3$ that can precipitate or dissolve and an estimation of the kinetic driving force that governs the reaction. These metrics are not fraught with the challenge of addressing waters with high alkalinity and low calcium as are the conventional indices nor do they generate conflicting outcomes vis a vis the Ryznar and LSI indices for special cases such as when pH$_A = \text{pH}_S$. The TSI range is essentially that of the LSI and for that reason its values have intuitive meaning in that zero indicates no scale, progressively more negative numbers indicate a logarithmic increase in scale dissolution and conversely, a progressively more positive TSI indicates a logarithmic increase in scale potential. Although the calculation of the TSI is not something that would be done with nomographs and tables, by entering into an Excel spreadsheet the same values used to calculate the LSI, and using the formulas previously cited, the TSI, TSI Driving Force and LSI, can all be easily obtained.
Figure 1: Calculation of pH Based on M Alkalinity
Puckorius: pH = 1.465*LOG10(M alkalinity) + 4.54
Kunz et al.: pH = 1.6*LOG10(M alkalinity) + 4.4
Caplan: pH = 1.56*LOG10(M alkalinity) + 4.3
Vanderpool: pH = 0.92*LOG10(M alkalinity) + 6.6

Table 1: Kunz et al Waters and Associated Indices
NB: The *pH₄ is calculated using the alkalinity:pH relationship defined by Kunz et al.

<table>
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<th>Water</th>
<th>pH₄</th>
<th>Temperature °F</th>
<th>Calcium ppm as CaCO₃</th>
<th>Alkalinity ppm as CaCO₃</th>
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<th>pH₄ (Given)</th>
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Table 2: Ryznar Water Quality Data

Table 3: Correlation of Scaling Indices
* Sample 1 was erroneously reported to have an RSI = 5.68 due to a computational error. The values in Table 2 were used to calculate the RSI given.

REFERENCES
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Too Good to be Green
Practical Evaluation of Treatment Chemicals For Scale Inhibition In Open Evaporative Seawater Cooling Systems

Gary E. Geiger and Roy Holliday.
GE Water & Process Technologies.

ABSTRACT
In certain parts of the world, the use of seawater as make up water for specially designed open evaporative cooling water systems is becoming increasing popular. This poses the same potential for corrosion, scaling, deposition and microbiological fouling as with most other fresh water make up sources used in cooling systems, but in the case of seawater, or brackish water, the potential and severity is much greater.

Corrosion is typically designed out by using corrosion resistant materials. Microbiology is typically controlled by chlorination since it is the most cost-effective. Scaling and deposition remain a main concern, which lead to basic evaluation of deposit control agent performance in concentrated seawater in 2000 (6). Since these studies, advances and enhancements have been made in this domain, which prompted additional studies of scale control in seawater and cooling applications.

The studies utilized an evaporative cooling tower technique as opposed to the static or synthetic procedures used in the studies performed in 2000. This enabled evaluation of hydraulic operation together with chemical treatment. The viability of using synthetic seawater as opposed to authentic seawater, which would facilitate conducting a greater number of studies in a shorter period of time, was part of the evaluations performed.

It was demonstrated that selection of specific chemistry for scale and deposit control could allow the operation of seawater cooling systems at a higher concentration factor than that which is normally practiced, and potentially reduce or eliminate the use of acid for pH reduction. These findings will assist in reducing the cost of operating and environmental impact of such cooling systems.

1. INTRODUCTION
Industry relies heavily upon water, both in its production process and utilities. The requirement for cooling is present in most industrial and manufacturing processes, and may be achieved by cooling, directly or indirectly, with air or with water. By far, the largest and most common method is indirect cooling using water. These cooling systems may be once through, closed or open evaporative cooling systems. Good quality fresh water from natural sources is becoming scarce (1,2) and costly. This has forced some plants to look for alternative sources of water or making investments for pretreatment of poor quality water.

Water shortage issues have made seawater one of the feasible options (3), with a trend towards open evaporative seawater cooling systems as opposed to once through seawater systems. Despite its corrosive nature, abundance and consistency has placed it among the most competitive water sources for industrial cooling water applications. In the past, seawater or brackish water have been used as once through cooling water or cooling system make up water in some parts of the world. Desalinated seawater is also used as make up water to evaporative cooling systems. However, limitation of brackish water available for industrial use and the cost of desalination have resulted in supply limitations being imposed on industry in some locations, and thus created a need for recycling or reuse of water.

2. WATER TREATMENT REQUIREMENTS AND PRACTICES
Many modern day systems necessitate large cooling water circulation rates in order to provide the required cooling capacity and effectively dissipate heat loads of the plant. Such designs and requirements are well supported by the economics of a low cost or free of charge seawater supply and discharge.

Seawater, and potentially brackish water depending upon its salinity, is inherently corrosive to many metallurgies, even more so when concentrated in an evaporative cooling system. In systems using these types of water as make up, corrosion is designed out by the use of corrosion resistant metallurgies, such as titanium and copper alloys. This leaves particulate deposition, mineral scaling and microbiology fouling as the main areas requiring attention and a potential requirement for treatment chemicals.

Seawater cooling systems operate as either once through or open evaporative at low cycles of concentration. The high water consumption and discharge associated with these systems makes either continuous or intermittent halogenation the most cost-effective alternative for baseline microbiological control. Chlorination or bromination could be used, but one may question the logic of ap-
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plying a bromine-based program in a system using seawater initially containing 60 to 70 ppm bromide. The application of a cheaper chlorination program will oxidize the bromide to hypobromous acid and in effect result in partial bromination. With open evaporative cooling systems algae may be a potential problem. In some applications, halogenation may not be sufficient for control of algae, in which case non-oxidizing biocides or specific herbicides may be applied to supplement the halogenation program.

Many cooling tower manufactures believed that calcium sulfate solubility would limit the cycles of concentration that could be advisable with seawater to 1.2-1.5. Laboratory studies performed in the year 2000 concluded that open evaporative cooling systems operating at low cycles, in the order of 1.5 to 2.0, were susceptible to calcium carbonate deposition if an effective deposit control treatment program was not applied. Calcium sulfate became a concern at high cycles of concentration, in the order of 3.5 cycles.

The vapor pressure of water reduces with increasing dissolved solids concentration, evaporation rate and cooling tower performance will decrease. Evaporation rate decreases by about 1% for every 1% increase in specific gravity or every 10,000 ppm of dissolved solids. Therefore, the design and performance of the cooling tower may influence the upper limit of concentration to which the system may be operated.

2.1. Overview of Treatment Practices

In the 1980s the first chemical treatments applied to open evaporative seawater cooling systems were programs based on phosphonates and employed pH control, typically using sulfuric acid. The programs were designed to control both calcium carbonate and calcium sulfate. Systems were typically operated between 1.2 and 1.3 cycles of concentration. Materials of construction were chosen to minimise corrosion due to the aggressiveness of the cycled water. Depending on water quality, mainly particulate solids, polymeric dispersants were sometimes used to supplement the deposit control program.

Initially, copper alloys, such as Admiralty brass, were used for heat exchangers. This trended towards the use of cupronickel and subsequently to titanium as the material of construction, particularly surface condensers in power generation plants. The use of yellow metals at times implied a need for the use of amines for corrosion inhibition of copper and copper alloys.

The trend today, driven by safety concerns and economics, is for the elimination of the use of acid, thereby typically operating at naturally cycled up pH. Along with this, for economic reasons, there is a desire to operate at higher cycles of concentration.

Phosphonates, such as hydroxyethylidene diphosphonic acid (HEDP) or phosphonobutane tricarboxylic acid (PBTC), are commonly used for calcium carbonate scale inhibition. Although PBTC is considered to be a more effective scale inhibitor, HEDP is often considered preferable due to easier monitoring and control. Polymers can be used as stand alone scale inhibitors or blended with phosphonates. Polymers exhibit dispersant properties that contribute to control deposition of particulate matter. Low molecular weight polyacrylic acid homopolymer (PAA) has been successfully utilized to inhibit calcium carbonate scale formation in evaporative seawater cooling systems. Typically cycles of concentrations are controlled in the order of 1.4 and the pH controlled to a maximum of about 8.3. Seawater cooling systems have been operated up to 1.6 cycles of concentration without acid pH control, using HEDP as a stand alone calcium carbonate inhibitor, or blended with a sulfonated copolymer (SAA). When scale inhibitors are not applied, cycles of concentration are often limited to a maximum of 1.3 and the pH controlled at 7.9-8.0. The potential for calcium carbonate scale formation and/or the need for treatment are relative to the operating cycles of concentration, pH adjustment and inherent chemical composition of the seawater. As previously mentioned, some applications desire to eliminate the need for pH control using acid and to operate at higher cycles of concentration. This will obviously result in a higher cooling water pH and salinity, and hence increased potential for scale formation.

3. SCREENING AND EVALUATION OF INHIBITORS

3.1. Beaker Tests and Bench Top Unit Studies

The investigations conducted in the year 2000 were performed with synthetic seawater based upon a composition depicting a Mediterranean seawater application. Initial screening was performed with three day beaker tests at a bulk temperature of 60 °C. Various commonly used polymeric and phosphonate treatment chemicals were benchmarked. Subsequently, the two best performing phosphonates and polymers were tested under dynamic heat transfer conditions using an apparatus known as a Bench Top Unit (BTU), Figure 6.1.1a. Comparative tests with untreated seawater indicated that the limiting factor at low cycles was calcium carbonate as opposed to calcium sulfate. At 1.5 cycles of concentration, light calcium carbonate deposition was observed and at 1.75 cycles and above heavy calcium carbonate deposition resulted with the untreated water. Of the phosphonates evaluated, hydroxyethylidene diphosphonic acid (HEDP) and amino-trimethylene phosphonic acid (AMP) were judged to be the best. Of the polymers evaluated, a sulfonated acrylic acid copolymer (SAA) and a low molecular weight polyacrylic acid homopolymer (PAA) were judged to be the best. Overall, it was concluded that the polyacrylate polymer provided the most cost-effective performance, and being multifunctional it could also be beneficial at “higher cycles” where calcium sulfate deposition becomes a concern. No deposit was observed on heat transfer surfaces in the BTU studies at 3.5 cycles of concentration using the polyacrylate polymer, while a light calcium carbonate deposit was observed with the SAA copolymer. At 3.5 cycles, a moderate calcium sulfate deposit was observed with HEDP and heavy deposits of both calcium carbonate and calcium sulfate occurred with the AMP treatment.

Following this work, there have been several treatments successfully applied to open evaporative seawater cooling systems based on PAA alone and HEDP/SAA blends, but typically at relatively low cycles of concentration in the order of 1.5 or lower.

3.2. Evaluation of Inhibitors using an Evaporative Test Rig

Worldwide, there is pressure for industry to reduce operating costs, none the least in open evaporative cooling water systems. Although the cost of seawater may be cheap or free of charge, the cost of pumping, pretreatment, cooling water treatment chemicals, and where applicable discharge costs, mount up and can be significant in relation to the large volumes of water required for cooling systems operating at low cycles of concentration. Therefore there is a
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financial benefit if the operating cycles can be increased. However, this will increase the potential for scale formation, notably calcium carbonate and possibly calcium sulfate. In order to realize the benefit of operating at higher cycles an effective scale inhibitor treatment is essential. Based on this, developmental work was initiated to identify treatment approaches for high cycle operation under evaporative conditions using an Evaporative Laboratory Tower (ELT), Figure 6.1.1b. The main difference between a BTU and an ELT is that one does not obtain any significant evaporation in a BTU. Therefore, the BTU uses synthetic water made to the chemical composition of the cooling water to be tested. The ELT contains a cooling tower so controlled concentration of a given make up water chemistry can be performed. The ELT can use synthetic water made to the chemical composition of a subject make up water or an actual make up water from a plant or cooling system. The ELT contains six heat exchangers, allowing studies to be performed on up to six different metallurgies while the BTU only has one heat exchanger.

With an objective to perform several ELT evaluations, it was decided to synthesize seawater and use this as make up water. During the project there was a request to perform some specific evaluations for a European seawater application. This study was incorporated into the project, and in this case seawater from the subject application was obtained and used as make up water. This seawater was subsequently used for the remainder of the project since some anomalies were observed between results obtained using synthetic seawater compared to that using authentic seawater, as illustrated in Table 6.2.1. The difference in cycles apparently obtainable up to a point of failure, expressed as a percentage, are of the same order of magnitude. The composition of the synthetic water used for the ELT studies and initial BTU studies, together with that of the authentic seawater are shown in Table 6.2.2.

The evaluations were performed by operating the ELT at sequentially increasing cycles of concentration until a point that indicated a failure of the treatment to control deposition. The ELT was operated at a bulk water temperature of 32 °C (90 °F), which corresponds to an estimated skin temperature of 45 °C (113 °F), and a water velocity of 1.5 m/s (4.9 fps). In the various studies, Titanium (Grade 2), 90/10 Cu/Ni (CDA 706), 70/30 Cu/Ni (CDA 715) and Admiralty Brass (ADM 443) metallurgies were used.

A blank was performed with both the synthetic seawater and the actual seawater in which no treatment chemicals were applied. Chemical treatment programs based on a low molecular weight polycarboxylate polymer were evaluated on the synthetic water, and on the authentic seawater programs based on a low molecular weight polyoxyfuran derivative (POF), sulfonated terpolymer (STP)) and polyacrylate polymer (PAA) were performed.

To simulate halogenation as would typically be used for microbiological control, free residual chlorine of 0.2 ppm Cl₂ was maintained continuously in all of the studies.

4. RESULTS OF ELT EVALUATIONS

The evaluations were taken to a point, or the cycles of concentration, at which a failure of the treatment was judged to have occurred. Since the cooling water was cycled above that deemed to be the point of failure, deposition was deliberately created since the point of failure was exceeded. Therefore, concluded results, with respect to the cycles attained at the point of failure, are not necessarily reflected by the amount of deposit observed on heat exchange surfaces.

4.1. Synthetic Seawater

The first two evaluations were performed using synthetic seawater as make up water. As mentioned above, the cycles of concentration were sequentially increased stepwise, typically holding a target concentration for at least 24 hours, or over a weekend. The increase in concentration could be easily and accurately accomplished by adjusting the set point of the conductivity meter controlling the purge (blowdown) from the ELT.

Normally, the performance of treatments in BTU and ELT studies are primarily judged by the developing condition of the heat exchange tube(s) and/or corrosion coupons, and the trend of the overall corrosion rate and imbalance indicated by a corrosion rate meter (CRM). In this particular project, the main area of concern was deposition rather than corrosion, since in seawater cooling systems corrosion is typically designed out by use of corrosion resistant materials. The concentration of the cooling water was increased until deposits were visible on heat exchange tubes and/or deposition was indicated by the analyzed chemistry of the cooling water.

In the study with untreated synthetic seawater, deposition in the bulk cooling water was observed at a concentration factor of 3.6 cycles. Further increase in cycles of concentration resulted in a decrease in pH, alkalinity and calcium concentration of the cooling water. Figure 6.1.1. shows deposition observed on heat exchange tubes after a point or concentration factor that the study using untreated synthetic seawater was concluded to have failed. The point of failure was judged to be that when pH, alkalinity and calcium concentration decreased, indicating deposition of calcium carbonate. This was deposition within the bulk cooling water, within the cooling tower sump, and is not accurately reflected by deposits on heat transfer surfaces.

The evaluation of a low molecular weight polyoxyfuran derivative (POF) in synthetic seawater, at a concentration of 2 ppm active polymer, was deemed to fail at a concentration factor of 5.6 cycles. Further increase in cycles of concentration resulted in an increase in turbidity and decrease in pH of the cooling water in the ELT. The deposition observed was mainly on heat exchange tubes. The increase in turbidity of the water indicated that the polymer was not inhibiting bulk precipitation in the cooling water, but was effectively dispersing or holding the particulate crystals in suspension. Figure 6.1.2. shows deposition observed on heat exchange tubes at 5.6 cycles of concentration.

4.2. Authentic Mediterranean Seawater

Deposition was observed when the concentration factor reached 1.5 cycles with untreated seawater. Turbidity remained low throughout the study and slight deposition was observed in the sump of the ELT tower. Further concentration resulted in a decrease in the pH of the cooling water, indicative of a reduction in alkalinity and the formation of calcium carbonate deposits. Figure 6.1.3 shows the deposition observed on heat exchange tubes after a point or concentration factor where failure occurred. The deposition rate was higher than that in the untreated synthetic water on the copper alloy heat exchange tubes. Localized deposition was even observed with titanium heat exchange tubes.

Evaluation of 2 ppm polyoxyfuran derivative demonstrated that 2.5 cycles of concentration could be achieved without deposition. As
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cycles increased above 2.5, decreases in alkalinity and increases in pH occurred, indicative of the onset of calcium carbonate precipitation/deposition. Turbidity remained low throughout the evaluation and slight deposition was observed in the sump of the ELT tower. Figure 6.1.4 shows deposition observed on heat exchange tubes when the cycles exceeded 2.5. It was somewhat surprising that significantly lower limiting concentration factors were observed with equivalent evaluations using authentic seawater compared to that observed with synthetic seawater. The difference between the limiting concentration factor for authentic seawater and synthetic seawater is of a similar order of magnitude, 42% and 45%. From this it was concluded that the synthetic seawater lacked some components, albeit minor, that had an influence on deposit formation. This is supported by the significantly greater deposition rate on heat exchange surfaces with untreated authentic seawater, between 180 and 266 mg/cm²/year (1.2 and 1.7 g/in²/year), compared to that with untreated synthetic seawater, between 36 and 70 mg/cm²/year (0.2 and 0.5 g/in²/year).

In order to increase dispersion properties, but at a slight penalty of decreasing calcium carbonate scale inhibition, a blend of the low molecular weight polyoxyfuran derivative (POF) and a sulfonated terpolymer (STP) was evaluated at a dosage of 1 ppm active concentration of each. This combination yielded similar results to that observed with 2 ppm active POF. The limiting concentration factor was 2.5 cycles, above which a decrease in pH of the cooling water was observed, indicating the onset of calcium carbonate precipitation/deposition. No significant effect on the turbidity of the water was recorded. Figure 6.1.5 shows deposition observed on heat exchange tubes after a point or concentration factor that the study using untreated seawater was concluded to have failed. A relatively low deposition rate was measured on heat exchange tubes, between 1 and 12 mg/cm²/year (0.01 and 0.1 g/in²/year). The lower scaling observed with the POF/STP blend demonstrates the superior performance that can be achieved by combining an inhibitor (POF) and a polymeric dispersant (STP).

Treating with a low molecular weight polyacrylic acid homopolymer (PAA) at a concentration of 2 ppm active polymer did not show any visible deposition on heat exchange tubes or any apparent deposition until 5.0 cycles of concentration. Figure 6.1.6 shows the deposition observed on removal of the heat exchange tubes. Although it appeared that the PAA could achieve 5 cycles of concentration, this was not the case. Turbidity (precipitation) was observed at the onset of cycling the water and increased up to 1.7 cycles of concentration. At 1.7 cycles of concentration, the turbidity started to decrease significantly until 2 cycles were achieved, at which point the turbidity did not change. Water analyses did not show a loss of calcium and the pH did not decrease on cycling, indicating that calcium carbonate precipitation was not responsible for the turbidity. SEM/EDX analysis of deposits on both the heat transfer surfaces and the corrosion coupons identified magnesium as the primary component of the deposits, with little to no calcium present. FTIR analysis of deposits indicated the presence of carboxylic salts, but no calcium carbonate was detected. Deposit analyses strongly indicated that magnesium acrylate was the primary component of the scale deposits. Figure 6.1.7 shows the trends in cycles of concentration based on component concentrations and turbidity. The deposit on the heat transfer tubes was not clearly visible until the tubes had been removed and dried, while the wet deposit was colorless. Hence the evaluation based on visible deposition returned a false apparent ability to operate up to 5.0 cycles of concentration, but the true limitation is more likely to be in the order of 1.7 cycles.

Although corrosion was not a major aspect of this project, pitting was observed during the PAA study with the 70/30 copper/nickel (CDA 751) heat exchange tubes. Pit depths ranging from 8 to 44 μm. Figure 6.1.8 shows the pitting and corrosion observed. Pitting corrosion of the copper/nickel alloy did not occur in any of the other evaluations.

5. CONCLUSION

Laboratory studies under evaporative, heat transfer conditions indicated that systems using seawater as cooling tower make up water can increase the cycles of concentration from 1.2-1.4 to 2.5 with proper chemical treatment. Acceptable calcium carbonate scale control was achieved at 2.5 cycles of concentration with a polyoxyfuran derivative alone and a polyoxyfuran derivative/sulfonated terpolymer combination. Low molecular weight polyacrylic acid alone showed some promise as scale inhibitor, but resulted in pitting corrosion of 70/30 copper nickel heat exchange surfaces. Additionally, deposit analyses data strongly indicate that polyacrylic acid may form an insoluble salt that can result in fouling of both hot and cold surfaces.

REFERENCES
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### 6.2. Tables

<table>
<thead>
<tr>
<th>Comparative Treatment</th>
<th>Synthetic Seawater</th>
<th>Mediterranean Seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Untreated</td>
<td>2 ppm polyoxyfuran derivative</td>
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<tr>
<td>“Attainable” Cycles</td>
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<td>5.6</td>
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</table>

*Authentic / Synthetic for equivalent treatment* 42% 45%

#### 6.2.1. Comparative “cycles attainable” with synthetic seawater and with authentic seawater

<table>
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<tr>
<th>Component</th>
<th>Concentration</th>
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<td>pH</td>
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<td>Conductivity, μS cm⁻¹</td>
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<td>M alkalinity, ppm CaCO₃</td>
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<td>Calcium, ppm CaCO₃</td>
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<tr>
<td>Silica, ppm SiO₂</td>
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</tbody>
</table>

#### 6.2.2. Composition of seawater make up used for evaluations
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NCDs and Biological Control in Cooling Water Systems

William E. Pearson, CWT
February 2011

Abstract: An AWT ASHRAE-Liaison report presents and summarizes the ASHRAE 1361-RP research project on biological control in cooling water systems using non-chemical treatment devices. The ASHRAE funded 1361-RP research was a scientific evaluation of several classes of non-chemical water treatment devices (NCDs) for efficacy in reducing planktonic (bulk water) and sessile (biofilm) microbial populations within a pilot-scale cooling system. The AWT report follows the organizational format of the ASHRAE 1361-RP final report. In addition, it presents a summary of a critique and response to the critique of objections presented to the ASHRAE technical committee (TC3.6) that sponsored the research project.

INTRODUCTION

Microbial growth in cooling water systems leads to undesirable fouling that can decrease system energy efficiency, cause corrosion and has the potential to cause human infection, including Legionnaires’ disease. Control of microbial growth in these systems is typically achieved with the use of chemical (water treatment) biocides. Non-chemical water treatment methods have been used as an alternative to chemical water treatment, especially in the promotion of “Green Building” technology. However, few scientifically objective studies have been performed to verify the efficacy of these devices to control microbial growth in cooling tower systems. Thus, the specific objective of the ASHRAE 1361-RP research investigation was to provide a controlled and independent scientific evaluation of several classes of non-chemical treatment devices (NCDs) for controlling microbiological activity in a model cooling tower system.

ASHRAE 1361-RP investigated the efficacy of five (5) non-chemical devices to control the planktonic and sessile microbial populations within a pilot-scale cooling tower system. The devices included: magnetic, pulsed electric field, electrostatic, ultrasonic, and hydrodynamic cavitation technologies. Two model cooling towers were designed and operated to simulate field conditions with respect to heat load, recirculation, evaporative cooling, blow-down and make-up system requirements, etc. One tower served as the untreated control (T1) tower, while the NCD was installed on the second (T2) test tower. Each device trial was conducted over a minimum of 4-weeks tower operations. Heterotrophic plate counts (HPC) were monitored in both planktonic and biofilm testing regimes. Additional monitoring included temperature, conductivity, pH, alkalinity, hardness, total dissolved solids (TDS), ORP, and chloride. The make-up water used for each tower system was dechlorinated city (Pittsburgh, PA) tap water.

1361-RP Materials and Methods

SYSTEM DESCRIPTION SUMMARY

The following is a summary of the operational details of the pilot-scale cooling tower system. (In depth operational details of the system is presented in the ASHRAE 1361-RP final report.)

Two pilot-scale model cooling tower systems were constructed and used in 1361-RP to evaluate the performance of each device. The two model cooling towers were designed to be identical.

In each pilot-scale system, water was stored in a 60 gallon holding tank prior to being pumped at a 7 gpm (recirculation) rate into a stainless steel heating bath. Flow rate was controlled by using a side stream system placed immediately after the pump discharge. The sidestream returned a portion of the flow back to the holding tank. The rate of return flow was controlled by a needle valve and allowed manual adjustment of the flow rate to achieve the desired 7 gpm.

Immediately prior to entering the heating bath, the water flow was split into two paths with each flow path continuing into copper tubing coils. The two coils wrapped around a 15 kW immersion heater and the entire heating apparatus was surrounded by a stainless steel box containing dechlorinated (make-up) water. The box was sealed with a plexiglass lid to minimize evaporative losses. The immersion heater was controlled by a thermostat, which was adjusted throughout the trials to maintain a water bath temperature of approximately 120°F.

Once the system water passed through the two copper coils, the flow paths were combined. The flow was then diverted through a sampling rack containing a series of biofilm sampling coupons. The sampling coupons (5.61 cm² stainless steel washers) were scrubbed and autoclaved prior to installation in the experimental towers. The coupons were installed at the beginning of each device trial and were used to quantify biofilm growth within each of the cooling tower systems.

Upon exiting the sampling rack, the system flow passed through four number of sensors for data collection, including: pH, ORP, conductivity and temperature prior to the water entering the tower. Each of these sensing probes was connected to an Aquatrac Multiflex data collection system which recorded data at 1-hour intervals. The flow then passed through a flow meter to ensure that the system flow rate of 7 gpm could be maintained. An additional conductivity meter (probe) was positioned immediately prior to the tower entrance and was connected to a blowdown control system. Conductivity readings were used to control the tower blowdown based on a conductivity set point. The set point was chosen based on the make-up water conductivity to achieve 4-5 cycles of concentration in the test cooling tower systems.
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Flow entered each of the cooling towers by way of a 110-degree full cone square spray nozzle. This allowed the flow to be distributed evenly over the surface of the packing installed in each tower. The height of the packing in each tower was adjusted so that the spray from the nozzle contacted the packing at its uppermost edge, diverting flow through the interior of the packing rather than down the side wall of the tower.

Once the water travelled through the packing, it collected into a 20 gallon sump. Upon entering the sump, the water temperature decreased to 85-90°F, thereby maintaining a delta T across the packing of approximately 10°F. Cooling was accomplished by a variable frequency axial fan placed at the top of the tower, above the water entrance. The rate of airflow generated by the fan was controlled by a potentiometer to produce the desired 10°F delta T. The sump was connected to the holding tank via PVC piping, and as water traveled through the system it was pulled from the sump back into the holding tank, completing the cooling water cycle.

For each device trial, a control tower and a test tower were utilized. The control tower received no treatment during the testing process, while the device tower received treatment from the non-chemical device being evaluated. The device was activated at the beginning of the study, and it was not turned off until the investigation had been completed. The control tower in each device trial is referred to as T1 (Control), and the device tower is referred to as T2 (Device).

A total of five (5) non-chemical water treatment devices were tested over the course of the investigation. Before the beginning of each device trial, several measures were taken to ensure consistent starting conditions. Each tower was treated with dilute acetic acid and bleach solutions and allowed to operate for several hours in order to eliminate any residual microorganisms in the system and to remove scale formed during the previous trial. Both towers, including associated sumps and holding tanks, were scrubbed with acetic acid to remove as much scale as possible. Each system was drained completely and refilled with clean make-up water. The draining and refilling process was repeated a minimum of 2 times for each tower prior to the beginning of a new device trial. Additionally, the plastic packing in each of the towers was replaced prior to the initialization of a new test. The new packing was installed after the tower had been drained and rinsed to reduce the amount of residual solid material which it collected.

**BIOLICAL MONITORING SUMMARY**

The following is a summary of the biological monitoring performed in 1361-RP. (In depth details of the biological monitoring is presented in the ASHRAE 1361-RP final report.)

1. Bulk water samples were collected twice weekly. Biofilm samples were collected weekly.
2. A series of three dilutions was plated for HPC testing of each bulk water and biofilm sample.
3. The range of dilutions used for make-up water analysis was 10⁻³ – 10⁻⁴ and that of the bulk water tower dilution range was 10⁻⁴ – 10⁻⁵. The biofilm sample dilution range was 10⁻⁴ – 10⁻⁶.
4. Heterotrophic plate count bacteria test dilutions were plated according to Standard Method 9215 pour plate protocol. The minimum / maximum concentration limits were 1.0 CFU/mL / >300,000 CFU/mL.
5. In addition, measurements of cellular ATP were performed using a test kit manufactured by LuminUltra™ Technologies Ltd. By comparing the measured number of RLUs (relative light units) to a standard (known) ATP concentration, it was possible to determine the concentration of ATP present in each tower system biological sample.
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ULTRASONIC DEVICE (UD)
The use of ultrasonic energy to inactivate microorganisms has been under investigation for a number of years. The interaction of ultrasonic energy with water results in a cavitation process that is explained as a result of the process known as sonication. It is surmised that the collapse of these cavitation bubbles is responsible for bacterial inactivation.

The UD operates by diverting water from the cooling system sump or holding tank through a venturi and into an ultrasonic treatment cell. The flow velocity is increased by passing through the venturi and air is introduced into the water stream. According to the manufacturer, the vacuum pressure generated by the venturi during normal operation should be between 0.4 and 0.75 bar below atmospheric pressure. The water/air mixture then enters an ultrasonic treatment chamber containing 6 ceramic transducers. Upon exiting the treatment cell, the water passes through a basket filter prior to discharge back into the cooling system sump.

The ultrasonic device evaluated in 1361-RP was installed according to the manufacturer’s specifications, and a representative from the manufacturer approved the final installation. A sidestream was constructed for the application of this device, with the sidestream intake positioned near the outlet end of the 60 gallon storage tank and the outflow positioned near the storage tank’s inlet.

HYDRODYNAMIC CAVITATION DEVICE (HCD)
When fluids are subjected to sudden high pressure changes, very small vapor bubbles may form within the fluid in a process known as cavitation. These bubbles quickly collapse, leading to extremely high local temperatures, pressures and fluid velocities. The implosion of these small bubbles of fluid vapor within a liquid has been the mechanism attributed to inactivation of surrounding microorganisms.

Operation of the HCD involves diverting water from the cooling system sump or holding tank into the device, where treatment is effected and the water is returned back to the recirculating system. Water drawn from the system sump enters a pressure-equalization chamber. The flow of water is then split into two separate streams and each of these streams enters a vortex nozzle. The HCD was installed in this study according to the manufacturer’s specifications. According to the manufacturer, the collision of these two conical streams creates a vacuum region which results in the formation of cavitation bubbles. The collapse of these bubbles generates high shear forces, temperatures, and pressures, leading to microbial inactivation.

PRE-DEVICE TRIAL DATA
CHEMICAL DISINFECTION PROTOCOL
To provide scientifically defensible evidence that an industry-tested disinfection method was capable of controlling microbial growth in the experimental system operated in the study, a chlorination (positive control) test was performed prior to the beginning of the device trials. Demonstrating the effectiveness of a disinfection test indicates that the comparison between accepted and experimental treatment mechanisms is valid.

During this test, both T1 (Control) and T2 (Device) systems operated untreated for seven days. On the eighth day, samples were taken and a spike dose of chlorine representing approximately 14 mg/L free chlorine was added to each of the towers. Following the spike dose, a stock solution of chlorine was continuously pumped into each tower system to maintain a free chlorine residual of approximately 1 mg/L for 3 days. Each tower demonstrated a 2-3 log reduction in planktonic microbial activity within 3 days from the beginning of chlorination. The chlorination produced a 4-5 log reduction in sessile microbial activity in each of the tower systems. Make-up water heterotrophic plate counts observed during this chlorination test were comparable to those observed during the device trials which followed.

CONTROL TOWER (T-1) & TEST TOWER (T-2) OPERATIONS
Extensive pre-device trial data, including make-up water consumption, blowdown, conductivity, temperature, water chemistry and biological profiles of the T1 and T2 tower systems in operation demonstrated consistent operation of both the T1 and T2 towers. The chemical and physical parameters were comparable for each of the tower systems and each operated at 5-6 cycles of concentration.

The make-up water quality and performance of T1 (Control) throughout the course of the entire investigation were monitored in order to ensure similar conditions of operation for each individual device trial.

The average values observed in the control tower (T-1) for all of the combined data runs demonstrated consistent, comparable and reproducible operations. The target temperature differential throughout the investigation was 10°F. During all other device trials, a temperature differential of approximately 9-13°F was maintained.

BIOLICAL PARAMETERS
The average heterotrophic plate count log was 4.4 (CFU/mL) for the make-up water over the course of the investigation. Throughout each device trial, a planktonic population of between 10⁵ – 10⁶ CFU/mL was maintained in the control tower. An average sessile heterotrophic plate count of 2.6 x 10⁶ CFU/cm² was observed for T1 (Control) for the entire investigation.

1361-RP EXPERIMENTAL RESULTS
Chemical and operational data
Detailed analysis of the chemical and operational data collected during the investigation of the five (5) non-chemical devices can be obtained from the ASHRAE 1361-RP final report.

DEVICE TRIAL RESULTS
The following is a summary of the device trial results and findings in 1361-RP. (In depth details of the device trials is presented in the ASHRAE 1361-RP final report.)

Magnetic Device (MD)
The results presented in the 1361-RP report demonstrate that the magnetic (MD) non-chemical device did not significantly reduce biological activity compared to the control tower. Planktonic heterotrophic plate counts, ATP measurements, and sessile heterotrophic plate counts from T1 (control) and T2 (device) showed no significant differences at any point during the investigation. Tower operational conditions were comparable throughout the course of the device trial.

Pulsed Electric Field Device (PEFD)
The results presented in the 1361-RP report demonstrate that the pulsed electric field (PEFD) non-chemical device did not significantly reduce biological activity compared to the control tower. Two different trials were actually conducted for the PEFD device at different cycles of concentration. This was done to accommodate the manufacturer’s claim that higher cycles were needed than the 5-6 of the experimental design. The second trial was done at 6-8 cycles of tower concentration. Planktonic heterotrophic plate counts and ATP measurements from T1 (control) and T2 (device) showed no significant difference at any point during either of the device trials.
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The same behavior was observed for sessile heterotrophic plate counts in two tower systems during both device trials.

**Electrostatic Device (ED)**

The results presented in 1361-RP demonstrate that the static electric field (ED) non-chemical device did not significantly reduce biological activity compared to the control tower. Planktonic heterotrophic plate counts and ATP measurements from T1 (control) and T2 (device) showed no significant difference at any point during the investigation. The same trend was observed for sessile heterotrophic plate counts in the two tower systems.

**Ultrasonic Device (UD)**

The results presented in 1361-RP demonstrate that the ultrasonic (UD) non-chemical device did not significantly reduce planktonic or sessile microbial populations compared to the control tower. Heterotrophic plate counts for both planktonic and sessile microbial populations were comparable for T1 (control) and T2 (device). In addition, ATP measurements showed no significant microbial reduction in the device tower system when compared to the control tower system.

**Hydrodynamic Cavitation Device (HCD)**

The results presented in 1361-RP demonstrate that the hydrodynamic cavitation (HCD) non-chemical device did not reduce planktonic or sessile microbial populations compared to the control tower. Heterotrophic plate counts for both planktonic and sessile microbial populations were comparable for T1 (control) and T2 (device). In addition, ATP measurements showed no significant microbial reduction in the device tower system when compared to the control tower system.

**1361-RP (REPORT) CONCLUSIONS**

Five NCDs were evaluated in the ASHRAE 1361-RP study for efficacy in reducing planktonic (bulk water) and sessile (biofilm) microbial populations within a pilot-scale cooling system. The devices included magnetic, pulsed electric field, electrostatic, ultrasonic, and hydrodynamic cavitation. Two model towers were designed and operated to simulate field conditions. One tower (T1) served as the untreated control, while the NCD was installed on the second tower (T2) serving as the test tower.

Each device trial was conducted over a 4-week period. Heterotrophic plate counts (HPC) were used to monitor biological growth in both planktonic and attached phase. Physicochemical monitoring included temperature, conductivity, pH, alkalinity, hardness, total dissolved solids, ORP, and chloride. Make-up water for each system was dechlorinated (Pittsburgh, PA) city tap water.

Under the experimental conditions used in 1361-RP, no statistically significant difference (p values in a t-test above 0.05) in planktonic and sessile microbial concentrations (HPC) was observed between the control tower and a tower treated by any of the five NCDs evaluated. Biological and chemical parameters were comparable in T1 and T2 for all device trials.

A standard chlorine (chemical treatment) protocol was tested in the pilot-scale cooling towers as a positive control response. Chlorine addition was able to achieve significant reduction in both planktonic (2-3 orders of magnitude) and sessile (3-4 orders of magnitude) microbial growth in the test tower systems. Chlorination (positive control) was repeated three times throughout the study and the results clearly showed that free chlorine was able to control biological growth in every instance, even after heavy microbial colonization of model cooling towers.

The results of this study conducted under well-controlled conditions show that NCDs did not control biological growth under the conditions of the testing in the pilot scale cooling tower systems. As with any research project, the conclusions that can be drawn to full-scale applications are limited by the extent to which the variables possible in full-scale are understood and appropriately modeled against controls. The study can only properly conclude that the devices did not successfully control biological growth under the conditions tested.

As with any biological control protocol, it is prudent for building owners and engineers to sufficiently monitor and test water samples for all systems that require biological control. If the testing shows an issue, appropriate adjustment of technology or protocols followed by additional testing is important to prevent potential health or operating issues.

**PEER (NCD) CRITIQUE OF 1361-RP FINAL REPORT & ASHRAE RESOLUTION**

The ASHRAE technical committee that sponsored 1361-RP was TC3.6 (Water Treatment). Prior to a committee vote to approve, or not, the final technical report from the 1361-RP investigators, TC3.6 was presented with a ‘critique’ of the research project and its findings from the NCD manufacturers that participated in 1361-RP and other associated peers.

In addition to TC3.6, the 1361-RP PMS (Project Monitoring Subcommittee), the 1361-RP PI team (principal investigators), as well as various involved ASHRAE directors participated in extensive exchanges, communications and meetings to respond and deal with the objections raised with the 1361-RP study. Ultimately, agreement and/or committee consensus was reached on the objections with the investigators including some additional information and/or explanations in the final 1361-RP report.

TC3.6 voted unanimously 13-0-3 (3 abstentions) to approve the 1361-RP final technical report on September 24, 2010.

**PRIMARY OBJECTIONS & REBUTTAL TO 1361-RP FINAL REPORT**

The major objections raised and presented to refute the negative performance results reported in 1361-RP for the NCDs are summarized and presented as follows.

1. **MAKE-UP WATER:** The research (test) towers make-up water, after dechlorination and storage, had an average total HPC count of 10^6 CFU/mL – making it a ‘contaminated’ and ‘extreme’ (not realistic) make-up water supply.

   The critique acknowledged that make-up water chemistry parameters (pH, alkalinity, hardness, chlorides, etc.) were all statistically (and acceptably) consistent. However, it was presented that the ‘biological content’ of the make-up water was poorly ‘controlled’ and was an ‘execution anomaly’ as an inability to deliver consistent make-up water quality to the test towers. As a result, there was a continuous biological inoculation of the test towers.

   Exception was particularly taken with the de-halogenation method decided upon by the research team and ASHRAE Project Monitoring Subcommittee (PMS). While UV (ultraviolet light) was specified in the 1361-RP research project work statement, activated carbon filtration was opted as a more efficient and effective means to accomplish the requirements in 1361-RP.

   It was further stated that “high nutrient loads could overwhelm the various NCD mechanisms ability to control microbiological activity” – however, this was “not a disadvantage when operated according to Manufacturer’s instruction in commercial settings”.

   **Rebuttal/Response: Make-up Water:** The 1361-RP research (test) towers make-up water, Pittsburgh city tap water, was required to be dechlorinated per the work statement and experimental design to remove any influence of municipal disinfection treatment that...
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could bias the control (T1) and/or device (T2) test tower systems. The decision to use activated carbon filtration versus the work statement proposed ultraviolet (UV) radiation was simply a matter of practicality and efficiency for the 1361-RP experimental design, actual tower systems operation and volume of make-up water to be processed.

Dechlorination was accomplished by passing Pittsburgh city (tap) water through a fixed-bed activated carbon adsorber. The filter column contained a coconut shell based activated carbon.

The coconut shell (based) filter was chosen, in particular, for the removal of trace level organics from water streams with little to no background TOC levels and its quality to add little to no nutrient to the treated water stream.

The make-up water for each cooling tower was stored in four 125-gallon polyethylene tanks to provide enough water for two days of tower operation and, thus, an approximate tank residence time of 48 hours. In between device trials, the carbon column was flushed by running water through it at twice the flow rate necessary for chlorine removal (> 6 ppm) for a minimum of 1 hour.

As well, critical to the entire 1361-RP project was the establishment of a certain quantitative and viable microbial population in the test (and control) tower systems – and, desirable, that it would happen naturally. If not, an alternative artificial microbial (microcosm) seeding approach would have been required – with all the potential problems and drawbacks of it being questioned and ‘critiqued’ as compared to larger scale (real world) systems. The fact that municipal water ends up with higher microbial (HPC) counts after it has been dechlorinated, than what is had when treated, is expected. The fact that the dechlorinated Pittsburgh city water, make-up for 1361-RP, was able to result in the test towers being populated with the design/desired 10^6 CFU/mL (HPC) microbial populations was a positive.

2. CHLORINATION: The ‘amount’ of chlorine used in the chlorination test for positive control demonstration in 1361-RP was excessive and represented an ‘unreal’ amount – and indicated the biological loading on the test cooling towers were an “extreme” case. The chlorination critique took root in reaction to a comment made during the 1361-RP webinar report (March 22, 2010) – that, “it seemed like it really took a lot of chlorine (feed) to maintain the (1 ppm) residual during the three days of the test”. However, the chlorine stock solution that was continuously fed to maintain the 1 ppm (free) chlorine was made by diluting 5.25% (reagent grade) sodium hypochlorite to a 0.0832% sodium hypochlorite solution – with a resultant (quantity) feed of 14.4 liters over the three days and the appearance of “a lot of chlorine”.

As well as any chlorine (oxidant) demand, the pH of the system (water) must also be taken into consideration when discussing chlorine requirements and effectiveness. When chlorine is added to water it becomes hypochlorous acid and hypochlorite ions in a quantity determined by pH.

Hypochlorous acid (HOCI) is 100 times more powerful an oxidant and disinfectant than is the hypochlorite ion (OCl^-). At a pH of 7.5, there is approximately 50% of each in solution. At a pH of 8.5, 90% is as hypochlorite ion and just 10% is as hypochlorous acid. Thus, the effectiveness of chlorine declines with increased pH in a system – requiring nearly four times as much at pH 8.5 than at pH 7.5 for comparison.

An average pH of 8.6 was observed in the operating (cycled) test cooling towers in 1361-RP. A commensurate amount of chlorine was required for demand and to maintain the 1 ppm free residual for the positive control trials.

3. SCALABILITY: Small scale and pilot-scale cooling tower systems are not reliable comparisons to real world (large) systems. In further elaboration on scalability, it was presented that small scale systems have a “much higher surface to water volume ratio than full-scale systems” and that “low water volume could mean a biologically monolithic system lacking the dynamics found in full-scale systems”.

Rebuttal / Response to Scalability Critique: Small scale and pilot-scale cooling tower systems have been extensively used in research for various chemical, including microbiological, mechanical and operational studies and systems applications. Close attention and supervision was provided by a multi-disciplined team of experts involved with 1361-RP for the construction and operation of the small scale (pilot-scale) test towers in the research project.

The two model cooling towers in 1361-RP were designed to be identical. Extensive pre-device trial data, including make-up water consumption, blowdown, conductivity, temperature, water chemistry and biological profiles of the T1 and T2 tower systems demonstrated consistent and operational functionality. Chemical and physical parameters were comparable for each of the tower systems and each operated at 5-6 cycles of concentration.

This (critique) statement or claim is basically without any substantial data or proof—other than to counter the results observed in 1361-RP with those purported to be observed in real world (large) systems for NCD devices and biological control.

REFERENCES

Note: Complete references are provided in the ASHRAE 1361-RP final report cited below.


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ABSTRACT

Hyperbolic concrete cooling towers in seismic zones that have been exposed to corrosion causing conditions of the embedded reinforcement are susceptible to deterioration over a period of time. When repair to such towers are considered, large areas of concrete will probably need to be removed from the thin concrete shell or veil of such structures. This may impair the structural integrity to withstand dynamic loading due to earthquakes. The paper provides a basic approach in developing some guidelines for repairs to the veil to minimize the risk of structural distress in a seismic event that occurs without warning.

INTRODUCTION

Seismic analyses of a hyperbolic natural draft cooling tower were conducted with the purpose of examining the effects of typical concrete distress and possible installation of cathodic protection systems (which may require making slots in both the longitudinal and circumferential directions of the veil) on the structural behavior of the tower. Based on the observed response, guidelines were provided for conducting surface repairs and installing cathodic protection systems while minimizing vulnerability of the tower in a seismic event.

The hyperbolic cooling tower used in this study was located in a mild seismic zone and was designed primarily for wind loads. A detailed discussion of the analysis of the tower for wind is given in a previously published paper, Complex Structural Analysis Simplifies Repair Phasing in Restoration of Hyperbolic Cooling Towers (1). For this study relatively more severe mapped seismic ground acceleration parameters provided in ASCE/SEI 7-05 “Minimum Design Loads for Buildings and Other Structures” (2) were used. The tower was first analyzed for seismic forces in the asdesigned state to provide a baseline to which the response of a distressed tower could be compared. The tower was then analyzed for the repair phase taking into consideration typical corrosion-induced concrete distress on the exterior surface of the tower veil and making slots to accommodate the cathodic protection system.

Approach

The following approach was implemented for this study:

Modeling the cooling tower columns, ring beam and veil using the finite element software package ANSYS (3);

Determining an appropriate code specified seismic response spectrum;

Determining the response of the tower to seismic loads in the asdesigned state under the action of gravity and seismic loads; Modeling an envelope of veil distress based on observed distress on cooling tower veil from condition assessments;

Incorporating slots in the distressed cooling tower model that may need to be provided for installation of the cathodic protection system;

Analyzing the distressed condition model and deducing the effects of distress on the response of the tower to seismic loads.

Background

Structure Description

The reinforced concrete tower analyzed was constructed in the nineteen eighties. The height of the tower analyzed is approximately 137 m (450 ft). The tower veil is supported at the bottom by pairs of diagonally oriented precast rectangular concrete columns. The inner diameter is approximately 104 m (340 ft) at the bottom of the veil, 31 m (100 ft) at the throat (location of the least veil diameter), and 34 m (110 ft) at the top of the veil. The thickness of the reinforced concrete veil wall is typically between 20 to 24 cm (8 to 9.5 in.) and increases to 79 cm (31 in.) and 99 cm (39 in.) at the top (or cornice) and bottom (or ring beam) elevations of the veil, respectively. The veil concrete has a specified compressive strength of 27.6 GPa (4000 PSI). The veil is reinforced with interior and exterior mats of reinforcement in both the vertical and circumferential directions with a clear concrete cover of approximately 3.8 cm (1.5 in.). Reinforcement used in the veil has a yield strength of 414 GPa (60,000 PSI).

The veil consists of cast-in-place reinforced concrete jump-form construction which originates from the concrete ring beam or lintel supported by columns. Concrete placement lift height (i.e. vertical distance between successive construction joints) for the veil is about 1.8 m (6 ft). There are a total of 67 lifts in the veil (see Figure 1). No as-built survey of the cooling tower was conducted to confirm the geometry or verticality of the structure. Thus, geometrical imperfections that can possibly occur during construction were not considered in the analysis.

COOLING TOWER MODELING

Three-dimensional models of the cooling tower in the as-designed and distressed condition states were created using the finite element analysis software package ANSYS. Columns were restrained against translation and rotation at the foundation level since flexibility of the foundation system was not considered in the analysis.

A combination of three-dimensional beam and solid elements were used to model the columns, ring beam, and veil. The columns were modeled with threedimensional beam elements. The ring beam, veil, and cornice were modeled using threedimensional reinforced concrete solid elements. Dummy beam elements were used to provide rotational compatibility between the solid elements representing the
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the finite element model.  The model deteriorated and the repair methods expected to be employed.  Metate of the worst case of distress caused by both corrosion-induced towers, the scenario that incorporated all the conditions mentioned above is discussed in this paper.  This model is a conservative estimate of the maximum considered earthquake (MCE). Two spectral acceleration parameters are provided in seismic hazard maps for constructing the spectrum, namely:

- Mapped MCE spectral response acceleration parameter at short periods ($S_s$), and Mapped MCE spectral response acceleration parameter at 1 second ($S_1$)
- The mapped values of spectral accelerations provided in ASCE/SEI 705 are for a specific site class (Site Class B, which is made of soft rock) and for 5% of critical damping. For site classes other than provided in the maps, site class coefficients are provided for modifying the spectral acceleration parameters.

The MCE is converted to a design earthquake by multiplying spectral accelerations by 2/3. The design earthquake has a lower return period than the MCE. Design spectral accelerations are based on a lower bound estimate of the margin of safety against collapse thought to be inherent in structures designed in accordance with the ASCE/SEI 705 provisions. It is believed that the design provisions provide adequate reserve capacity in most structural elements to resist collapse at the MCE hazard level. The following parameters obtained from ASCE/SEI 7-05 were used to construct the spectrum and in postprocessing the analysis results:

- Occupancy Category: IV
- Site Class: D
- Seismic Design Category: D
- Occupancy Importance Factor (I): 1.5
- $S_s$: 0.7g, and
- $S_1$: 0.2g.
- Response Modification Coefficient (R): 3.0
- Redundancy Factor (p): 1.0

Note that $S_s$ and $S_1$ are expressed in terms of gravitational acceleration (g). The MCE response spectrum and corresponding design response spectrum are shown in Figure 8 and Figure 9, respectively.
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The response spectra are shown for periods relevant to the vibration characteristics of the models analyzed.

Analysis

The finite element models were analyzed under the action of dead loads and the earthquake response spectrum. Dead loads were applied first, after which the spectrum analysis was conducted. Two orthogonal horizontal components of the earthquake were considered. Rotational symmetry in both the asdesigned and distressed-condition models allowed effects of the two horizontal components to be determined by applying the load along a single horizontal axis of symmetry. The vertical component of the earthquake was neglected per ASCE/SEI 705 provisions. For each model a modal analysis was first conducted to determine the natural frequencies. The fundamental frequency of the asdesigned model was 1.0806 Hz. The distressed-condition model had a fundamental frequency of 0.91214 Hz. The response spectrum was then applied to the model and modal participation factors determined. Modal participation factors give an indication of the contribution of each mode to the total dynamic response of a structural system. Four modes were determined sufficient to contribute a modal mass of at least 90% of the actual mass of the structure (the minimum per ASCE/SEI 705) in the direction of the spectrum. These modes were combined for the seismic response using the complete quadratic combination (CQC) method with 5% of critical damping. The CQC method is discussed in “A Replacement for the SRSS Method in Seismic Analysis” (4). For threedimensional models and in cases were modes are closely spaced, the CQC method provides a better statistical estimate of maximum structural response than the square root sum of squares (SRSS) method, which is more commonly used. For the asdesigned model, the four combined modes yielded a modal mass participation of 93.6%. In the distressed-condition model, the four combined modes yielded a modal mass participation of 95.3%. Stability of the cooling tower (buckling) was beyond the scope of this study and was not investigated. This may however warrant investigating especially when large areas of concrete are removed from the thin shell of the structure.

Results

Distributions of maximum principal stresses across the height of the tower are shown for the asdesigned model in Figure 10. These stresses are due to the dead load and design response spectrum. Dead load stresses (D) are compressive and are shown on the negative axis. Stresses caused by the response spectrum (E) could either be positive or negative due to the oscillating nature of the structure in a seismic event. They are shown on the positive axis because the squaring operation inherent in the modal combination removes signs from directional signed quantities. Earthquake stresses designated “0 deg” are stresses in the direction in which seismic loads were applied in the model. Earthquake stresses designated “90 deg” are stresses in a direction 90 degrees from the direction of seismic load application. Due to rotational symmetry in geometry, these stresses are identical to stresses that would occur in the direction of seismic load application (0 degree direction) if the loads had been applied in the 90 degree direction.

Maximum stresses along a meridian of the tower due to the response spectrum are shown for the two horizontal components of the earthquake. The total seismic response was obtained by combining 30% of the stresses due to one component with 100% of the stresses due to the other (ASCE/SEI 705). The combination resulting in the maximum stress distribution was used. The total seismic response (force effects) was then divided by the quantity R/I as provided in ASCE/SEI 7-05. Dead load and seismic load effects were then factored and combined. The load factors and combinations were taken from ASCE/SEI 705 and ACI 31808 “Building Code Requirements for Structural Concrete” (5). Identical load factors and combinations are given in both references:

- 1.2D + 1.0E (for dead load compression and seismic load compression)
- 0.9D + 1.0E (for dead load compression and seismic load tension)

The stresses shown in Figure 10 are stresses for which the tower would be designed if it were located in a region within the United States for which the spectral acceleration values used were applicable. To check the possibility of veil cracking under the action of applied loads a tensile strength of 2485 Mpa (360 PSI) was used. This tensile strength is the stress corresponding to a strain of 0.0001 in concrete (“Reinforced Concrete, Mechanics and Design” (6)). It can be seen from the load combinations labeled “C” and “T” that calculated design stresses were within the elastic range. This, however, provides no information on the ability of the tower to dissipate energy released in a seismic event, which is beyond the scope of this paper.

Figure 11 and Figure 12 show unfactored maximum stresses determined for the asdesigned and distresscondition models, respectively. Since it was not practical to apply the R/I divisor to stresses in the distressed model, they were removed from the asdesigned model stresses to ensure an unbiased comparison between Figure 11 and Figure 12. Combined dead load and seismic stresses in Figure 11 are higher than those in Figure 10 because the quantity R is used to reduce calculated forces (and force effects) to a strength level in Figure 10. In the seismic design process, force effects are reduced by R while displacement effects are amplified by R. The overall goal is not to prevent cracking but to ensure that the designed structure has sufficient strength and ductility to dissipate energy released in a seismic event.

The abrupt changes in stress at elevations of about 15.2 m (50 ft) and 83.8 m (275 ft) in the distressed-condition model occur at areas in the model where 3.5 in. of concrete was removed from the exterior surface of the veil (Figure 5). The reduction in cross section at these locations led to the development of high local stresses. Between the two locations discussed above, 25.4 mm (1 in.) of concrete was removed. Since the change in section in this region of the model was relatively small compared with the upper and lower regions, the increase in stress from the asdesigned state was less severe. The load combination for seismic load tension in Figure 12 shows tensile stresses greater than the tensile strength of concrete at elevations between 83.8 m (275 ft) and 110.5 m (362.5 ft). It should be noted that veil thickness is smallest in this region. Compressive stresses, however, were still within the elastic range (from the definition of modulus of elasticity of concrete in ACI 318-08, concrete was considered elastic in compression if stresses were equal to or less than 45% of the specified compressive strength). Since the response spectrum analysis was linear elastic, stresses greater than the tensile strength of concrete could develop in the model. In reality concrete is likely to crack before these high stresses can be reached.

The ratio of stresses in the distressed state to stresses in the asdesigned state is shown in Figure 13 for both compression and tension. The plot shows that there is generally a more severe increase in tensile stress than compressive stress in the distressed-condition model. Due to the higher tensile stresses, the potential for concrete cracking is significantly increased in the distressed condition. The primary purpose of undertaking structural repairs is to restore structural performance to a level as close as possible to the original design intent. By minimizing the stress ratios in Figure 13 such that they are as close to one as possible (in areas where they are greater
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than one), vulnerability of the cooling tower to failure in a seismic event can be reduced.

CONCLUSION

The hyperbolic cooling tower used for this study was designed primarily for wind loads. The analysis conducted was intended to estimate behavior of the tower in the event of an earthquake from which guidelines for repair could be developed. To this end, spectral accelerations more severe than exist in the geographic location of the tower were arbitrarily used for the purpose of this study.

Results of the analyses indicated elastic behavior of the cooling tower in the asdesigned condition. It was expected that existing corrosion-induced concrete distress and reduction in the effective area of cross section of reinforcing bars would diminish the ability of the tower to resist seismic loads. It was also expected that any future damage resulting from the concrete removal process for surface repairs and cathodic protection installation would further diminish structural capacity. Results from the distressed condition model showed that cracks could be expected to form in the region of minimum veil thickness, though maximum tensile stresses in the asdesigned model did not occur in this region.

Cooling towers vary in height and geometry and are subject to different seismic load conditions depending on their location. When a repair program is undertaken for any cooling tower, careful analysis needs to be conducted in both the existing and distressed conditions to fully understand their capacities and constraints that need to be imposed in executing the work to maintain structural integrity of the relatively thin shell structure. The guidelines suggested below are to help minimize the potential for failure during repairs to the tower veil:

- A thorough condition survey of the tower should be conducted such that models can better approximate the current condition of the tower.
- Before repairs commence the owner and repair contractor should be made aware of the ability of the tower in its current state to withstand seismic loads.
- The owner should be made aware of risks associated with removal of more concrete than what is delaminated/spalled for repair purposes (e.g. when steel is undercut during repairs).
- If swing stages are to be used during repairs, input from the repair contractor regarding the number and width of the swing stages will be helpful in determining how much of the veil surface can safely and realistically be worked on at a particular time. Such scenarios need to be analyzed carefully for the vulnerability of the veil in a seismic event.
- The anchorages for the support of the swing stages also need to be carefully designed.
- It is generally recommended that concrete removal and repair be conducted in a symmetric manner around the cooling tower.
- The linear response spectrum analysis done in this study is a reasonable basic analysis to get an understanding of the vulnerabilities of the tower to a seismic event. However, to better predict behavior and possibly simulate the mode of failure of a cooling tower under seismic loads, a nonlinear dynamic analysis is warranted. Such an analysis implicitly considers buckling failure modes, which cannot be investigated with a response spectrum analysis. Time history seismic data in the region where the tower is located will be needed for such an analysis to be conducted.

REFERENCES

5. American Concrete Institute, Building Code Requirements for Structural Concrete, ACI 318-08.
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Figure 3. Finite element model of circumferential columns

Figure 4. Orientation of reinforcement within elements
- Green (horizontal) lines represent circumferential steel
  - Red (vertical) lines represent meridional steel

Figure 5. Schematic of distress envelope

Figure 6. As-designed column section

Figure 7. Model of distressed column section
Figure 8. Maximum Considered Earthquake response spectrum

Figure 9. Design response spectrum

Figure 10. Design level stresses (as-designed model)

Figure 11. Unfactored maximum stresses (as-designed model)

Figure 12. Unfactored maximum stresses (distressed condition model)

Figure 13. Ratio of stresses in the distressed state to stresses in the as-designed state
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Robert Giammaruti
Hudson Products Corporation

ABSTRACT
This is a follow-up on the Cost of Noise paper presented in 2008 (TP08-16). The 2008 paper focused on how noise affected project cost as a function of reduced far-field noise, for a static heat exchanger design. However, an air-cooled heat exchanger designer must take into account a second component when looking at noise: specifically, how to balance the cost of the air-cooler metallurgy and design pressure with site noise requirements. In this paper, we will look at the effect of far-field noise as a function of air-cooler metallurgy and design pressure. The goal will be to demonstrate how these additional parameters influence optimum air-cooler cost design.

INTRODUCTION
• As in the 2008 paper (Reference 1) we will look at the effect of air-cooler materials and design pressure on an 11 bay bank of Air-Cooled Heat Exchangers (ACHEs). These are the assumptions that went into this analysis:
  • The total airflow delivered by the fans to the item is maintained as noise is reduced. Individual fan airflow and corresponding static pressure will vary as air-cooler bays are added.
  • Noise reduction is achieved by speed reduction of the fans, modification of the fans to different blade counts, blade types and addition of fans via additional air-cooler bays. No other noise abatement devices were considered. Only standard motors, gears or drives were employed.
  • Far field noise predictions are for fans only. No attempt was made to assess noise generated by the drive/gear systems or motors.
  • Inlet conditions and tip clearances of the fans remained constant.
  • Far field noise for the ACHE was predicted at 100 meters perpendicular to the long side of the units, 2 meters above the ground.
  • Tolerance on far field Sound Pressure Level (SPL) noise predictions are +/- 2 dBA.
  • Tolerance on cost estimates is +/-10% to 15%.

AIR-COOLED HEAT EXCHANGER DESCRIPTION
The base design air-cooled heat exchanger (ACHE) described in this paper (Figures 1 and 2) is a grade mounted, induced draft item built to the API-661 Standard (Reference 2). The ACHE has a thermal duty of 29.3MW (100 Million Btu/hr) cooling light gasoline from 60.3C (141F) to 37.8C (100F) at an ambient design temperature of 32.2C (90F). The base item consists of 11 individual bays with 12.2 m (40.0ft) long 25.4 mm (1.0 in) OD tubes with extended surface. The extended surface consists of extruded aluminum fins 15.9 mm (0.625 in) high fins spaced at 10 fins per inch. The tubes are spaced in an equilateral tube pitch of 63.5 mm (2.5 in). The individual bays are 4.98 m (16.34 ft) wide with an overall item with of 54.8 m (179.8 ft). Height from the bottom of the tube bundle frame to grade is 2.74 m (9.0 ft).

The base mechanical fan drive systems consist of 25 HP, 60 HZ, single speed motors, synchronous belt speed reduction, and 3.96 m (13 ft) fiberglass reinforced plastic (FRP) fans with 4 blades. Each bay has two mechanical drive systems. Additional fans were added two at a time by adding one complete bay.

Table 1 lists the common operating parameters of all the ACHE fans studied. Table 2 lists the airflow and static pressure of each fan as a function of the number of bays used.

<table>
<thead>
<tr>
<th>Fan Parameter</th>
<th>Value or Description</th>
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<tr>
<td>Air Density, kg/m³ (lb/ft³)</td>
<td>1.157 (0.0722)</td>
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<td>Inlet Bell Type</td>
<td>Rounded (R/D = 0.05)</td>
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<tr>
<td>Fan Diameter, m (ft)</td>
<td>3.96 (13.0)</td>
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</table>

Table 1. ACHE common fan-operating parameters.
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1-800-634-9160 (24 Hours)
E-Mail: hudsonproducts@hudsonproducts.com
Table 2. ACHE fan-operating parameters per bay count

<table>
<thead>
<tr>
<th>Number of Bays</th>
<th>Air Flow m³/sec (ACFM)</th>
<th>Static Pressure Pa (in H2O)</th>
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<td>11</td>
<td>72.53 (153,680)</td>
<td>129.5 (0.52)</td>
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<td>12</td>
<td>66.49 (140,875)</td>
<td>108.8 (0.44)</td>
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<td>13</td>
<td>61.37 (130,037)</td>
<td>92.7 (0.37)</td>
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<td>14</td>
<td>56.99 (120,750)</td>
<td>80.0 (0.32)</td>
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<td>15</td>
<td>53.19 (112,699)</td>
<td>69.7 (0.28)</td>
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<tr>
<td>16</td>
<td>49.86 (105,655)</td>
<td>61.3 (0.25)</td>
</tr>
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DESIGN PRESSURE VS. DESIGN METALLURGY

Overall, far field air-cooler noise is nearly exclusively due to the axial flow fans used and the speed (RPM) at which they are operated. This is due to the low frequency noise axial flow fans emit, normally in the 125 to 250 Hz range, which tend to travel farther than high frequency noise associated with drive systems and motors. Thus, fans are the focus of attention when determining far field noise requirements.

The designer has one or more of the following options available in order to meet the far field noise target:

- Reduce the fan speed (RPM)
- Increase the number of fan blades
- Use wider chord fan blades
- Use ultra low noise fan blades
- Lower the per fan duty point (airflow and static) by increasing air-cooler surface (i.e., bays)

However, unlike other types of heat transfer equipment that employ axial flow fans, there are two added variables for which the designer must account – design pressure and design metallurgy.

For a given thermal design, design pressure will dictate the thickness of the pressure vessel box header (Figure 3) as well as the process tube thickness. The higher the design pressure, the higher the cost of the air-cooler. Similarly, design metallurgy also affects air-cooler price. The higher the alloy needed, the higher the material cost, and the higher the air-cooler cost. Figures 4 and 5 shows the effect of design pressure and metallurgy respectively on air-cooler costs.

Figure 4. Effect on design pressure on air-cooler costs.

Figure 5. Effect on metallurgy on air-cooler costs – carbon steel = 1.00

As shown in Figures 4 and 5, it is clear that, while design pressure has an impact on the overall cost of an air-cooler, metallurgy dominates. Figure 5 quantifies that metallurgy alone can increase the cooler cost anywhere from 2 to 10 times that of a standard carbon steel item. Thus, for the purpose of this paper, only metallurgy will be considered when evaluating the cost of far field noise.

LOW NOISE FANS OR ADD SURFACE?

Given the large effect of material cost on overall air-cooler price, a designer has to balance the use of lower noise (and more expensive) fan equipment versus using standard fan equipment and more heat exchanger surface. (Lower per fan airflow and static pressure) Table 3 shows the number of bays needed to meet the far-field specified SPL at 100 meters for the air-cooler units described earlier.

Table 3. Number of bays required to meet the specified SPL at 100 meters.

<table>
<thead>
<tr>
<th>Sound Pressure Level per Fan @ 100 Meters dB(A)</th>
<th># Bays STD Fan Type</th>
<th># Bays VLN Fan Type</th>
<th># Bays ULV Fan Type</th>
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<tr>
<td>52.4</td>
<td>14</td>
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<td>11</td>
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<tr>
<td>51.1</td>
<td>15</td>
<td>12</td>
<td>11</td>
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<tr>
<td>48.2</td>
<td>16</td>
<td>14</td>
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STD – Standard Noise, VLN – Very Low Noise, ULN – Ultra Low Noise

The SPL at 100 meters can be achieved with standard noise (STD), very low noise (VLN) and ultra low noise (ULN) fans depending on the amount of heat transfer surface used. Additional bays are required, over the initial 11 bay design, to achieve the desired results.
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as the far field noise level is reduced. (See Figure 6 for a general size comparison of the three fan types used for this analysis.)

Figure 6. Size comparison of standard noise (foreground), very low noise (middle) and ultra low noise (back) fan blades

As one can see in Figures 7, 8 and 9, the lowest cost combination varies as both a function of metallurgy and noise. Referring to Figure 7, for all materials selected, the 11 bay options with VLN fans provides the designer with the optimal cost selection for the given far field noise requirement. Referring to Figure 8, as the SPL at 100 meters is reduced to 51.1 dBA, the ULN fan option begins to provide the lowest overall cost option for the high alloys. As the far field SPL at 100 meters reaches 48.2 dBA, the ULN fan supplied air-coolers have the lowest overall cost for all metallurgies employed, as shown in Figure 9. This is despite having nearly doubled the fan and mechanical costs of the VLN fan system and four times the cost of the STD fan system.

Thus, as the far field noise levels are reduced, the ULN fan systems can provide the overall lowest air cooler cost, despite their significant additional cost. This is especially true for the higher alloy materials.

Author’s Note: The material pricing used to develop this analysis is subject to significant price volatility. The results shown here can be significantly affected by material price swings. Given that every situation is unique, the owner/operator is encouraged to investigate all possibilities with the OEM/Supplier.

Figure 7. Cost comparison of multiple metallurgies at 52.4 dBA 100 meters (SPL)

Figure 8. Cost comparison of multiple metallurgies at 51.1 dBA 100 meters (SPL)

Figure 9. Cost comparison of multiple metallurgies at 48.2 dBA 100 meters (SPL)

SUMMARY

The cost of noise (in this case lower noise) significantly impacts the cost of an ACHE depending on how low the far field noise requirement is and the metallurgy employed. The designer should be aware that the expense of advanced low noise fan and associated mechanical equipment may offset additional alloy air-cooler bays under certain circumstances. However, the opposite is generally true for carbon steel and low alloy materials.

While this analysis is far from exhaustive, the author hopes this paper provides the reader with an additional perspective on overall unit noise. To wit, your optimal cost solution may be as much a function of metallurgy as noise.

REFERENCES

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<th>Agency Name</th>
<th>Contact Person</th>
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| A, B         | Clean Air Engineering  
7936 Conner Rd  
Powell, TN 37849 | Kenneth Hennon  
www.cleaniel.com  
kennon@cleaniel.com | 800.208.6162 | 865.938.7569 |
| A, B         | Cooling Tower Technologies Pty Ltd  
PO Box N157  
Bexley North, NSW 2207  
AUSTRALIA | Ronald Rayner  
coolingwrtech@bigpond.com | 61 2 9789 5900 | 61 2 9789 5922 |
| A, B         | Cooling Tower Test Associates, Inc.  
15325 Melrose Dr.  
Sanley, KS 66221-9720 | Thomas E. Weast  
www.cttai.com  
cttai@ao.com | 913.681.0027 | 913.681.0039 |
| A, B         | McHale & Associates, Inc  
4700 Coster Road  
Knoxville, TN 37912 | Thomas Wheelock  
www.mchale.org  
tom.wheelock@mchale.org | 865.588.2654 | 425.557.8377 |

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Type B license is for the use of remote data acquisition devices which can accommodate multiple measurement locations required by larger towers.

### Licensed CTI Drift Testing Agencies

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| Clean Air Engineering  
7936 Conner Rd  
Powell, TN 37849 | Kenneth Hennon  
www.cleaniel.com  
kennon@cleaniel.com | 800.208.6162 | 865.938.7569 |
| McHale & Associates, Inc.  
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NUMBER OF PARTICIPATING MANUFACTURERS

Through 12/01/2011

Private Brands  Manufacturer Brands

YEAR

CTI Journal, Vol. 33, No. 1
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# Cooling Towers Certified by the CTI under STD-201

Internet links for the Manufacturers, their specific product lines, and the selection information for each product line can be found at: [http://www.cti.org/certification.shtml](http://www.cti.org/certification.shtml)

Revised 12/08/2011

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<td>Sinro Air-Conditioning (Fogang) Co. Ltd.</td>
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<td>JNC Series</td>
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Internet links for the Manufacturers, their specific product lines, and the selection information for each product line can be found at: [http://www.cti.org/certification.shtml](http://www.cti.org/certification.shtml)
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