Call on the Screening Experts

Replace your existing bar screens on line, without any basin modifications with our unique, continuous screening.

**Vari-Flow SS Series**

**Traveling Sump Screen**

The Vari-Flow SS Series Traveling Sump Screen is custom fabricated to easily replace stationary screens while your unit stays in full operation. The screens can be automated and are available in more than 20 different screen-mesh sizes. The Traveling Sump Screen is patented, manufactured and distributed by Industrial Cooling Tower Services. Let the experts handle your equipment screening needs with this easy-to-use, cost efficient solution.
Contents

Feature Articles
8 Film Formation, Stability And Corrosion Inhibition Of Surface Deposited Film Inhibitors
Jon J. Cohen, Henry A. Becker and Sean Parmelee

14 Accurately Determining Drive Shaft Natural Frequencies
Duane Byerly

22 Application of Controlled Release Chemistry to Cooling Towers
Miles Stoffer and Kevin Emery

28 Experimental Characterization of Wind Effect on Natural Draft Cooling Towers
Christophe Duquennoy

50 Water Reuse – As Time Goes By Do The Less Attractive Approaches Or Options Now Look More Attractive
Roy A. Holliday and Gary E. Geiger

56 Fiberglass Reinforced Polyester in Cooling Towers - Structural Application
Ken Mortensen

66 How Sensor Mounting Affects Measurements
David A. Corelli

Special Sections
71 CTI Licensed Testing Agencies
74 CTI Certified Towers
72 CTI ToolKit

Departments
2 Multi Agency Press Release
2 Meeting Calendar
4 View From the Tower
6 Editor’s Corner
CTI Journal
The Official Publication of The Cooling Technology Institute

Vol. 34 No. 2 Summer 2013

Journal Committee
Paul Lindahl, Editor-in-Chief
Art Brunn, Senior Editor
Virginia Manser, Managing Director/Advertising manager
Donna Jones, Administrative Assistant
Graphics by Sarita Graphics

Board of Directors
Jack Bland, President
Frank L. Michell, Vice President
Steve Chaloupka, Treasurer
Tom Toth, Secretary
Billy Childers, Director
Trevor Hegg, Director
Natasha Jones, Director
Philip R. Kiser, Director
Dean Lammering, Director
Helene Troncin, Director

Address all communications to:
Virginia A. Manser, CTI Administrator
Cooling Technology Institute
PO Box 73383
Houston, Texas 77273
281.583.4087
281.537.1721 (Fax)

Internet Address:
http://www.cti.org

E-mail: vmanser@cti.org

FUTURE MEETING DATES

Annual Conference

February 2-6, 2014
Hilton (Greenspoint)
Houston, TX

February 8-12, 2015
Sheraton
New Orleans, LA

Committee Workshop

July 13-16, 2014
Sheraton Steamboat
Steamboat Springs, CO

July 12-15, 2014
Tradewinds Island Resort
St. Pete Beach, FL

For Immediate Release
Contact: Chairman, CTI Multi-Agency Testing Committee

Houston, Texas, 3-May-2013

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 September 1, 2013, at the CTI address listed.

FASTEC INTERNATIONAL

FRP Shapes & Decking
Crane Quality Corrugated Fiberglass Panels
CCA Treated High Quality Lumber & Plywood

Super Competitive Pricing
Lightening Fast Customer Service
Fabrication Facility Opening September 2013!

GAIENNIE LUMBER COMPANY

Industrial Products Division
BOX 1240 • OPELOUSAS, LA 70571-1240
800-326-4050 • 337-948-3067
Email: CT@Gaiennie.com
Swifter CTX Series

The next generation of industrial fans for cooling towers and heat exchangers.

swifterfans.com
GLOCON INC • PARSIPPANY NJ USA • 973-463-7300
View From The Tower

I hope everyone is enjoying Summer 2013 and I want to thank all of the member companies for supporting the attendance at our recent Summer Workshop at the Hilton Del Mar outside of San Diego, California. We had an excellent turnout with over 100 attendees and much progress was made by each of our three standing committees on updates and completion of several important standards and guidelines.

Some of the important issues addressed at the Summer Workshop were as follows:

Certification Administrator
We are very close to selecting a dedicated Certification Administrator to oversee the Thermal Certification and Multiagency Testing programs. This process has taken longer than the committee originally envisioned; however, the enhanced scope of work document has resulted in numerous applicants for the position. I also wish to extend thanks to Tom Weast and his company, CTTA, for willingness to assist us during the transition period, once a Certification Administrator is selected. My sincere thanks to all of the members of the Certification Committee for their dedication to producing a detailed scope for our recent open solicitation for the Certification Administrator position.

STD-202 Standard For Publication of Custom Cooling Tower Thermal Performance Test Results

This document is almost complete and has undergone ad hoc and legal review. It may be a published CTI Standard by the time of this message.

STD – 159 Legionellosis Related Practices for Evaporative Cooling Systems

We are making progress. This document has also completed ad hoc review and the committee is continuing to work on suggested revisions and edits. A rush to publish this standard is not in the best interest of our user community as the primary goals of 159 are to provide environmental, operational, and design practices for the control of legionella bacteria in evaporative cooling systems.

2014 Winter Meeting: Feb 2-6 at the Hilton North, Houston, Tx.

Our program committee has received lots of excellent abstracts for potential presentation and Vicky Manser has already filled more than half of the 44 Table Top Exhibits available. If your company has not already reserved a table top space, please do so now.

Please enjoy the remainder of the summer and thanks again to all of the participants in our Summer Workshop.
The Industry’s Most Trusted Source in Components!

Dynamic Fabricators

We are known for providing dynamic solutions resulting in quality advantages and competitive pricing. Providing excellent customer service is our #1 priority. It's what keeps our customers coming back.

Your Complete Cooling Tower Supply Source with Locations in Wapato, WA & Elmore, AL

- Header, Bypass, Riser and Lateral Distribution Syst.
- Fan Stacks, Fan Ring, Inlet Bells, FRP Basins.
- Fiberglass Pipe Saddles, Tanks, Access Hatches, Doors, Molded Stairs & Distribution Splash Boxes.

Your dynamic partner in cooling tower components...

Toll-Free 877.604.6525
www.dynafab.net • Email us at: sales@dynafab.net
Dear Journal Reader,

As I celebrate my 45th anniversary with one of the founding companies of the Cooling Technology Institute, I have spent some time thinking back to earlier days of our industry. My first exposure to the industry was in the mid to late 50’s, as a boy. My father worked for about 5 years in what was called the Apparatus group then and I believe he was designing gearboxes. His first big project was designing a test rig for gearboxes on a field erected wood structure. It had a natural-gas-fired Cadillac engine for motive power. The test rig and the temporary worker who helped my father were both still at the lab when I started working there in 1968 - after my first year of engineering school.

Working in a lab setting was kind of a playground for engineer types and gave me exposure to the depth that exists around trying to design cooling towers to be what is expected of them in the real world. Between my childhood experience with my father’s co-workers and my time at the lab later, an appreciation of people who were involved in the company and our industry developed. By the time I graduated from college, I knew a lot of people and had heard a lot of stories about the days before I was involved myself. A lot of interesting and unusual people have been involved in our industry, and that is understated as some of you know. Having known and heard the stories from a lot of people who worked through some of the earliest years of the industry has made my apparent experience a bit longer than the actual.

One thing that I learned over the years is that the current CTI is not the first one. There was actually one started in 1939 that included Binks, Fluor, Foster Wheeler, Lilie-Hoffmann, Marley and Schubert Christy. It was called the Water Cooling Tower Association. It lasted until 1941. There was another attempt made after the war in 1948 as a product section in a predecessor of the Air-Conditioning Heating and Refrigeration Institute. The 3-4 companies involved are not fully known, as no records exist. However, the participants are known to have included some of those listed above. Ultimately, they decided a more industrial and power oriented focus was needed than available within AHRI. They evidently liked the “institute” name, as the Cooling Tower Institute was formed in 1950, headquartered in Basking Ridge, NJ. All three attempts were manufacturer-only trade associations. The seven charter companies in 1950 were Fluor, Foster Wheeler, Hudson Engineering, Lilie-Hoffmann, Marley, J.F. Pritchard and C.H. Wheeler. Some overlap is obvious with the 1939 group. CTI later was forced to transition to an industry association, enabling its survival to today. Supplier and owner/operator member categories were added.

Another unusual thing I learned that many would not know today is that the cooling tower industry was actually designated as a critical defense industry during WWII, and its manufacturing capability was not converted to other purposes as were so many others. Our industry produced products through the war that were used in manufacturing necessary equipment and in generating the electric power to do the manufacturing. They were also used in the Manhattan Project, at Oak Ridge, Paducah and Los Alamos. I remember my father flying to Tennessee once in the late 50’s for a meeting on the Oak Ridge cooling towers - on a giant looking four engine Constellation Super G, which may have been more impressive to me at the time than the purpose of his trip.

Our industry has a deep and colorful history. I hope I have baited your interest.

Respectfully,

Paul Lindahl
CTI Journal Editor
MADE IN THE USA

Fiberglass Shapes & Decking for Cooling Towers -- Produced EXCLUSIVELY in the United States of America

Dimensional FRP Wood Alternatives

3½" x 5½" x ¼" EXTREN® Rectangular Tube

3½" EXTREN® Square Tube

3½" EXTREN® Channel

5½" EXTREN® Channel

1½" deep SAFDECK®

DURAGRID® R-8300 Pultruded Grating

Learn more by scanning with your smartphone or mobile device!

Our Design Manual is now ONLINE! Visit now to sign up for 24-hour access to the most up-to-date design information available!

The World's Largest Supplier of Pultruded Products for the Cooling Tower Industry!

400 Commonwealth Avenue, Bristol, VA 24201
(276) 645-8000 • Fax (276) 645-8132
info@strongwell.com • www.strongwell.com

www.strongwell.com/designmanual
Abstract
A novel methodology for studying the formation of surface deposited corrosion inhibitors on copper has been developed. The methodology has been reported previously, including a detailed study of the mechanism of film formation. This study continues the use of the test method; detailing kinetics of film formation for various surface deposited film inhibitors not previously reported, corrosion rates using various inhibitors and affects of halogenated compounds. Results of synergistic mixtures of film deposited inhibitors will also be presented.

Introduction
The class of organic corrosion inhibitors commonly referred to as “azoles” is based on the indene structural motif, and generally contains three heteroatom (N or S) substituents in or on the five-membered ring. Common corrosion inhibitors in this class include 1H-benzotriazole (“benzotriazole” or BTAH), the pair of isomers 4- and 5-methyl-1H-benzotriazole (collectively referred to as “tolyltriazole” or TTAH), the pair of isomers 4- and 5-n-butyl-1H-benzotriazole (collectively referred to as “butylbenzotriazole” or BBTAH), 2-mercaptobenzothiazole (“mercaptobenzothiazole” or MBT), and the pair of isomers 4,5,6,7-tetrahydro-4-methyl-1H-benzotriazole and 4,5,6,7-tetrahydro-5-methyl-1H-benzotriazole (collectively referred to as “tetrahydrotolyltriazole” or H4TT). Coordination complexes containing azole ligands are known for a variety of divalent transition metals and post-transition metals, including manganese, iron, cobalt, nickel, copper, zinc, and lead, with the azoles generally adopting a bridging mode to form polymeric compounds. As a result, these metal-azole complexes are highly insoluble, forming stable films on the surface of metals. This effect is well known for copper, where azoles find widespread use as anodic corrosion inhibitors.

In addition to traditional copper corrosion inhibition applications, particular interest in the interplay of copper and other metallic surfaces typical of commercial and industrial hydronic systems. The relatively noble copper ion can form a microgalvanic couple on certain metallic surfaces, electrodepositing and giving rise to pitting corrosion. This effect occurs well within the pH region in which such surfaces are predicted to be electrochemically passive, significantly narrowing the window of safe operation for such systems. A clearer picture of the processes underlying galvanic corrosion in the presence of copper and the ability of corrosion inhibitors to block these processes, is thus desired.

In this work, the development and corrosion inhibition of chemisorbed azole films on copper as are studied via quartz crystal microbalance, gravimetric analysis, and bulk solution methods. Detailed kinetic and mechanistic information is described from laboratory studies, including a comparison of the chemisorption and corrosion inhibiting properties of the three azoles studied.

Experimental
Bulk solution & gravimetric analysis
A series of borate buffer solutions were prepared, as detailed in the following table:

| Table 1: Composition of borate buffers used for precipitation study. |
|-------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| pH  | Borax, ppm   | Boric acid, ppm | Sodium nitrite, ppm as NaNO₂ | Sodium nitrite, ppm as NaNO₂ | Sodium molybdate, ppm as Na₂MoO₄ | Copper, ppm as Cu²⁺ |
| 7.0 | 125 | 1000 | 5100 | 250 | 10 | 10 |
| 8.0 | 125 | 1000 | 5100 | 250 | 10 | 10 |
| 9.0 | 125 | 1000 | 5100 | 250 | 10 | 10 |
| 10.0 | 125 | 1000 | 5100 | 250 | 10 | 10 |

10 ppm copper in the form of copper sulfate solution was added to each buffer. In all five cases, the added copper quickly precipitated as a green floc, with the fastest precipitation occurring at high pH. This gelatinous material filtered slowly at high porosity to obtain a dense, dark green cake. Acidification was found to bleach the green chromophore and bring the solid material into solution. Similar precipitates were found to form when copper sulfate solutions were mixed with tolyltriazole and butylbenzotriazole. The copper-tolyltriazole complex was obtained as a gelatinous dark green precipitate, while the copper-butylbenzotriazole complex was obtained as a gelatinous green-brown precipitate.

Quartz crystal microbalance
Kinetics of chemisorption (and adsorption in general) make use of the concept of sites, in which the reaction rate is proportional not only to the concentration of the adsorbate, but also to the concentration of free sites, i.e. those surface sites which have not yet been occupied by an adsorbate. If the concentration of adsorbate is sufficiently high, the reaction becomes pseudo-zero order, with the adsorbate concentration effectively becoming a part of the reaction rate constant. This simplifying assumption is valid insofar as...
the adsorbate concentration does not change over the course of the experiment. A rate equation for such a process,

\[ A + S \rightarrow AS \]

where \( A \) is the adsorbate species, \( S \) is a free site, and \( AS \) is the adsorbed species, is as follows:

\[ \frac{d[AS]}{dt} = k[A](1 - \theta) = k'(1 - \theta) \]

where \( k \) is the first-order reaction rate constant for adsorption, \([A]\) is the concentration of adsorbate at the surface, \( \theta \) is the fraction of sites which are occupied by adsorbed species, and \( k' \) is the pseudzero order rate constant that includes the (constant) concentration of adsorbate. A site balance can be written:

\[ [S] + [AS] = S_0 \]

where \( S_0 \) is the total number of sites, including those that are occupied ([AS]) as well as those that are unoccupied ([S]). The fraction of occupied sites, \( \theta \), is defined as follows:

\[ \theta = \frac{[AS]}{[AS] + [S]} = \frac{[AS]}{S_0} \]

which implies that the fraction of unoccupied sites, \( (1 - \theta) \), is defined as follows:

\[ 1 - \theta = 1 - \frac{[AS]}{S_0} \]

Incorporating this result into the rate equation yields, after separation of variables and integration, the following integrated rate law:

\[ [AS] = S_0 (1 - e^{-\frac{k't}{S_0}}) \]

This result is consistent with Langmuir adsorption with monolayer coverage. More complex kinetic models, in which multiple layers of adsorbate are possible and other equilibria compete for adsorbate and/or sites, are more widely applicable. A number of such models were considered for this work, but the best fit to the data was obtained with Langmuir adsorption competing with a secondary equilibrium between free adsorbate and multiple-site adsorption:

\[ A + S \rightarrow AS \]

In the preceding equation, \( n \) corresponds to the size of an adsorption site for the secondary equilibrium, relative to the size of an adsorption site for the primary, irreversible step. Here, the rate of change in \([AS]\) is again given by:

\[ A + nS \leftrightarrow AS_n \]

and the rate of change in \([S]\) is given by:

\[ \frac{d[S]}{dt} = -k_1[A][S] - nk_2[A][S]^n + k_{-2}[AS_n] \]

The sum of \([AS]\) and \([AS_n]\) yields the total mass of adsorbate on the surface, and it is this total which is probed by a mass-sensitive instrument such as a quartz crystal microbalance (QCM):

\[ \frac{dM}{dt} = -\frac{d[A]}{dt} = \frac{d[AS]}{dt} + \frac{d[AS_n]}{dt} \]

where \( M \) is the total mass of adsorbate. One possible physical interpretation of such a model is irreversible chemisorption of the metal-azole film competing for surface sites with reversible physisorption of azole, where the area required for adsorption differs between the two processes by a factor of \( n \).

With copper-coated quartz crystals, the buffer solution used was softened Chicago municipal water with borax (100 ppm as B) and sodium hydroxide added to achieve a pH of 9.5. Because this solution absorbs carbon dioxide from the atmosphere (lowering its pH) relatively quickly, fresh buffer solutions were made up prior to each run. Formation of an azole film on copper was found to be sufficiently slow and to produce a sufficiently thick film that runs could be done in a constant-temperature bath (at 25 °C) with only brief manual stirring at the moment of azole addition. All azoles were added in a slug dose equivalent on a molar basis to 10 ppm benzotriazole. Kinetic data showing the adsorption of BTAH, BBTAH, and TTAH on copper are presented in the following figures:

**Figure 1:** Experimental adsorption transient (blue line) and model fit (black line) for benzotriazole on copper.

**Figure 2:** Experimental adsorption transient (blue line) and model fit (black line) for butylbenzotriazole on copper.
Figure 3: Experimental adsorption transient (blue line) and model fit (black line) for tolyltriazole on copper.

Note that the horizontal and vertical scales used in Figures 1 – 3 are significantly different, with benzotriazole forming a much thicker film than butylbenzotriazole or tolyltriazole, but with butylbenzotriazole forming a film significantly faster than the other two azoles.

To verify that these apparent adsorption transients are not merely artifacts of the changing liquid environment around the quartz crystal, a run was performed in which a “blank” consisting of dilute sodium hydroxide solution (to mimic the pH and conductivity of an azole solution) was injected. No such transient response was observed.

Finally, the effect of concentration was investigated for BTAH, with runs performed at 1, 5, and 10 ppm. A single plot comparing the copper QCM response to these conditions is shown below:

Figure 5: Experimental adsorption transients for benzotriazole on copper (1 ppm, blue line; 5 ppm, red line; 10 ppm, green line). Curves of best fit using the aforementioned kinetic model are shown as black lines.

As would be expected, the 1 ppm adsorption transient displays the slowest adsorption. But counterintuitively, it also displays the greatest total adsorption, with the 5 and 10 ppm runs being essentially identical to one another, both in terms of adsorption rate and total adsorption.

Kinetic fit parameters based on the QCM data are presented for both metals in the following table:

<table>
<thead>
<tr>
<th>Azole:</th>
<th>BTAH</th>
<th>BTAH</th>
<th>TTAH</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_1 (s^{-1})$</td>
<td>0.000121</td>
<td>0.000135</td>
<td>0.000302</td>
</tr>
<tr>
<td>$k_2 (s^{-1})$</td>
<td>0.0000480</td>
<td>0.000015</td>
<td>0.000128</td>
</tr>
<tr>
<td>$n$</td>
<td>2.58</td>
<td>3.88</td>
<td>2.17</td>
</tr>
<tr>
<td>$S_0 (cm^2)$</td>
<td>0.00135</td>
<td>0.00172</td>
<td>0.00107</td>
</tr>
<tr>
<td>$S_0' (cm^2)$</td>
<td>0.00115</td>
<td>0.00115</td>
<td>-</td>
</tr>
<tr>
<td>Coefficient of determination, $R^2$</td>
<td>0.958</td>
<td>0.972</td>
<td>0.972</td>
</tr>
</tbody>
</table>

Table 2: Parameters used to fit the previously described kinetic model to experimental data for adsorption of azoles on copper.

Discussion of results

Bulk solution & gravimetric analysis

The rapid formation of a gelatinous green precipitate when an azole solution is exposed to soluble copper is consistent with the polymeric depiction of copper-azole complexes. This direct reaction between copper ions and azoles explains the latter’s efficacy as an anodic corrosion inhibitor, precipitating with dissolved copper ions in the hydrodynamic boundary layer and forming a passive film on the surface of the metal.

Quartz crystal microbalance

Before discussing the kinetic model considered in this work, it must of course be stated that whether the postulated model actually physically describes the system, or is merely an arbitrary numerical fit, remains to be seen. An attempt will be made to explain as many qualitative and quantitative features of the data set as possible in order to substantiate the physical interpretation. It is worth noting that many other multi-step models were tried, but all gave much poorer fits to the data, in some cases despite having considerably more parameters.

The curves of best fit in Figures 1-5 were produced using six adjustable parameters, the values of which are given in Table 2 above. These parameters include $k_1$, the irreversible rate constant for chemisorption; $k_2$ and $k-2$, the forward and reverse rate constants for the competing physisorption equilibrium; $n$, the ratio of the area for physisorption to that for chemisorption; and $S0$ and $S0'$, two different available surface areas. The parameter $S0$ was taken to apply at low azole concentration, e.g. 1 ppm benzotriazole, while the parameter $S0'$ was taken to apply at high concentration, e.g. 5 and 10 ppm benzotriazole.

Notably, for all runs, the best fit value of $k2$ is several orders of magnitude larger than those of both $k1$ and $k-2$, suggesting that the hypothetical physisorption process is kinetically much more facile than the irreversible chemisorption process, and moreover, that even the physisorption process is exothermic enough that the barrier to desorption is relatively high. Additionally, the values of $S0$ for all runs were roughly comparable.

The fact that the values of $n$ that were obtained are greater than unity can be understood physically to mean that an azole molecule adsorbed via the hypothesized physisorption process occupies a larger area on the copper surface than does a molecule adsorbed via the chemisorption process. Since both physisorbed and chemi-
DTEA II™ is an organic deposit cleaner, penetrant and dispersant used in industrial cooling water systems. It is also an effective corrosion inhibitor. Applied in a coordinated manner with biocides, DTEA II provides water treatment professionals with a highly effective Biofilm Control Program, yielding improvements in biofilm, corrosion and scale control.

**Lower Costs**
- A fouled water system slows operations, increases costs and may result in a complete system failure.
- Failures cost money in replacement parts, wasted man-time and missed deadlines.
- DTEA II penetrates biofilm which allows biocides to work more effectively, from every angle, thus reducing the level of biocide needed.

**Increase Efficiency**
- Used regularly, DTEA II maintains maximum operating efficiency by keeping surfaces clean.
- A system free from deposits allows optimum heat transfer from vital components.
- Cleaner systems, like an engine, provide more power, smoother operations and increased efficiency.
- Maintaining a system with DTEA II allows peace of mind that the system is continually kept clean, with a proven chemistry, and increases customer satisfaction.

**Simplify Operations**
- No special dosing equipment required.
- DTEA II and a small amount of biocide provide a complete Biofilm Control Program.

DTEA II is available in both liquid and solid slow-release forms. Not sold as biocide in the USA.

Call Us Today!
To get the protection you need!
888 739-0377

AMSAs, Inc.™
4714 S. Garfield Rd. • Auburn, Michigan, USA • 48001
Tel: (899) 662-0377 Fax: (899) 662-6481
sales@amsainc.com
www.amsainc.com

AMSAs, Inc. manufactures DTEA II™ Chemistry.
AMSAs, Inc. exclusively serves industrial water treatment service companies.
sorbed azoles are likely to approach a copper surface with a similar geometric orientation, this difference suggests that the chemisorbed film is polymerized in a direction normal to the surface of the metal, such that several azole molecules may effectively occupy the same surface site.

The issue of film orderliness may also bear upon the rate of adsorption. It is possible that the speed at which the chemisorbed film is formed controls its orderliness, such that at the lower concentration of 1 ppm, a thick, orderly film can be constructed, while at higher concentrations, the faster rate of chemisorption results in an increasingly disordered, and hence thinner, film. Analogous to the packing of spheres, there is a lower limit to the efficiency of developing a film, so a minimum film thickness at high concentrations would be expected, analogous to totally random-packed spheres. Similarly, there should be a maximum film thickness at very low concentrations, analogous to close-packed spheres, perhaps at concentrations even lower than 1 ppm. If diffusion of azole through a disordered film is prohibitively slow, then the relatively thin film that forms initially will not equilibrate to a more dense film over any reasonable period of time. In this view, the S0 and S0’ parameters subsume the true number of sites, S0,true, as well as a multiplicative factor related to the orderliness of the film, f, where f depends inversely on the concentration of azole in solution.

Alternatively, the micellar structures formed in azole solutions may be invoked to explain the puzzling behavior observed in Figure 5. The azoles, particularly the aliphatic-substituted tolyltriazole and butylbenzotriazole, are amphiphilic molecules, meaning that they possess both polar and non-polar functionalities. Amphiphilic molecules are well-known to form structured phases in solution, such as spherical micelles, in order to minimize the total surface energy of the system. For these species, there exists a concentration, known as the critical micelle concentration (CMC), above which micelles begin to form. Near the CMC, a solution may exist in a metastable state such that addition of more azole leads to formation of micelles and actually causes a decrease in the concentration of monomeric azole. At concentrations much higher than the CMC, essentially all additional azole is used to construct new micelles, leading to a constant monomer concentration with increasing total azole concentration. The result of this phenomenon is that chemical processes sensitive only to the concentration of monomeric azole, such as adsorption on copper metal, may display counterintuitive kinetics, like those seen in Figure 5. At 1 ppm benzotriazole, most of the azole can be hypothesized to exist as monomers, and so there is considerable material available with which to build a thick, ordered film. At 5 ppm, however, much of the azole can be hypothesized to exist in micelles, meaning that relatively little material is available for adsorption. A further increase in total azole concentration to 10 ppm does not significantly change the observed adsorption kinetics, because the additional azole is tied up in the form of additional, non-reactive micelles. This explanation, however, fails to account for the observation that the film is formed more slowly at 1 ppm than at 5 and 10 ppm, despite a purportedly higher monomeric azole concentration. Additionally, it is not clear why the concentration of monomeric azole should be operative at all with regard to total film thickness, given that the azole is present, even for 1 ppm total azole, at levels orders of magnitude higher than are needed to coat the relatively small surface area of the QCM crystal. Accordingly, the orderliness explanation appears to be more consistent with the existing data.

Conclusion
It has been demonstrated that azoles form an insoluble complex with copper ions. This polymeric copper-azole complex has been shown to form a measurable film on virgin copper surfaces, and it is hypothesized that the polymer chains are oriented normal to the copper surface, allowing for thick films to develop. Moreover, it has been shown that slower film formation with a 1 ppm benzotriazole solution results in a thicker film than does faster film formation with 5 or 10 ppm solutions. Indeed, no significant difference was observed in either the rate or the thickness of the film formed when the benzotriazole concentration of the solution was increased from 5 to 10 ppm. These results were rationalized in a manner analogous to the packing of spheres, with slower film formation favoring a more orderly film development, allowing for more dense coverage of surface sites. Finally, a mechanism involving a competition between reversible physisorption and irreversible chemisorption has been postulated to account quantitatively for the experimentally observed kinetics.
Before we supplied three large pultruded FRP sea water cooling towers for a nickel plant in New Caledonia, we thought this island territory located between Australia and Fiji was only an exotic honeymoon destination. But ever since our first overseas job in 1969, we have exported cooling towers to over 50 countries around the world - even in the remotest corners of the planet, for ambient temperatures ranging from -30°C to +50°C, for fresh water and for sea water, for diverse applications such as in giant power plants, fertiliser plants, steel plants, paper mills, sugar mills, air-conditioning plants and so on. Some of the most discerning customers, consultants and contractors in the world have ordered Paharpur cooling towers and certified our quality and service as equal to the best anywhere. Whether it is in Asia, Europe, Africa, Australia, the Americas... or even an island territory in the middle of the South Pacific... Paharpur is there, serving customers faithfully.

Paharpur Cooling Towers Ltd, Paharpur House, 8/1/B Diamond Harbour Road, Kolkata - 700 027, INDIA
Phone: +91-33-4013 3000 • Fax: +91-33-4013 3499 • phtccu@paharpur.com

PAHARPUR USA, Inc. Suite 135, 18300 East 71st Avenue Denver, CO 80249, USA • Phone: +1-303-989 7200
Fax: +1-720-962 8400 • info@paharpurusa.com

AIR-COoled HEAT EXCHANGERS COOLING TOWERS AIR-COoLED STEAM CONDENSERS
Duane Byerly  
Rexnord Corporation

Abstract
Mechanical drive equipment must be selected correctly and operate flawlessly with minimal vibration. Drive shafts must be designed and manufactured with precision to prevent operation near a natural frequency. The market has become more sophisticated in determining and controlling the natural frequency of drive shafts. As a user, you must be cautious of the supplier you choose for your drive system critical components. Not all manufacturers have a sufficient level of understanding; therefore, any manufacturer should provide you with the data to support the natural frequency values they publish.

The advent of composite coupling systems has significantly reduced the weight of the drive shaft and made single span couplings more practical. These long single span shafts become susceptible to excitation from blade pass frequency (BPF), particularly as the spacer tube diameter increases beyond six inches.

Significance of accurately predicting a beams natural frequency
A cooling tower structure is made up of long beams and panels. These components all have natural frequencies that should be checked in the design phase of the structure. The frequencies where the response amplitude is highest are known as the system's resonant frequencies and these components may cause a vibration. Fan stacks also have a natural frequency. Similarly, the drive shaft which is typically a long beam has a natural frequency. When a natural frequency of a beam or structure is coincident with an excitation frequency the structure has the potential to reach its resonant frequency and vibrate. Historically, this has caused problems in cooling towers and cost money to correct.

When resonance occurs in a drive shaft, the shaft can have displacement in the center of the shaft. If the magnitude is high enough, there will be significant deflection. If the conditions are right, the vibration response can get quite high.

Many times this will result in shutting down the fan and cause possible extended down-time for the plant. It is necessary that when selecting the drive shaft this is taken into consideration. Since the CTI Chapter 10 (section 10.8.4.4 Critical Speed) was released containing the new 15% safety margin (Figure 1), many composite shafts have been sold with operating speed at 15% under their natural frequency with no problems reported from any installation. This has been a successful implementation of CTI Chapter 10 moving from a 1.3 to 1.15 safety margin operating speed to critical speed.

Figure 2. Experimental data of drive shaft and end displacement near critical speed (Ncr = Critical speed). This is well under the 15% range allowed by CTI.

Figure 2 shows a plot of experimental data of a drive shaft that was run up to speed and recorded displacement at frequent intervals higher and lower than the natural frequency. This plot clearly demonstrates the narrow band that a composite shaft exhibits. In testing it has been found that a properly 2-plane balanced composite drive shaft spacer will fall well under the 15% range. A true reading is that a composite spacer will safely operate within 5% either side of its natural frequency.

Beam natural frequencies and excitation frequencies
In any mechanical system it is detrimental when a natural frequency is coincident with an excitation frequency. Figure 3 shows a frequency spectrum. The natural frequency of a drive shaft and the excitation frequencies must not overlap. A cooling tower drive shaft is a beam that has a natural frequency. It would be most concerning when a natural frequency falls directly on an excitation frequency because this will almost certainly cause a resonant condition.
A Complete Power Transmission Package to Keep You Cool.

Solutions for the Cooling Tower Industry

Cooling towers are one of the harshest environments for power transmission equipment. Moisture, chemicals, and minerals attack the equipment driving cooling tower fans, making durability, corrosion resistance and superior customer service a priority.

That's why customers choose Addax® Composite Couplings and Falk® Renow® Prager® repair and asset management services.

- Lower total cost of ownership — properly maintained, the cost-effective Addax Composite Coupling can last the life of the cooling tower, while its lower weight results in less wear on other system components
- Professional on-site inspection, evaluation, service and repair or replacement of gear drives, couplings and bearings
- Same-day, emergency delivery of gear drives and couplings for many applications are available to maximize your uptime
Steel offers significantly longer and lighter weight carbon fiber drive shafts than steel by a factor of three. This ratio advantage allows for a modulus / density ratio of a carbon fiber composite to exceed that of steel. Composite materials will have better damping properties and will be more inherently stable due to a lower coefficient of thermal expansion. This stability of the carbon fiber composite will offer a negligible shaft deflection. Other factors can influence the shaft excitation such as: blade pitch, low-hanging blades, inconsistent blade pitch, blade distance from shaft, shaft mass, shaft diameter and possibly others. If there is a vibration, it usually manifests itself in the blade pass excitation frequency.

When the drive shaft is experiencing a blade pass harmonic, the pressure pulse forces the drive shaft to deflect and could cause visible shaft deflection. Other factors can influence the shaft excitation such as: blade pitch, low-hanging blades, inconsistent blade pitch, blade distance from shaft, shaft mass, shaft diameter and possibly others. If there is a vibration, it usually manifests itself in the motor and gearbox. Vibration monitoring on the motor bearing and gear pinion bearing will detect this. Properly designed and selected shafts exhibit an extremely low vibration contribution to the overall spectrum.

Blade Pass Frequency
The phenomenon of Blade Pass Frequency (BPF) exciting the natural frequency of the drive shaft is due to the pressure pulse created by adjacent fan blades passing overhead. BPF is calculated by multiplying fan speed by the number of blades.

\[ \text{BPF} = \text{Fan Speed} \times \# \text{ fan blades} \]

BPF and multiples of BPF are excitations on the spectrum. The fan blades induce a forcing frequency caused by pressure pulsations on adjacent components in a cooling tower. A vibration may occur if the drive shaft’s natural frequency coincides with the fan blade pass frequency. A common industry practice is to ensure that shaft natural frequency and blade pass frequency be 8% apart to assure there is no overlap. CTI chapter 10 recommends a ±8%. This range is a safety factor that will protect against natural frequency coincident with the blade pass excitation frequency.

When the drive shaft is experiencing a blade pass harmonic, the pressure pulse forces the drive shaft to deflect and could cause visible shaft deflection. Other factors can influence the shaft excitation such as: blade pitch, low-hanging blades, inconsistent blade pitch, blade distance from shaft, shaft mass, shaft diameter and possibly others. If there is a vibration, it usually manifests itself in the motor and gearbox. Vibration monitoring on the motor bearing and gear pinion bearing will detect this. Properly designed and selected shafts exhibit an extremely low vibration contribution to the overall spectrum.

Behavior of composite drive shafts versus steel shafts
The mass of an equivalent steel drive shaft will be significantly higher than an all-composite spacer shaft. The steel shaft will weigh as much as 5 times more depending on the selection. Certainly a larger rotating mass can create higher reaction forces on the motor and gear reducer. In addition, steel drive shafts can change in shape slightly from thermal expansion causing imbalance and vibration. Composite materials will have better damping properties and will be more inherently stable due to a lower coefficient of thermal expansion. This stability of the carbon fiber composite will offer a behaviorally lower vibration design. The specific stiffness (Young’s modulus / density) ratio of a carbon fiber composite exceeds that of steel by a factor of three. This ratio advantage allows for significantly longer and lighter weight carbon fiber drive shafts than steel offers.

Method used to test for natural frequency
Modal testing is a very common method used to test a long beam’s natural frequency. In the industry, this is sometimes referred as a “bump test”. Equipment needed for this test has become more sophisticated and accurate over recent years. Typically, this test is done with a transducer or an accelerometer input and a host computer or other hand-held device to collect and analyze the data. The input signal is analyzed using Fourier analysis. The mathematics for this analysis is typically contained in the software of the test equipment. If set-up and calibrated accurately, modal testing has been a very effective method to capture a drive shaft’s natural frequency.

Lab testing of uninstalled long span shafts must effectively model installed conditions to achieve accurate results. When conducting this test, care must be taken to precisely model the end conditions. If the end conditions are not properly locked in and understood, then the results will be incorrect. For example, when modeling a drive shaft in a cooling tower with a large mass motor and a large mass gear reducer on each end, the lab set-up should be the same to accurately simulate the real-world condition. Placing the shaft on V-blocks will generally not produce correct results.

Current method used to calculate natural frequency
The most traditional method of calculating a drive shaft’s natural frequency is to use the “uniform beam, simply supported” model. It can also be called pinned-pinned end condition. This is commonly presented in literature as shown in the equation below:

\[ N_{cr} = 9.87 \sqrt{\frac{E \times I \times g}{w \times L^4}} \]

Where
\[ N_{cr} = \text{Critical speed of shaft} \]
\[ E = \text{Youngs modulus} \]
\[ I = \text{Moment of inertia} \]
\[ g = \text{Acceleration of gravity} \]
\[ w = \text{Mass per unit length} \]
\[ L = \text{Length of beam} \]

The common formula presented by CTI in chapter 10:

Critical RPM = \( (ID^2 + OD^2) \times K \times (L/2)^2 \)

Where
\[ N_{cr} = \text{Critical speed of shaft} \]
\[ ID = \text{Tube inside diameter} \]
\[ OD = \text{Tube outside diameter} \]
\[ K = \text{constant - depends on tube material} \]
\[ L = \text{Length of beam} \]

Both of these formulas produce the same results for a given simply supported drive shaft of same geometry; however, the constant (K) must be established correctly. Some manufacturers develop their own constants based on specific properties of their drive shaft. Actual practice has shown that a drive shaft is not a uniform beam simply supported. Mass on each end of this beam distorts the modal response and deviates from the conventional model. This model (equation) does not account for the end mass.

Why have we deviated from the model and not predicted accurately? The difficulty is in predicting the modulus of the composite tube. The market offers different material types, different fiber winding orientations, and different fiber volumes. All of these variables create different longitudinal modulus values.
It's what's inside that really matters.

C. E. Shepherd Company, L.P.
www.ceshepherd.com

Better components make better towers.

Since 1957, our primary business has been innovation!
We encourage inquiries for custom product solutions!

- PVC Coated Hanger Grids
- Stainless Steel Hanger Grids
- Gull Wing Splash Fill Slats
- V-Bar Splash Fill Slats
- Film Pack
- Drift Reduction Units
- Nozzles & Accessories

C. E. Shepherd Company, L.P.
2221 Canada Dry Street
Houston, TX 77023
Telephone: 713.924.4300
Fax: 713.928.2324
www.ceshepherd.com
sales@ceshepherd.com

Whether your project requires new construction or retrofit, standard products or custom solutions, Shepherd Tower Components are a perfect fit.
Natural frequency predictability of steel and composite tubes

Steel tubing seems to follow theoretical modeling more predictably than carbon fiber tubing. As an isotropic material, steel and its properties are somewhat more predictable in nature than composite materials which are orthotropic materials. Experimentation on steel tubing (Figure 4) suggests that it is consistent with existing mathematical modeling. In steel, translational processing losses are not prevalent as found in orthotropic materials; however, wall thickness inconsistency and straightness variability are found in steel tubing.

Composite tubing can also have variability in wall thickness and straightness. Comparatively, the same straightness or wall thickness inconsistency would be more obvious in the steel tube due to the much higher density of the steel. This would manifest itself as imbalance and vibration and be more difficult to correct. Manufacturing variability of straightness and wall thickness in composite tubes has generally not been a big concern but clearly dependent on using a qualified supplier.

Orthotropic composite tubes are designed and analyzed using Classical Lamination Theory (CLT) which utilizes laminated shell theory and rule of mixtures to accurately predict tube properties. However, composite materials and carbon fiber in particular can be somewhat difficult to determine its actual Young’s Modulus in the longitudinal direction. Experimentation has shown a difference between actual natural frequency and the predicted model.

Figure 4 illustrates the difference between actual and predicted natural frequency of a 4.25 inch composite tube. However, experimentally, the modulus value generated in CLT is not accurately translated to actual in this tube.

Figure 4. Natural frequency predictability of a steel tube and predictability of a carbon fiber tube.

Not all composite tubes are created with equal performance characteristics.

Performance characteristics of composite tubes include: Young’s modulus, torsional strength, density and thermal expansion coefficients. These tubes are made primarily of carbon fiber and wet wound using the filament winding process. Since this process is sensitive to operator error, there is a large potential for variability of composite tube properties between manufacturers.

Several factors will affect the final properties of a composite tube. Variables include fiber wind angle, resin content, void content, degree of resin cure, variability in fiber modulus, micro fiber damage and others. During the wet filament winding process, the fibers experience some breakage in the handling process. As these fibers are pulled off the creel and wet-out through the resin bath, some fiber damage occurs. Therefore the properties from the raw fiber do not always translate to the tube properties efficiently. These losses are grouped in a category called “translational losses”. The term is defined as the efficiency loss of strength and modulus from the original fiber material to the properties of the final composite laminate.

Know your drive shaft supplier

Unpredictability with published tube natural frequency models makes obvious the importance of working with reputable and experienced drive shaft suppliers. Variables such as translation losses can change from one manufacturer to another. If these variables are not understood and properly controlled, the resulting processing inefficiencies could affect the quality of the tube which will affect the Young’s Modulus which will affect the natural frequency. If this frequency is not understood, there could be a vibration in the cooling tower.

How to accurately model the natural frequency of a composite tube.

General form of equation for a given tube size: This method requires the tube geometry, tube material and all other variables except length to be held constant.

\[ N_{cr} = K_n \times L^c \]

Where \( K_n = \) Constant
\( L = \) Length
\( c = \) Power constant

For a given geometry and material, the critical speed equation reduces to a simple power function with length times a constant (K_n). The question at hand is: how do you make the model accurately predict the actual? Using the model in Figure 5, the constant can be changed (lowered) which will shift the line down to intersect the experimental data.

Figure 5. Natural frequency predictability of a carbon fiber drive shaft assembly.
COOLING TOWER PROTECTION

Before After

No Special Training Needed Easy To Apply By Hand Non-Toxic & No VOC's

Wet/dry cycles and constant temperature changes create cooling tower horror stories of corrosion. Now there’s a safe, simple solution. Denso Tape Systems provide protection for piping, conduit, electrical boxes, hangers, valves, flanges, and sprinkler systems.

FOR MORE INFORMATION
CALL: 281-821-3355
FAX: 281-821-0304
E-MAIL: INFO@DENSONA.COM

www.densona.com
After shifting the model down to closer match the data points, the lines still do not line-up perfectly. The model predicts high on the shorter spans and low on the longer spans. Although not as much error, the model can be shifted to better match the actual data. This shift can not be done with the constant ($K_n$) in the equation. This shift must be done with the power constant ($c$). A curve fit exercise can be used to calculate the constant $K_n$ and the constant $c$. The significance of this finding is that the power function is no longer squared, but rather something different to better correlate with the actual data.

Figure 7 shows the final correlation between the mathematical model and the modal test data of a drive shaft. The correlation coefficient ($R^2$) of 0.9988 in this case shows extremely tight agreement between model and data for this range of data. Final form of the equation for this shaft is shown in Figure 7.

Conclusion

There are many variables that contribute to the actual natural frequency of a driveshaft. Accurately modeling the shaft must be clearly understood by the manufacturer and relayed to the customer to prevent vibration.

It has been determined experimentally that the mathematical standard published equation does not accurately model a composite drive shaft. This equation is generally used for a long cylinder with pinned-pinned end conditions. A drive shaft is not truly a cylinder. It has end flanges and flexing elements with mass that will vary and ultimately affect the ability to model it as a cylinder. CTI Chapter 10 (section 10.8.4.4 Critical Speed) presents a general form of the natural frequency equation with a range of constants for steel and composite. It is recommended that this equation be used only for reference.

Qualified manufacturers of drive shafts have a mathematical model with correct constants for each drive shaft size configuration incorporated into their selection program. Calculating drive shaft frequency without comparative physical modal testing is not sufficient. Because not all manufacturers have a sufficient level of understanding, caution must be used in applying drive shafts from manufacturers who do not effectively design and model drive shafts for natural frequency variables. Additionally, not all manufacturers check for blade pass frequency and this can be a concerning problem as it could result in vibration.

Finally, it is recommended to use a 1.3 safety factor on critical speed above operating speed for steel drive shafts. Steel shafts present higher reactionary forces than equivalent composite shafts. Following the recommendation of CTI Chapter 10, composite shafts need only a 1.15 safety factor on critical speed above operating speed. However, it is recommended to use a 1.3 factor when using a composite shaft from a source that has not demonstrated the ability to effectively model and test their product. Manufacturers must substantiate theoretical versus actual lateral critical speed values of the drive shaft. Accurately Determining Drive Shaft Natural Frequencies
D-SERIES

SPECIFICALLY DESIGNED FOR OPERATION AT PEAK EFFICIENCY, HOWDEN D-SERIES FANS DELIVER OPTIMUM AERODYNAMIC PERFORMANCE WITH EXCEPTIONALLY LOW POWER CONSUMPTION.

Critical applications such as air-cooled condensers and field erected cooling towers demand the best possible cooling performance. Howden D-Series fans deliver high operating efficiencies while offering low power consumption.

The efficiency benefits of the D-Series go beyond the inherent high efficiency of the fan itself. Taking a systems approach to design, the D-Series optimises the interaction between the fan and the application, to raise the performance of the whole cooling operation and deliver significant reductions in running costs.

FOR MORE INFORMATION CONTACT

Howden Cooling Fans  tel: +31 74 255 6000  e-mail: cooling.fans@howden.nl  www.howdencoolingfans.com
Miles Stoffer  
Dober Technology & Innovation  
Kevin Emery  
Chemtreat, Inc

This paper discusses the successful application of controlled release technology to HVAC cooling systems. This technology is ideally suited for systems under 500 tons and where traditional liquid chemicals are too hazardous or difficult to apply. The technology eliminates maintenance and operation of metering pumps, liquid chemical storage and spill containment. Due to the concentration of the actives, less material is required making roof top towers much more practical to treat. The coated or contained chemistry eliminates many of the traditional chemical handling concerns. The simplicity of the system and environmental friendliness make it ideal for new construction. This technology eliminates the need for liquid chemical storage, containment and metering pumps.

This paper will discuss systems that are ideal candidates for this technology, systems that are poor fits, system design and start up, monitoring, and actual applications.

Discussion of Technology

Controlled release technology is designed to protect systems by delivering consistent and reliable feed of scale and corrosion inhibitors and biocides over a 30 day period.

The scale and corrosion inhibitors are applied in the form of tablets which are encapsulated by a polymer membrane coating. The type of polymer coating and amount applied are critical in optimizing a 30 day release profile as exhibited in Figure 8. The dry actives contained inside the membrane coating release via osmosis inside of specially designed feed systems as seen in Figure 3.

Both oxidizing (BCDMH and DBDMH) and non-oxidizing (DB-PNA) are delivered through osmosis. The mechanism to control the release of the biocides is a canister with a membrane lid. Due to the solubility differences of the biocides, a different membrane is paired with the different biocide chemistry in order to optimize the controlled release of chemicals for 30 days as seen in Figure 9.

Ideal Candidates

Because this technology is solid the chemistry is concentrated and requires manual labor to load the feeders it is logistically limited to smaller applications. The products key benefits are related to the safety of application, concentration of the actives, coated chemistry, and simplicity.

- Small difficult to access systems less than 500 tons are ideal applications
- Disinfected and filtered make up streams
- Seasonal HVAC applications
- Evaporative Condensers
- Waters that can be treated with all organic alkaline or alkaline phosphate programs
- New construction

Poor Fits for Controlled Release Chemistries

Due to the nature of the product, feed systems have to be sized for peak load and flexible enough to handle the lower loads as well. The chemical feeds at a consistent rate, but the user must anticipate a higher load during from 9 AM to 6 PM. This higher load will result in higher blow down rates and lower chemical residuals. The system should be designed to tolerate a wide range of actives since fine control is neither practical nor probable. Typical targets are 20 –25 ppm of inhibitor as product with a 15 – 30 ppm practical range. This variability must be considered when setting control points to prevent over adjustment. The flow rates through the feeders may vary based on size of the system but 2 – 5 gpm is adequate for most systems. Filtration of the water to the feeders is highly recommended based on actual applications and the tendency of the feeders to accumulate suspended solids.

Oxidizing biocides must be fed in a separate feeder with a separate return to the tower to prevent destruction of the inhibitors. Feeders for oxidizing biocides should also be equipped with a pressure relief valve and plumbed to prevent backflow to the inhibitor feed system. A typical solid halogen tablet feeder is suitable replacement for solid release technology if desired. Fine control can be established with an ORP probe and solenoid valve.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control Method</th>
<th>Suggested Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>Conductivity Meter</td>
<td>Continuous</td>
</tr>
<tr>
<td>Biological Control</td>
<td>Dip slides, Total Chlorine, Tower Appearance</td>
<td>Weekly or daily</td>
</tr>
<tr>
<td>Halogen Control</td>
<td>ORP is an optional control method</td>
<td>Continuous</td>
</tr>
<tr>
<td>Inhibitor Level</td>
<td>Actives Monitoring by polymer or phosphonate monitoring</td>
<td>Weekly</td>
</tr>
<tr>
<td>Corrosion Rates</td>
<td>Coupons</td>
<td>Quarterly or Annually</td>
</tr>
</tbody>
</table>

Table 1: Program Monitoring
ChemTreat, the new direction in industrial water treatment, introduces these innovations to the market place:

- New Phos-FREE (non-phosphorous) all organic inhibitor technology
- PolyTrak® actives based monitoring and control for on-site system performance optimization
- Quadraspere® patented quadpolymer technology that dramatically improves corrosion and deposit control in high stress water treatment applications

**Better Performance, Bottom-line Savings.**

Each of these innovations is a unique way of improving system performance with cleaner, longer-lasting equipment. You reduce maintenance costs and minimize unscheduled shutdowns.

Breakthroughs like these join a growing array of components and capabilities that we configure to maximize your particular water management and control systems.

**Satisfied Customers.**

Innovative technology combined with the experience and stability of our sales representatives, has earned ChemTreat the lowest customer attrition rate in the industry: 2% versus 15-20% for our competitors.

By forming a partnering relationship with our customers, ChemTreat delivers the best possible products and services for your specific applications.

We will be glad to prove it to you with a systems survey and our cost-saving recommendations.

An ISO 9001 And An ISO 14001 Certified Company

4461 Cox Road-Glen Allen, Virginia 23060
Phone: 804-935-2000-Fax: 804-965-6974
www.chemtreat.com
Corporate Office Complex and Office Center in Brea, California

This complex has several buildings and a total of five cooling towers ranging from 150 – 300 tons. Prior to using the current technology personnel had to move hazardous chemicals through office space and use ropes to hoist pails to the application point. See Figures 1 and 2 for the liquid feed systems employed prior to controlled release. In addition to the safety concerns the site was having issues with metering pump reliability and having bacteria, scaling, and corrosion issues as the result of chemical feed reliability. These programs were changed to controlled release technology in 2012 with excellent results. The program targets a Langelier Saturation Index of < 2.5 to prevent scaling. Photographs of the feed systems are provided in Figures 3 and 4.

### Make up Water Chemistry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>500 – 800 micromhos</td>
</tr>
<tr>
<td>M-alkalinity as CaCO₃</td>
<td>100 – 150 ppm</td>
</tr>
<tr>
<td>Calcium Hardness as CaCO₃</td>
<td>150 – 200 ppm</td>
</tr>
<tr>
<td>Magnesium Hardness as CaCO₃</td>
<td>60 - 100 ppm</td>
</tr>
<tr>
<td>Silica</td>
<td>12 – 20 ppm</td>
</tr>
<tr>
<td>Chlorides</td>
<td>40 – 60 ppm</td>
</tr>
</tbody>
</table>

### Results

Corrosion rates for mild steel have been consistently ≤0.9 mpy and corrosion rates for copper have been <0.1 mpy. The facility management team and operations personnel are extremely satisfied with the performance and safety improvements provided by the controlled release technology. Additional improvement can be made by filtering the flow to the feeders to prevent suspended solids from accumulating in the feeders and creating flow issues.

### University in Miami, Florida

This is a larger system at the upper end of the application range at 2000 tons that runs up to 80% of design. The motivation for controlled release was to get away from handling hazardous chemicals. The program also targets a Langelier Saturation Index of < 2.5 to prevent scaling.

### Make up Water Chemistry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>312 micromhos</td>
</tr>
<tr>
<td>M-alkalinity as CaCO₃</td>
<td>60 - 70 ppm</td>
</tr>
<tr>
<td>Total Hardness as CaCO₃</td>
<td>70 ppm</td>
</tr>
<tr>
<td>Chlorides</td>
<td>50 ppm</td>
</tr>
</tbody>
</table>

### Results

Corrosion rates for mild steel have been 0.5 mpy and corrosion rates for copper have been <0.1 mpy while running at 5 – 6 cycles of concentration. The facility management team is satisfied with the application and has experienced no failures.

### Comfort Cooling for a Bank Building, Cincinnati, Ohio

See Figure 6 for a photograph of the feed system. This system was previously treated with paste technology as illustrated in Figure 7, but had seen failures due to inconsistent control. The paste feeders can vary feed with demand, but due to the fact that they dissolve the product and make a concentrated solution pumping is still necessary so complexity increases over traditional liquid chemistries and some of the benefits seen by employing controlled release aren’t realized.

### Summary

Controlled release technology is a very effective alternative to traditional liquid products in systems with clean water supply and consistent loads. The technology is ideal for difficult to access systems like rooftop units, and smaller systems under 500 tons. The key features of this technology include the simplicity of application and elimination of hazardous chemical handling and reliability. Multiple field applications within the design parameters have been very successful. The product cost is higher than liquid chemistries, but the convenience factors and labor savings have continued to favor this technology where appropriate.
WE’RE THE SMART CHOICE

Our FRP is the superior material choice for cooling towers. Beyond outstanding products, we deliver outstanding support for new and renovated cooling tower projects.

- Fabrication & Assembly
- Kitted Shipments Available
- Nationwide Logistics & Warehousing
- Guaranteed Ship Dates
- PROForms® 25-Year Limited Warranty
- Pre-Engineered Stair Towers
- Design & Engineering for Peripheral Systems

CTI Member Serving the Industry for 20+ Years

BEDFORD ADVANTAGE
We’re the FRP supplier with a total solution: logistics, warehousing and PVC fabrication!
Figure 3: Brea, California Controlled Release Feed System

Figure 4: Brea, California Controlled Release Feed System

Figure 5: Miami, Florida Controlled Release Feed System on a Large System

Figure 6: Cincinnati, Ohio Controlled Release Feed System

Figure 7: Cincinnati, Ohio Paste Feed System
Figure 8: Controlled Release Inhibitor Results from testing rigs

Figure 9: Controlled Release biocide (DBNPA) Results from testing rigs

creates standards for fills

world leading producer of ‘Trickle Fills’

‘Trickle Fills’ combine performances of cellular fills with low drop pressure + non-fouling effect of splash fills; (vertical, crossflow or mixed structure)

‘MECHANICAL ASSEMBLY’ for reduced shipment costs; ASTM E84 available

better cold water temperature as cellular fills CTI-Journal Vol. 33 no. 2 (2012, 62ff)

better prices as cellular fills!

‘NC20’

up to 3m modul-length

production of full range of products

support by computer programm online

PP + PVC

HEWITECH GmbH & Co. KG; Am Langenhorster Bahnhof 16; info@hewitech.de
www. hewitech.de

48607 Ochtrup / G E R M A N Y
Tel:+49 2553 970260; Fax: 970265
Experimental Characterization of Wind Effect on Natural Draft Cooling Towers

Christophe Duquennoy
Edf (Electricite De France) – Dtg

1. Abstract
Wind effect on natural draft cooling towers induces performance degradation. For a utility like EDF operating 28 natural draft cooling towers for its nuclear power plants, it is an important issue to take this wind effect into account as long as it can lead to large losses. This is the reason why since 30 years EDF ask to manufacturers to take into account this effect in the guarantee. This is done by means of wind curves describing the impact of wind on cold water temperature. But, as long as these curves are based on manufacturer experience, they remain theoretical and include margins. Thus, it is of EDF interest to characterize the real effect of wind on its cooling towers. The paper will shortly describe EDF’s performance e-monitoring tool and explain how it can be used to build experimental wind curves. Then, examples will illustrate the way these curves can help to quantify different kind of wind effects like those due to the presence of obstacles close to the tower.

2. References
2. NF EN 14705, « Method of measurement and evaluation of thermal performances of wet cooling towers », European Standard, October 2005.

3. Introduction
Performance loss of natural draft cooling towers can be induced by large wind velocities. Thus, for a utility like EDF operating 28 natural draft cooling towers for its nuclear power plants, it is an important issue to take this wind effect into account as long as it can lead to large losses. But, as long as these curves are based on manufacturer experience, they remain theoretical and probably include margins. Thus, it is of EDF interest to characterize the real effect of wind on its cooling towers. The paper will describe EDF’s performance e-monitoring tool and explain how it can be used to build experimental wind curves. Then, examples will illustrate the way these curves can help to quantify different kind of wind effects like those due to the presence of obstacles close to the tower.

4 Natural Draft Cooling Tower Monitoring
3.1. From Acceptance tests to monitoring
During the old 70’s and 80’s, EDF performed a large amount of research studies concerning the best way to perform thermal performance acceptance tests for natural draft cooling towers (some of these studies are referred in [1]). These studies helped to defend the idea that the best way to perform acceptance tests for natural draft cooling towers is to use extended tests as those described in the European acceptance test code [2]. Since that time, EDF has always considered that although expensive, this kind of extended test is the best way to avoid large financial losses due to performance deviation. Thus more than 20 thermal performance acceptance tests were performed using this approach. As it is defined in the acceptance test code [2], 300 test periods are necessary to validate an extended test. This can occasionally be obtained during a period of 2 months but most of the time test duration is between 3 to 6 months. Thus, over the years, EDF developed skills for this kind of long term test concerning the most relevant instrumentation to use (number, position and type of sensors) or the importance of both stability and validity test selection criterion.

As a matter of fact, EDF was able to develop a monitoring tool for its cooling towers [3] based on a simplification of the instrumentation and data selection process described in the acceptance test code [2]. The aim of such a tool is to be able to monitor thermal performance so that performance deviations with respect to an initial reference are caught. This means that the aim of this monitoring tool is not to give an absolute value of the performance but to detect as accurately as possible performance variations. Of course, the initial reference is evaluated by means of an acceptance test.

This monitoring tool called SPA (for Suivi de la Performance des Aéroréfrigérants meaning Cooling Tower Performance Monitoring in French) was finally installed in 2010 on all 32 cooling towers used as a heat sink for EDF nuclear power plants. It is used by operation teams on site and by different engineering departments of EDF. SPA already gave very promising results avoiding a number of losses for EDF and helping to adapt cooling tower maintenance policy [4]. Work is still being done to improve data treatment methods and allow quicker, easier and more accurate performance deviation detections [5]. However it is already clear for us that another promising application of SPA is the use of data to have a better understanding of wind effect on our cooling towers performance. This is the purpose of this paper.
Delivering
“Objectivity & Reliability on Quality”
For Value With Trust!

India’s No.1 FRP Cooling Tower, with over 18,000 Satisfied Customers

India’s First Cooling Tower with CTI (USA) certification for ‘A-SERIES’ Towers.

Upto 1500 TR available in single / multiple cell.
Introducing 100% non-corrosive, pultruded fibreglass structure.
Conforms to the standards & specifications for Green Buildings.

Advance GRP Cooling Towers Pvt. Ltd.
405, ‘Span Centre’, R.K. Mission Marg, Santacruz (W), Mumbai - 400054. INDIA
Tel: 2600 1067 Fax: 2600 0303. E-mail: sales@advance2020.com
Branch Offices: • Bangalore: 09900521598 • Delhi: 09953658971 • Chennai: 09445155645

www.frpcoolingtowers.com
3.2. Instrumentation

Physical parameters which have to be measured to perform extended tests [2] on natural draft cooling towers are the same as those listed in CTI ATC 105. Here below, we will give examples of what is done by EDF to measure these parameters for acceptance tests and what is done for SPA. This will help to highlight the simplifications which were done for EDF monitoring tool.

3.2.1. Cold water temperature measurement

In manufacturer’s point of view, the best location to measure average cold water temperature is the closest to the cooling tower outlet. Indeed this reduces the number of other circuits located between cooling tower outlet and cold water measurement location. On the other hand, when the measurement is done very close to the cold water basin, thermal stratification can occur. Thus, a good number and location of RTD sensors in the section is necessary to avoid too large spatial uncertainties.

For EDF cooling towers, the most relevant location is generally either on the filtration grid located just after cold water basin outlet or in the cold water pipe between the basin outlet and the circulating pump. For both locations, between 9 to 16 sensors are regularly installed on dedicated supports (see fig 1).

Due to difficulties to access to these locations, it was considered not reasonable to use such instrumentation for SPA. This measurement was replaced by two RTD installed in thermowells located a few meters upstream two of the 6 condenser inlets (see fig 2). The main advantage of this location is that it is downstream water circulation pumps. Thus, liquid fluid temperature can reasonably be considered homogeneous in the measurement section which allows using only two sensors. Another great advantage of this location is that it allows for easy access for instrumentation maintenance.

3.2.2. Wet bulb temperature

Even if this can be differently specified within the contract, wet bulb temperature generally refers to the air inlet wet bulb temperature. For natural draft cooling towers, a good number and location of sensors in the air inlet is required. The approach used by EDF is to use between 4 to 8 masts around the air inlet. For example, when 4 masts are used, they are generally placed so that there is one mast for each cardinal direction (north, east, south and west). On each mast, between 3 to 5 sensors are used. The total number of sensors is between 20 to 24 sensors depending on the used acceptance code (for example ref [2] imposes 8 masts and 3 sensors for each mast).

Figure 1: Illustration of supports used to install sensors for cold water temperature measurement during extended tests.

Figure 2: Location of SPA cold water temperature measurement at condenser inlet.
The Industry’s Most Complete Line of Cooling Tower Products...

From the smallest HVAC towers to the largest natural draft towers, we are leading the way with enviro-friendly innovations like non-glue Mechanical Assembly and anti-microbial AccuShield Products.

brentwoodindustries.com
watersales@brentwoodindustries.com
610-235-1103

READING, PA USA • LEBANON, PA USA • MARTINSBURG, WV USA • HOPE, AR USA • SURPRISE, AZ USA • HOROVICE, CZECH REPUBLIC • BANGKOK, THAILAND
For extended tests based on European acceptance code [2], it is allowed to evaluate wet bulb temperature by measuring dry bulb temperature with a RTD sensor and the relative humidity with a hygrometer. Furthermore, the location of the RTD and the relative humidity doesn’t necessarily have to be at the exact same location. This means that in the case of the natural draft cooling towers it is acceptable to use only one hygrometer for each mast. Figure 3 gives examples of wet bulb measurement location on two of the EDF towers.

For SPA, the choice was made to use only one mast located at the air inlet between the wind direction and the tower (see figure 4). Three RTD are used to measure dry bulb temperature which significantly reduces the number of sensors to be maintained.

The relative humidity used to evaluate the inlet wet bulb temperature is the ambient relative humidity measured close to the site’s meteorological station far away from the tower. Even if it is quite sure that this choice induces bias on the performance evaluation, it is considered to be acceptable for a monitoring tool which aim is to detect deviations and not to evaluate absolute performance. This choice is completely justified when considering the instrumentation maintenance aspect of the problem. Indeed, for safety reasons, the site hygrometer has to be checked very often based on French Meteorological Lab references (Météo France). With a hygrometer installed in the middle of the air inlet (~6 meters high) it would have been much more difficult for the operator to ensure good metrological maintenance. This would have induced, for sure, an increasing bias of the SPA performance estimation. With the site hygrometer, the bias can reasonably be considered constant.

### 3.2.3. Wind velocity and direction measurement

Considering the acceptance code [2], wind velocity and direction shall be measured at a height of 10 meters high on a mast located in an open spot at a minimum distance of 300 m from any sizeable obstacle (cooling tower, machine room relief, etc.). Most of sites’ meteorological masts respect these constraints. It was thus decided to use site meteorological masts for SPA.

Table 1: Stability criterions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acceptance test</th>
<th>Monitoring tool SPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circulating water flow</td>
<td>less than 2% variation</td>
<td>less than 0.2%</td>
</tr>
<tr>
<td>Heat load</td>
<td>less than 2% variation</td>
<td>less than 0.2%</td>
</tr>
<tr>
<td>Air ambient wet bulb temperature</td>
<td>less than 10°C variation</td>
<td>less than 10°C</td>
</tr>
<tr>
<td>Wind velocity</td>
<td>less than 10 m/s variation</td>
<td>less than 10 m/s</td>
</tr>
<tr>
<td>Soil temperature</td>
<td>less than 5°C variation</td>
<td>less than 5°C</td>
</tr>
</tbody>
</table>

It is also mentioned in the acceptance code [2] that for extended tests wind velocity shall be measured by means of three cup-type anemometers and three weather vanes. For obvious reasons of instrumentation maintenance of SPA, it was decided to use the available sensors on each site. Thus, for most of the sites, wind velocity and directions are measured using SODAR System (Sonic Detection And Ranging).

Note that according to [2] for extended tests, no wind velocity has to be measured at the top of the shell elevation. This is due to the fact that the wind curve used to calculate the guarantee at different wind velocities is based on wind at 10 meter high (see §5.1). As long as for extended tests, more than 300 test periods are used to evaluate the thermal performance, the discrepancy due to non-measurement of this top-shell velocity is reduced by the averaging data process of test results. Even if with SODAR System it is possible to measure wind velocity at different height, only the velocity measured at 10 m high was kept for SPA.

### 3.3. DATA Selection

As explained in the European code [2], for extended tests, test periods must be of ten minutes. Within a test period, data must be recorded at least every 2 minutes. For SPA all the parameters characterizing the operation of the cooling tower are recorded every minute. These acquisitions are averaged every ten minutes so that one average value of each parameter is available every ten minutes. This constitutes what is called a test period from which the performance can potentially be evaluated.

However, all these test periods are not necessarily relevant. Indeed, if they were calculated under conditions out of the validity domain of the physical model (see §4.4), they cannot be used to characterize the performance of the cooling tower. In order to avoid this kind of error, validity and stability filters are applied on measured data. Selection criterions recommended in European code [2] are listed in table 1 and 2. The way they are simplified for SPA is also given in table 1 and 2.
Moore Sets The Standard In Axial Flow Fans.

Since 1940, Moore Fans has provided customers with high-efficiency, high-quality Axial Flow Fans for industrial applications worldwide. Operating in air-cooled heat exchangers, cooling towers, and radiators, Moore fans keep liquids cool in refineries, power plants, process plants, gas compressors and limitless other industrial settings.

Special Design Features Of The Class 10000 Fan

- Resilient Blade Mounting – For more than half a century all Moore fan blades have been designed with a resilient blade mount, virtually eliminating all moment forces on the hub and shaft, improving durability; ideal under extreme operating conditions.
- Chord Width – Improve performance with fewer number blades for the same performance requirements, resulting in a lower overall cost.
- Blade Angle Adjustment – Blades are factory preset for specified performance conditions eliminating the need to set during field installation.
- Adjustable Diameter – Designed to permit fan diameter adjustment by as much as +/- 1.5 inches (3.81 cm), greatly easing installation.
- Ideal Variable Speed – With Moore’s resilient mount system, there are virtually no critical speeds to be avoided.
- Available Blades – Available in both odd and even number of blades, up to 16.
- Ultra-Low Noise MAG Fan – The Minimum Acoustic Geometry (MAG) fan is a low noise option to reach the most stringent noise objectives. Available in diameters of five feet thru 14 feet and in clockwise (RH) and counterclockwise (LH) rotation. The MAG is designed for both electric motor and engine driven applications.
- Strengthened Design – For engine drive and larger fan diameter applications from three to 24 feet.

Today, Moore Fans has some 175,000 fans in operation around the world. And with sales offices in North America and in Europe, Moore factory engineers and customer service representatives stand ready to help you analyze your air moving requirements, choose the right product, and provide reliable service and support, before and after the sale.

For more information on the Class 10000 Fans or any of the family of quality products from Moore Fans call 660-376-3575 or visit us online at moorefans.com.
3.4. Performance indicator: DOET

SPA monitoring tool was described in detail by Wolf [3]. It is based on one indicator: the deviation from optimal expected temperature (DOET or ETOA in French). This indicator is the difference between measured cold water temperature ($T_{cw}$) and optimal expected cold water temperature (OET or TOA in French).

The OET is calculated by means of a physical model based on a heat exchange Merkel’s law (Me):

$$Me = C \left( \frac{Q_A}{Q_{TE}} \right)^n$$

where

$$Me = \int_{T_{cw}}^{T_{cw}+R} \frac{C_{pe}}{(h_s - h)} dT_{cw}$$

And a draft equation:

$$\rho_1 - \rho_2 = \frac{1}{2} \frac{gH}{C_f} V_D^2$$

Where, $Q_A$ is the air mass flow rate, $Q_{TE}$ is the water mass flow rate, $T_{cw}$ is the cold water temperature, $h$ is the air enthalpy, $h_s$ is the enthalpy of saturated air at the temperature of the water, $C_{pe}$ is the specific heat of water, $R$ is the cooling tower range, $T_1$ and $T_2$ are density of the air at inlet and outlet, $H$ is the draught height, $g$ is the gravity acceleration, $V_D$ is the mean frontal velocity of the air at the exchange body inlet. $C$, $n$ and $C_f$ are manufacturers’ data provided before the acceptance tests as a guarantee. The wind effect is generally taken into account through $C_f$ coefficient which is provided as a function of wind velocity measured at 10 meter high ($V_{10}$).

Using these equations, the OET can be evaluated for each test period as a function of parameters characterizing the operation of the cooling tower: Dry bulb inlet temperature (DB), Inlet Relative Humidity (RH), Wind Velocity ($V_{10}$), Atmospheric Pressure (PATM), Heat Range (R), Circulating Water Flow (Q), make up water temperature (TAPP).

Finally, a DOET is calculated for each test period:

$$DOET = OET - T_{cw}$$

A DOET close to zero means that the measured temperature is close to the expected temperature: the performance of the cooling tower equals the guaranteed initial performance. A DOET higher than zero indicates that the measured temperature is higher than the expected temperature which can potentially be attributed to performance loss. In theory the DOET should never take negative values since there cannot be improvement of performance compared to the one checked during acceptance tests.

4. Wind Curve construction

4.1. Theoretical Wind Curve: OET versus $V_{10}$

4.1.1. Where do these curves come from?

Wind induces performance loss on natural draft cooling towers. For a utility like EDF operating 28 natural draft cooling towers for its nuclear power plants, it is an important issue to take this wind effect into account as long as it can lead to large losses. This is the reason why since 30 years EDF asks manufacturers to take into account this effect in the thermal performance guarantee.

To do so, EDF applies the methodology discussed in [1]. For any project (new tower or retrofitting) it is asked to manufacturers to guarantee the approach for a 4 m/s wind velocity.

It is also asked to manufacturers to guarantee a weighted approach which can be considered as an annual average approach of the cooling tower. Due to wind effect, this weighted approach is generally different from the 4 m/s approach. To calculate this weighted approach, EDF have to provide manufacturers with wind class definition and associated weighting coefficients. Wind classes are generally of the size of 2 m/s (from 0 to 2 m/s, from 2 to 4 m/s, from 4 to 6 m/s/...). As it is explained in reference [1], weighting coefficients are generally based on the annual frequency of each wind class. In some cases, they can also take into account the evolution of the electricity cost versus wind [1].

For new cooling towers only, EDF also asks manufacturers to provide wind curves describing the expected evolution of the cold water temperature versus wind velocity (all other operating parameters being equal to design value). If there are two or more manufacturers in competition, it will be of the interest of each manufacturer to provide the most realistic wind curve as possible (see discussion in [1]).

For retrofitting projects, wind curves cannot be provided by manufacturers as long as the cooling tower was not necessarily designed by the same manufacturer. Then, EDF provides a wind curve in the contract (generally based on previous acceptance tests performed on the tower) so that the manufacturer can take margins in its design if he considers that this wind curve will not be consistent with the real wind curve after retrofitting.

**Remarks:** it can easily be understood that it is of EDF interest to provide as realistic wind curve as possible. Indeed, if wind curve provided by EDF underestimates the impact of wind velocities different from design (4m/s) on cold water temperature, manufacturers will want to take large margins which would probably increase the cost of the project. On the other hand, if wind curve provided by EDF overestimates the impact of wind velocities different from design on cold water temperature, manufacturers will easily reach the guarantee making easy profits. These wind curves are used to verify guarantee as described in [2] for extended tests. Practically speaking, these curves are used to evaluate the OET for each operating condition (see §4.4).

4.1.2. Example of theoretical wind curve

The equations of the model used to calculate the OET are solved by computer software which allows evaluating, for each cooling tower, OET versus different operation parameters (see §4.4). It is thus possible to impose for all parameters the nominal value except for wind velocity. This leads to a theoretical wind curve like the one shown on figure 5.
The future of cooling towers, **today.**

FIELD-ERECTED COOLING TOWERS / NEW & REPLACEMENT INSTALLATIONS
REPAIR & RECONSTRUCTION SERVICES / PARTS

Energy Efficient - Environmentally Friendly - Design and Layout Flexibility
Reliable Year-Round Performance - Simplified Maintenance
Quiet Operation - Extended Service Life

**CCSolutions**
Composite Cooling Solutions, L.P.

www.compositecooling.com
info@compositecooling.com
817.246.8700

Follow Us
4.2. Deviation from Theoretical wind curve: Doet versus V10

The deviation between real wind curve and theoretical curve is given by the variation of DOET versus wind velocity. To build this kind of curve for sufficiently high wind velocities, validity criteria which limits the maximum velocity to 4 m/s (see table 2) is disregarded.

To reduce data dispersion test periods are ordered with wind velocities. Then for each group of 200 test periods, one average DOET (DOET200) is calculated. Meanwhile, the corresponding average velocity is also calculated (V10200). Then, DOET200 versus V10200 can be plotted (see figure 6). It must be understood that each plot on figure 6 is already an average of 200 valid and stable test periods. This probably explains the relatively reduced scattering of the plots (amplitude ~0.2 K).

4.3. Real wind curve

Finally, by summing theoretical wind curve (figure 5) and the experimental deviation between real wind curve and theoretical wind curve (figure 6), one obtains a curve providing the experimental real wind curve for the considered cooling tower (see figure 5).

Note that wind curve on figure 5 describes average dependency of nominal cold water temperature versus wind velocity. It should be translated to meet the guaranteed design value of the tower (for example given at 4 m/s velocity for EDF).

5. Examples of observed behavior

5.1. Cruas NPP: Rain zone Obstacle effect

5.1.2. Situation studied

The situation which is studied here refers to cooling tower CR3 (see figure 9). The first analyzes of SPA data is done by operators on site by plotting the evolution of month average DOET (DOET\textsubscript{month}) versus time. In 2010, the operators obtained a curve showing a rapid variation on DOET\textsubscript{month} of ~0.64K between March and April 2010 (see figure 10). To analyze more accurately this behavior, it is necessary to plot directly the evolution of DOET versus time for each stable and valid test period.

Figure 6: Example of DOET\textsubscript{200} versus Wind velocity (V10\textsubscript{200})

From these plots, an interpolated curve can be deducted. The resulting curve represents the average deviation between real wind curve and theoretical wind curve. To reduce interpolation mistakes, the connection to zero velocity can be adjusted so that it corresponds exactly to test points at low velocities (see figure 6).

5.1.1. General presentation of the site

Four nuclear power plants of 900 MW each are operating on Cruas site. Each NPP is using a natural draft cooling tower as a heat sink. Cruas is in the south east of France, in the Valley of Rhone River (see figure 9). One specificity of this region is that wind is blowing quite often with as much situations with wind velocity between 0 to 2 m/s than with wind between 2 to 4 m/s or between 4 to 6 m/s (see table 3). Furthermore, whichever is the wind class considered, the dominant wind direction is North (~65% of the time).

Table 3: Wind statistics for Cruas site

<table>
<thead>
<tr>
<th>Wind Class</th>
<th>Fraction for each Wind class</th>
<th>Wind class</th>
<th>Wind coming from South sector [90°;270°]</th>
<th>Wind coming from North sector [270°;90°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 2 m/s</td>
<td>40.1%</td>
<td>23.9%</td>
<td>76.1%</td>
<td>23.9%</td>
</tr>
<tr>
<td>2 to 4 m/s</td>
<td>31.8%</td>
<td>37.5%</td>
<td>62.5%</td>
<td>37.5%</td>
</tr>
<tr>
<td>4 to 6 m/s</td>
<td>20.3%</td>
<td>32.5%</td>
<td>47.6%</td>
<td>32.5%</td>
</tr>
<tr>
<td>6 to 8 m/s</td>
<td>6.5%</td>
<td>35.0%</td>
<td>64.4%</td>
<td>35.0%</td>
</tr>
<tr>
<td>More than 8 m/s</td>
<td>1.2%</td>
<td>30.2%</td>
<td>68.8%</td>
<td>30.2%</td>
</tr>
</tbody>
</table>

5.1.2. Situation studied

The situation which is studied here refers to cooling tower CR3 (see figure 9). The first analyzes of SPA data is done by operators on site by plotting the evolution of month average DOET (DOET\textsubscript{month}) versus time. In 2010, the operators obtained a curve showing a rapid variation on DOET\textsubscript{month} of ~0.64K between March and April 2010 (see figure 10).

To analyze more accurately this behavior, it is necessary to plot directly the evolution of DOET versus time for each stable and valid test period. Figure 10 shows that DOET clearly changed on the 10\textsuperscript{th} of April.
Your tower represents a HUGE investment...

Isn’t it worth investing a small amount to keep it “in the Pink” by preservative spraying the wood structure?

PREVENTION IS ALWAYS THE RIGHT SOLUTION!!!

Decay Prevention & Slime Control with PROVEN RESULTS

Nationwide Since 1964

Also Featuring:

- Fill Cleaning
- Fan Deck UV
- Protective Coating
- Dry Mothballing
- Wood Analysis
- Structural Inspections
- Spray-In Basin Linings

Spray Technician applying red dye colored preservative.

COOLING TOWER SOLUTIONS
by Spraying Services, Inc.

Phone: 713.941.1944 • Fax: 713.941.2545

www.sprayservices.com
To estimate the amplitude of the performance loss, it is possible to calculate separately the averaged DOET in April before and after the 10th of April. We found a variation of 1K between DOET before 10th = 0.1K and DOET after 10th = 1.04K. This variation was not justified and had to be explained.

Figure 9: Satellite view of Cruas site

Figure 10: Cooling Tower n°3 - DOET month (up) – DOET (down) – Evolution versus time.

5.1.3. Analyses of the data

The 9th of April at midnight, Cruas NPP number 4 was stopped for maintenance. The day after, CR3 started showing performance losses. As long as there is no direct connection between the two NPP, this suggests that there could be a interaction between cooling towers CR4 and CR3. The hypotheses was that as long as the two cooling towers are close to each other and that CR4 is between the dominant wind direction (North) and CR3, there could be a change in wind effect on CR3 when NPP4 is in operation or not.

To prove this hypothesis, we plotted the evolution of DOET versus wind velocity for wind coming from north sector (figure 11) separating situations when NPP4 is in operation and when it is stopped. It clearly appears on figure 11 that when NPP4 is in operation, DOET averagely decreases while wind velocity increases, whereas when NPP4 is stopped, DOET decreases.

Using obtained wind curves, it can be evaluated that for an average wind of 2 m/s coming from north, the average performance degradation induced by this phenomena is ~1.25K. Considering the fact that on Cruas site wind velocity is generally more than 2 m/s and comes from north 65% of the time (see table 3), we can deduce that this phenomena seems to explain the performance degradation observed on figure 10.

Figure 11: DOET versus wind velocity with NPP4 in operation (up) or stopped (down) – Wind coming for north
Your stainless-steel fastener source.

Simpson Strong-Tie is your source for fasteners. Our wide selection of stainless-steel bulk and collated nails, screw/nail washer assemblies, and self-drilling screws are easy to install and provide superior results in wood, fiberglass and corrosive environments. Fasteners are available in 305 and 316 series stainless steel.

To learn more about the entire line of Simpson Strong-Tie® fasteners for cooling tower construction and repair, call (800) 999-5099 or visit www.strongtie.com/fasten.
When things heat up, call Aggreko.
Aggreko Cooling Tower Services (ACTS) is the world’s largest provider of rental cooling tower solutions. For over 20 years, we have successfully helped customers solve their cooling water limitations - under any circumstances.

From the planning stages to the turnkey installation of convenient modular cooling towers, ACTS has the solutions to help you keep your cool, 24/7/365.

ACTS provides proven rental cooling tower solutions to:

- **Overcome thermal discharge temperature limitations**
- **Minimize post-disaster downtime**
- **Maintain cooling capacity during partial or complete tower repair**
- **Lower cooling water temperatures and reduce turbine back-pressure**
- **Add cooling water capacity with no capital commitment**

Contact Aggreko today for all your rental cooling tower needs. Call us at 866.215.7963 or visit us online at www.aggreko-cooling-tower-rentals.com.
5.1.4. Conclusion

The analyses of the data show that when CR4 is not in operation, performance of CR3 reduces. This is probably due to the fact that when CR4 is in operation, the rain zone acts as an obstacle which protects CR3 air inlet from wind effect.

This phenomenon induces 3 MW loss. Building a wall around CR4 could be a solution to avoid this performance loss. As long as this situation will not occur very often (~1 month every year), the investment is probably not justified. However, this kind of phenomena should be taken into account when designing new plants and especially concerning the position of towers with respect to each others.

5.2. Civaux NPP: sound Walls Effect

5.2.1. General presentation of the site

Two nuclear power plants of 1450 MW each are operating on Civaux site. Each NPP is using a natural draft cooling tower as a heat sink. These two cooling towers are EDF’s only ones on which sound walls around the air inlet were built. These towers were designed without taking into account the influence of sound walls on thermal performance. This means that the theoretical wind curve used as a reference in the model describing wind effect on cold water temperature doesn’t take into account the existence of walls in front of the air inlet. Thus theoretical wind curve is similar to standard wind curves for natural draft counter flow cooling tower (see figure 12).

5.2.2. Deviation from theoretical wind curve

Figure 13 was obtained using available SPA data from January 2011 to February 2012. For this period, the number of stable and valid test periods is 12587 for CV1 and 16640 for CV2.

The aim of this example is to characterize sound wall influence on wind effect. Thus, to avoid parasitic influence of other buildings on the site, we exclude all the test periods for which an obstacle is between the cooling tower and wind direction. Excluded sectors are from 135° to 297° for CV1 and from 270° to 10° for CV2 (see figure 12). After this selection, 5926 test periods are still available for CV1 and 12735 test periods are still available for CV2.

5.2.3. Real wind curve

Experimental wind curve is obtained figure 14 by summing curves plotted on figures 12 and 13.

5.2.4. Analyses of the results

First, it should be noted that for CV1 the number of test periods is far less than for CV2. This is mainly due to the fact that authorized wind sectors for CV2 correspond to site dominant wind direction. As a matter of fact, wind curve obtained for CV2 is probably more reliable than the one obtained for CV1. This is specially the case for wind velocity over 5 m/s for which there are almost no data for CV1. Thus, wind curve obtained for CV1 on figure 14 is not valid for such large wind velocities. However, it clearly appears on figure 14 that for a given wind velocity, real cold water temperature is significantly under the one obtained using theoretical wind curve. For a wind velocity of 4 m/s, we observe a 0.6K decrease of cold water temperature for CV1. For CV2, the reduction is only of ~0.3 K. For a wind velocity of 6 m/s the reduction for CV2 reaches 0.7K. The evaluation of the average losses (considering...
KIMCO, The Altimate in environmental-friendly Cooling Tower!

KIMCO serves all kinds of cooling towers with numerous new options. Enjoy the benefits!

- Plume Abatement Design
- Super Low Noise Design
- Anti-Bacteria, Legio-Free Tower
- High Efficiency, Energy Saving Design
- Non-Corrosion FRP Structure Construction
- CTI Certified Models are Available: Dyna-Cool / CKL / Endura-Cool

For more information, contact:
E-mail: kimco@kimcoct.com

Website: www.kimcoct.com

ISO 9001
IS0 14001

CTI Member

02-18-01
05-18-02
09-18-03

Modular Type, FRP Tower
Counter Flow FRP Tower
Field Erected, Counter Flow, Plume Abatement, Concrete Tower
Field Erected, Counter Flow, Steel Tower
all wind velocities) leads to 0.68 K for CV1 (~ 4MW) and 0.39 K for CV2 (~ 3MW) for CV1.

Figure 14: Comparison between theoretical and real wind curves for CV1 and CV2.

5.2.5. Conclusion

This deviation between theoretical and real wind curves could of course be due to manufacturers margins. The opportunity that we have now with SPA to build real wind curves gives EDF an opportunity to better control these margins for coming retrofitting.

Another interpretation is that the observed deviation is due to sound walls. Wind wall would act as an obstacle surrounding the tower reproducing the phenomena observed for Cruas cooling tower (see §6.1) for all wind directions. If this is the case it could really be worthwhile build sound walls for other towers (expected gain of 3 MW during at least 30 years of operation). This result is very interesting for EDF as long as in the past, some manufacturers explained us that wind wall induce performance degradation. Our result shows that this is not necessarily the case.

Finally, it should be mentioned that if the effect studied here is due to sound walls, the result certainly depend on the geometrical characteristics of the walls (distance from the tower, height…). Thus, optimization of sound walls would probably still have to be done before deciding to build sound walls.

5.3. Dampierre: Comparison between 4 Cooling towers of the same site

5.3.1. General presentation of the site

Four nuclear power plants of 900 MW each are operating on Dampierre site (see figure 15). Each NPP is using a natural draft cooling tower as a heat sink. A retrofitting is planned for each of these four towers in the coming years. Acceptance tests following these retrofittings will be based on European code EN 14705. To do so, EDF has to provide wind curves to manufacturers. To build these wind curves, we performed extensive analyses to understand as accurately as possible the interactions between different buildings of the site (other cooling towers, machine room…) and the cooling towers. Main results of this study are briefly presented here after.

Wind velocity and direction measurements are done on a mast located in a non obstructed area at about 700 meters south-east of cooling tower DA4.

5.3.2. Influence of wind direction on wind curves

As long as the four towers of Dampierre site are the same (shell and fill), theoretical wind curve is the same for each tower. This is the reason why all the curves used for the following analyses are plots of $DOET_{200}$ versus $V10_{200}$. They will be called “deviation curves”. This choice is done because it allows more accurate comparison between towers.

The first result of this study is the comparison of wind curves obtained without any selection of wind sector. It clearly appears Figure 15 that wind effect differs from one tower to another. For example, for 4 m/s wind velocity, there is a difference on cold water temperature close to 0.8K between cooling towers DA2 and DA4. As we already mentioned, the four cooling towers are the same. Thus, there shouldn’t be such discrepancy between the four deviation wind curves.

To understand the direction of this behavior, we studied the influence of wind direction sectors on the wind curve. Due to the orientation and location of buildings and towers on Dampierre site, we consider four wind sectors: 0° to 90°, 90° to 180°, 180° to 270° and 270° to 360° (see figure 15).

On figure 16 we plotted for each wind sector the four deviation wind curves for DA1. It clearly appears on this figure that wind curves significantly differ depending on the wind sector. For example, when wind comes from sector 0° to 90°, wind curve is far behind the others and decreases quicker with wind velocity. On the other hand, for wind sector 180° to 270°, deviation wind curve is flatter which means that
COOLING TOWER INSPECTION & REPAIR

Bleed-through, spalls and cracks are the beginning signs of deterioration. Our inspectors and engineers can provide detailed inspections, including shape surveys and strength calculations, leading to any necessary shell repairs.

With our sister company Bierrum, who specializes in the design and construction of hyperbolic cooling towers around the world, we have access to proprietary rigging and engineering services for hyperbolic cooling towers.

We have completed repairs to cooling towers shells, lintel beams and columns. Replacing ladders, platforms, and lightning protection is routine, and now inspections with an engineering review are all within our scope.

INTERNATIONAL CHIMNEY CORPORATION
55 South Long Street, Williamsville, NY 14221
800-828-1446 Phone: 716-634-3967
www.internationalchimney.com Fax: 716-634-3983
Email: gms@internationalchimney.com
theoretical wind curve is close to real wind curve. A possible explanation for this observation is that cooling tower DA2 is or isn’t an obstacle for DA1 depending on the direction where wind comes from: sector 0° to 90° or 180° to 270° (see figure 15).

Figure 16: Deviation wind curves sector by sector for DA1 (up) and DA4 (down)

Figure 16 also shows the same kind of plots for DA4. It appears that deviation wind curves for wind coming from sector 180° to 270° is significantly higher than other curves (between 0.6K to 1K). The same phenomenon was observed for DA3. The only explanation we found for this phenomenon is that machine room is reorienting wind of sector 225° to 270° so that the wind velocity seen by DA4 (or DA3) is higher than the wind measured at meteorological mast. As a consequence, DA4 (or DA3) thermal performance is reduced which increases the cold water temperature.

Another possible approach to analyze the data is to plot on the same figure deviation wind curves obtained of the four cooling towers for one wind sector (see figures 17 and 18). This approach allows confirming some hypothesis done to explain the observed deviations.

For example, figure 17 shows that DA3 and DA4 behave the same way when wind comes from 0 to 90° sector. On the other hand, DA1 and DA2 deviation wind curves differ from DA3 and DA4 wind curves. This is probably due to the fact that when wind comes from 0 to 90° sector, DA1 and DA2 are aligned with wind direction. Based on figure 17, this configuration seems to induce thermal performance improvement for both DA1 and DA2. For DA2, this performance improvement is not very strong (~0.2K for 5 m/s) whereas for DA1 it is stronger with a deviation between DA1 and DA3 of ~0.4K for 5 m/s wind velocity. DA1 is probably taking advantage of an obstacle effect due to DA2.

5.3.3. Synthesis of identified wind effects

5.3.3.1. Influence of a cooling tower upwind the observed cooling tower performance

This effect is observed each time wind comes from a sector corresponding to the alignment of two cooling towers. It leads to significantly improve performance of the cooling tower which is protected from wind by the other tower. This effect only appears for wind velocities higher than 2 or 3 m/s. For curves obtained for Dampierre site, the amplitude of this phenomenon is between 0.2K to 0.6K for a wind velocity of 5 m/s.

Figure 17: Comparison of DA1, 2, 3 and 4 deviation wind curves for sector 0° to 90° or sector 180° to 270°

5.3.3.2. Machine room influence

Dampierre site is characterized by a very large machine rooms building. The building is 40 meters high and close to 400 meters long (see figure 15). Due to the position of this building on the site (see figure 15), it could modify the direction and velocity of wind creating a deviation between the wind velocity and its direction measured at meteorological mast and those seen by the cooling towers.

This hypothesis could explain the cold water temperature increase observed for wind velocity between 0 to 2 m/s for DA3 and DA4 cooling towers when wind comes from sector 180° to 270° (see figures 19 and 17). The cold water increase is between 0.6K to 0.8K.

Other buildings influence

The presence of buildings upwind cooling towers makes data difficult to analyze. This is the case for cooling towers DA1 and DA2 when wind comes from sector 90° to 180° (see figure 18).

This observation justifies the choice done in codes like the EN 14705 to exclude from valid test periods those with wind sectors corresponding to the presence of buildings. Indeed the cooling tower behavior is then very difficult to predict accurately. It is then very difficult to build relevant wind curve to be used during performance tests.
At HUDSON, we understand there is more to the design and production of fan blades than patented technology. We understand that there is more than establishing the highest standards in a manufacturing process, and we understand that there is more than providing the highest quality products and services to our clients – we understand that Hudson has a history.

A history developed over many years of producing the finest fan blades in the industry. We once again raise the standard with the introduction of the latest member of our famous Tuf-Lite® lineage.

With a history of fan blade production since 1955, Hudson continues to push the limits of axial flow fan technology.

HUDSON PRODUCTS CORPORATION
9660 Grunwald Road, Beasley, Texas 77417-8600
Phone: (281) 396-8300
Fax: (281) 396-8388
1-800-634-9160 (24 Hours)
E-Mail: hudsonproducts@hudsonproducts.com

www.hudsonproducts.com
5.3.4. Wind sectors for a similar wind behavior of the four cooling towers

Based on the upper analyses, it is possible to identify for each cooling tower, wind sectors which are not influenced by any significant parasitic phenomenon. This leads to new wind curves based on data consistent with these unperturbed wind sectors. As it is shown on figure 20, the four wind curves are the same on contrary to what was observed on figure 15.

5.3.5. Conclusion

During acceptance tests, the EN 14705 imposes to identify valid wind sectors for which wind could be perturbed due to the presence of obstacles upwind the cooling tower. This very analysis shows that it is not always as simple to identify valid sectors. For example, without our analyses, it would have been impossible to identify the specific behavior of DA3 and DA4 for wind sector 180° to 270° due to machine room.

6. Conclusion

This paper explains how EDF monitoring tool (SPA) can be used to build experimental wind curves describing the real average wind influence on natural draft cooling towers performance.

Some examples are then given showing how these experimental wind curves can be used to identify potential performance margins due to relative position of cooling towers with respect to other buildings or walls. This kind of phenomena is generally studied using CFD simulations. SPA offers the opportunity to do the same kind of study based on real monitored data.

This is a wonderful opportunity for EDF to develop skills concerning wind effect on natural draft cooling towers performance which will help to avoid excessive manufacturers’ margins for the coming retrofitting of EDF nuclear power plants.
POWER-GEN INTERNATIONAL

GENERATING CHANGE

NOVEMBER 12–14, 2013 | ORANGE COUNTY CONVENTION CENTER | ORLANDO, FL, USA

FOR TWENTY-FIVE YEARS

Register by September 6 and save $100 off full conference registration. Use this promotional code when registering to receive your discount: CTI

www.power-gen.com
Water Reuse – As Time Goes By Do The Less Attractive Approaches Or Options Now Look More Attractive

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

ABSTRACT
Reuse of lower quality waters as Make Up water to Open Evaporative Cooling Water Systems has been implemented and practiced for several decades. The driving force was often “image” or lowering environmental impact and/or economic benefits or reduced operating costs. Pareto’s Principle was often followed if not strictly applied, the easiest, lowest cost to implement approaches were those most often implemented. With the passage of time, more stringent restrictions on permitted discharge consents and/or increased cost or reduced availability of good quality water have emerged or developed in some parts of the world. This may have a significant impact upon the benefits and requirements of existing reuse applications and/or make the previously less attractive projects worth reconsidering. The additional requirements that current applications may require, more advanced techniques that may be used within reuse projects are discussed within this paper.

Concepts of Water reuse
For many decades water has been reused in industrial utility water service plants. One of the most common and popular receptor is an open evaporative cooling system as these systems can often accept a poor(er) quality of water. Water reuse infers that water from one plant, system or process is “reused” in another plant or process. This is slightly different to recycling water where water is reused in the same system or process. In order to reuse water it may be necessary to adjust the quality of the water in order to make it suitable for reuse in a given receptor system, which may be considered as “regeneration and reuse”.

Reasons why water is reused vary from “enhancing Corporate or Company image” to keeping plant(s) operating in areas of limited water availability or during periods of water shortage. Techniques can range from simple, cheap modifications to more involved options that may entail complex and expensive civil engineering exercises. Historically practiced techniques
Increasing cycles of concentration simply involves reduction of “blowdown” or non-evaporative water losses from the system. Increasing the quantity of condensate recovered, which would normally be within steam generation plant, may require some modification or addition of condensate pipework, obviously incurring engineering and labour costs. Either of these projects may require modification of applied water treatment programs and/or supplementing treatment programs with chemicals that possess specific functionality or properties. Examples may include the adjustment of corrosion inhibitors and deposit control agent in a cooling water treatment program, or the inclusion of condensate treatment and/or changing amines to one with a different distribution ratio.

Recovery of rinse water or wash water may require the installation of an intermediate holding tank, and possibly a pump, which obviously required availability of space and incur costs for the installation of the tank.

Stop leaks or water going to drain

Historically practiced techniques

Options Now Look More Attractive

• Increase cycles of concentration in evaporative plant
• Adopt or increase recovery of condensate
• Recovery of rinse water in an ion exchange treatment plant
• Recycle wash water in a batch process in a subsequent batch

ABSTRACT

• Stop leaks or water going to drain

Historically practiced techniques

Increasing cycles of concentration simply involves reduction of “blowdown” or non-evaporative water losses from the system. Increasing the quantity of condensate recovered, which would normally be within steam generation plant, may require some modification or addition of condensate pipework, obviously incurring engineering and labour costs. Either of these projects may require modification of applied water treatment programs and/or supplementing treatment programs with chemicals that possess specific functionality or properties. Examples may include the adjustment of corrosion inhibitors and deposit control agent in a cooling water treatment program, or the inclusion of condensate treatment and/or changing amines to one with a different distribution ratio.

Recovery of rinse water or wash water may require the installation of an intermediate holding tank, and possibly a pump, which obviously required availability of space and incur costs for the installation of the tank.

Stop leaks should be part of a continuous on-going maintenance program. Stopping the practice of discharging utility water to drain, however desirable, is often difficult or costly to implement and possibly yielding a low return on investment. Often the reason that the water is discharged to drain is that the water pressure is low or within an isolated or distant part of the plant, and possibly providing a relatively low volume of water. Typical examples are sample coolers and pump gland cooling. If a collection network, holding tank and booster pump are required, the cost of these often outweighs benefits potentially realised.

Reuse of water would invariably entail installation and/or modification of pipework which can be quite costly because of distance the water needs to be transported, particularly when pipework has to cross roadways or other transport system or require specialist civil engineering or construction work.

As mentioned above, open evaporative cooling systems are often the prime choice of receptor for the reused water. The source of water that is reused in the cooling system is quite extensive, a few examples being given below, and of greatly variable water quality. Feasibility depends largely on quality of water for reuse and proximity of source and receptor, which will influence cost to implement the project and subsequent return on investment.

• Boiler or steam generation plant “blowdown”
• Low cycle cooling water cascaded into a second cooling system
• Contaminated or suspect steam condensate
The Baldor RPM AC® Cooling Tower Direct Drive Motor sets a new standard in cooling tower motors. Designed exclusively for cooling tower applications, the RPM AC motor mounts directly to the cooling tower fan, eliminating high-maintenance gearboxes, drive shafts and couplings. Combined with Baldor's VS1CTD proprietary adjustable frequency drive, this slow speed, high torque combination operates at variable speeds to maximize system efficiency and minimize noise. Perfect for new installations or for retrofitting older, less efficient cooling tower systems, the RPM AC Cooling Tower motor and VS1CTD Cooling Tower drive offers improved reliability while greatly reducing maintenance costs and energy consumption.

Check out our website for case studies, installation photos and additional information about the revolutionary new RPM AC Cooling Tower technology from Baldor. We are truly changing the future of cooling tower technology!

baldor.com  479-646-4711

- Energy Efficient
- Unmatched Quality
- Superior Reliability
- Low Maintenance
- Quiet Operation
- Made in the USA

©2013 Baldor Electric Company

Download a QR reader app and scan this code for more information.  
http://qr2.it/6o/1031257
Process condensate
Cooling system “blowdown” reused in a quencher, scrubber or as fire main water
Plant waste water, RO reject water or secondary treated sewage

Reuse of boiler “blowdown” can have a consequential benefit of supplying phosphate from the internal boiler treatment program to supplement cooling water treatment program. Cascading cooling water entails reusing “blowdown” from a system operating at low cycles, such as one which is limited in chloride concentration because of 300 series austenitic steel heat transfer equipment within the system, in a system that can operate at higher cycles of concentration. Obviously treatment chemicals applied in the first system will be “carried over” into the second system and therefore ideally similar treatment programs, or at least compatible or complimentary programs should be applied to each system. Reuse of cooling system “blowdown” as fire main water can have a benefit of supplying “treated” water to the fire main system, although in a fire main the water would largely be stagnant, which may influence the efficacy of the treatment.

From a corporate or company image point of view, reuse of waste water in particular municipal sewage probably has the most impact, but can also pose the greatest challenge from aspects of cooling water treatment program and variability of water quality. Reuse of difficult waters may require adjustment of water quality and/or removal or reduction of certain contaminants which involves capital expenditure, rendering this type of project less attractive. However, with increasing cost of water and effluent charges or constraints on effluent discharge, drought or limited availability of water, economic climate and desire to reduce operating costs now and into the long term future, where justified, capital expenditure to realize water reuse projects can make projects which in the past were unattractive a viable proposition.

Simply increase cycles of concentration?
Increasing the cycles of concentration at which an open evaporative cooling system operates sounds like a simple matter of “reducing blowdown”. However, this may not appear to be as simple as it seems. There may be involuntary or uncontrollable water loss from the system that may be hydraulically limiting the maximum cycles at which the system can be operated. If these are the use of cooling water outside of the cooling system circuit, such as use of cooling water in scrubbers, then one must find an alternative, and by definition a cheaper, source of water for the scrubber or equipment using cooling water that is not returned to the cooling system. Water loss may be from leaks in which case simple maintenance and repair may help to reduce the voluntary losses. A form of leak is water that is not returned because of low pressure and remote or distant location from the cooling tower. An example of this is pump gland cooling which is often discharged to ground or drain. Collection and pumping of such waters can be quite expensive with little value with regard to return on investment. Is the “blowdown valve and pipeline” too large? In systems with a relatively small volume of water in the system which control cycles of concentration by a conductivity initiated “blowdown valve”, if the valve and pipeline is too large, that is upon opening jets or passes more water than required, then cycles will fall below a reasonable lower value for the sine wave of operating cycles. An orifice plate or restricting flow by means of a manually set valve installed in the “blowdown line”, or installing a smaller diameter “blowdown valve” will rectify this and reduce the “overshoot” of the “cycles at the end of the blowdown cycle”. These may seem like “common sense” but how many times are they observed and yet no action taken to rectify?

Apart from the scenarios mentioned above, a serious limitation to increasing cycles can be the projected cooling water chemistry and solubility of certain components. This is obviously dependent upon the chemistry of the water used to make up the system, but can related to a region in which the plant is located. A normal constraint on the upper cycles of concentration at which a system can be operated is commonly the solubility of calcium carbonate. However, there are certain parts of the world where silica concentration is high, and the limitation on cycles may be the silica concentration in the cooling water. A normal limiting concentration for silica is in the order of 200 ppm SiO₂, although recently developed technologies have been demonstrated to be capable of extending this limit towards 300 ppm SiO₂.

The limitation imposed by calcium carbonate is the degree of super saturation of calcium carbonate that the cooling water treatment program, specifically the calcium carbonate inhibitor, and plant design and operating parameters will permit. This is generally assessed by calculating the Langelier Saturation Index (LSI), Ryznar Stability Index (RSI), Puckorius Scaling Index (PSI), or other applicable Indices related to calcium carbonate solubility, of the cooling water, or more correctly “cycled make up water”, chemistry. Depending upon the treatment program and, where applicable, the calcium carbonate inhibitor applied, there are “accepted limit guidelines” for the limiting value of these indices, which in turn can be extrapolated back an upper limit for cycles of concentration at which the cooling water chemistry would be expected not to develop calcium carbonate scale in heat exchange equipment and/or cooling tower packing. Generally, it is a “Rule of Thumb” that “conventional” calcium carbonate inhibitors, such as phosphonates, will allow a system to operate up to a LSI of +2.5, although this may vary depending upon plant design and operation. More advanced inhibitors may allow this upper limit to be extended to LSI +2.8 to +3.0, again very much depending plant design and operation. “Precipitating” type programs have been claimed to be capable of allowing operation at even higher LSI of +3.5 and even +4.5. However, even though technology allowing operation at higher LSI may be available, subsequently allowing operation at higher cycles, solubility of other components may become the limiting factor. A common example in certain parts of the world and/or make up water sources or chemistry is magnesium silicate solubility. Again, as referenced in a previous section, silica or silicate solubility is involved in a secondary limiting factor on cycles of concentration.

If the concern is just the calcium carbonate inhibition technology ability to operate at higher cycles, one solution, possibly the simplest and cheapest, is to adjust or reduce the pH of the bulk cooling water using acid. As calcium carbonate solubility is affected by the pH of the water, reducing the pH will allow higher concentrations of calcium carbonate to be soluble. Super saturation, LSI and other Calcium Carbonate Solubility or Saturation Indices are also dependent, amongst other factors, upon the pH of the bulk cooling water, as illustrated in the formulae below where pHact is the pH of the water and pHsat is the pH of saturation for calcium carbonate.

\[
\text{Langelier Saturation Index (LSI)} = \text{pH}_{\text{actual}} - \text{pH}_{\text{saturation}} \\
\text{Ryznar Stability Index (RSI)} = 2\text{pH}_{\text{saturation}} - \text{pH}_{\text{actual}} \\
\text{Puckorius Solubility Index} = 2\text{pH}_{\text{saturation}} - \left(\frac{\left(1.465 \times \log_{10}(\text{Alkalinity})\right)}{4.56}\right)
\]

Related to LSI, if one is using a technology that has a limiting LSI of +3.0, and an increase of one cycle of concentration takes the LSI to +3.2, reducing the bulk water pH at the higher cycles by 0.2 pH units will bring the LSI back to +3.0. As a safeguard, in this instance one may reduce the pH at the higher cycles by 0.4 or 0.5 pH units.
The solubility of magnesium silicate is also related to the pH of the water, being more soluble at lower pH. Solubility of silica is independent of water pH. Therefore, installation of pH adjustment equipment, essentially a pH meter for measurement and control of pH, an acid dosing pump and, where needed, a tank for the acid will allow a system to be operated at higher cycles of concentration where the limiting factor is calcium carbonate and/or magnesium silicate. Where the limiting factor is solely silica pH adjustment will not have a significant effect.

**Tackling the more challenging water reuse projects**

In some cases reuse of poor quality water will limit the percentage of the poor quality water that can be used, as a make up water blend, in the cooling system and/or result in the reduction of the cycles of concentration at which the system can be safely operated from a corrosion and scaling potential aspect. The viability of reusing poor quality water is a balance of savings in water and treatment costs. However, the percentage of poor quality water that can be used and/or the cycles of concentration may be increased if the quality of the reuse water is improved, an approach which may be described as *regeneration and reuse*. This will inevitably incur capital expenditure for equipment, extra pipework and possibly civil engineering work. In the past, when the Pareto Principle was applied, this approach, possibly with the exception of simple filtration, was often dismissed, postponed or “shelved” because of cost. However, these costs may now be justified, even necessary, in today’s economic and/or environmental climate.

One approach would be the reduction of the dissolved solids in the water. This can be accomplished by utilizing Reverse Osmosis (RO) or Electrodialysis Reversal (EDR) techniques. It should be noted that removal of dissolved solids from water, particularly calcium and/or alkalinity, can result in an increase in corrosion potential of the water, particularly towards low carbon steel (LCS). This is the case with RO or Thermal Desalination (Desal) where almost pure water with very low dissolved solids is produced. Even when concentrated up in an evaporative cooling system, the pH and calcium concentration in the cooling water are low which renders the water “difficult to treat” and high LCS corrosion rates are often experienced. In this case a blend of the RO, EDR, or Desal water with “hard water” is desirable.

In some instances the constraint imposed by waters that can potentially be reused may be connected with discharge constraints and environmental concerns. These restrictions may be related to environmental concern such as salinity or the concentration of a given component or element such as sulfate or alkalinity, phosphorus, nitrogen or sulfur; or ecological concerns related to organic matter and its reaction with halogens used to control microbiological growth within the cooling water and the cooling system. The latter encompasses formation of Trihalomethane (THM) or generation of Adsorbable Organic halides (AOX). The solution to THMs and AOX is either the removal or reduction of organic compounds in the make up or cooling water, such as by carbon filtration or ozonation, or, the use of a non-oxidizing biocide or an alternative oxidizing biocide such as chlorine dioxide, hydrogen peroxide, peroxy acid, ozone or non-chemical device for control of microbiological growth.
These alternative biocides will be more costly than halogens such as chlorine or bromine, which will possibly increase treatment or operating cost. Any extra treatment cost and capital expenditure has to provide a return on the investment within an acceptable payback time through an overall reduction of operating cost and cost of ownership.

**Zero blowdown**

Zero blowdown is akin to operating at high cycles of concentration that are purely limited by losses other than deliberate blowdown of purge from the system. In a well maintained system with no leaks or use of cooling water by processes or equipment that does not return cooling water back to the cooling system, the hydraulic limitation to cycles of concentration that can be achieved is windage and drift, windage typically being the larger mass of the two. Obviously very good, low dissolved solids water is required for make up water as such an mode of operation can lead to cycles of concentration of over 20 cycles being achieved. Many systems using Desal water, demineralized water, condensate or RO water can operate with no deliberate blowdown or loss from the system, but may require additional chemical treatment, such as the use of alkali to increase pH and/or re-mineralization to increase the calcium concentration, to facilitate control of LCS corrosion, particularly when chlorination increases the concentration of aggressive chloride ions.

The desire for operation with zero blowdown has been a “vision” for several decades. “Softening” of the deliberate blowdown or purge was an early approach which would suffice if hardness salts were the only limitation. However, much of the aggressive ions, such as chloride and sulfate, will not be removed and their concentration will continually increase. RO or EDR of the deliberate blowdown or purge will remove a significant amount of the total dissolved solids in the water, which can then be returned to the cooling system, essentially reusing the pretreated blowdown as partial make up water, or **regeneration and recycle**. Consideration has to be given to the effect of the cooling water chemistry, particulate matter concentration and treatment chemicals on the membrane or the suitability of the membrane for an individual installation. Obviously the blowdown or purge stream, or the major part of the blowdown or purge, has to be accessible and available for reuse once pretreated.

Zero blowdown and zero discharge as often considered as being one and the same. This is not really the case since there will always be some, albeit little, non-containable water losses from the system in the form of windage, drift, and possibly leaks. Although these may not be directly discharged in the form of effluent, they are in essence “discharged” from the cooling system. RO or EDR plant will have to discharge concentrated brine so, although the discharged water volume may be less the dissolved solids concentration will be high, so the overall mass of dissolved solids will be roughly equivalent whether the blowdown if discharged directly from the cooling system or pretreated and the concentrated reject water discharged.

**Conclusion**

There are still opportunities that have not been exploited, to reuse water in open evaporative cooling systems. Environmental and ecological concerns or constraints, and the current economic climate may make techniques and approaches that were in the past “shelved” because of cost and poor return on investment, a viable proposition today. Over the past few years there have been technical and equipment developments that can also make certain reuse projects more viable and appealing.
Engineering Problems... Into Solutions

FOR OVER 20 YEARS, KIPCON HAS BEEN DESIGNING AND INSPECTING COOLING TOWERS OF ALL TYPES.

YOU NEED IT... WE DESIGN IT
Kipcon Inc. provides structural designs for new cooling towers and retrofits of existing towers, whether it be a cross-flow, counter-flow, wood, concrete, fiberglass, wet and/or dry system. This includes basin design and basin load tables.

YOU HAVE IT... WE INSPECT IT
Kipcon Inc. also provides complete cooling tower inspection services and can develop remedial plans of action for retrofitted towers.

YOU WANT DRAWINGS... WE WILL DRAFT THEM
Kipcon prepares drawing packages, including erection plans, connection and fabrication details.

Call us today to discuss your cooling tower needs.
Fiberglass Reinforced Polyester in Cooling Towers - Structural Application

Ken Mortensen

Fiberglass reinforced polyester, FRP, and closely-related variants have been used as primary Cooling Tower structure for over 20 years. FRP is a material well suited to the evaporative cooling environment. It is a very versatile structural material with good initial strength and predictability for service in all of the severe exposures offered by a cooling tower: immersion/basin, splash/fill, and 100% humidity/plenum.

FRP application in wood structure, as a primary load transferring component, goes back much further. This paper documents this history of FRP structural application development and discusses FRP material properties, testing, and standards in the Evaporative Cooling Tower market.

History

During the 1950’s, the development of new chemicals and polymers was a major thrust in the industrial expansion in the United States and Europe. New “plastics” were being synthesized, molded, tested, and applied in many applications. Ideas originated in the 1950’s include, the first plastic Coke bottle, Vinyl [PVC] records, polyester fiber for clothing, and the invention of polypropylene [PP] for injection molded parts like spray nozzles.[1]

In 1959, H. H. Braine of Marley, stated in his article “Why Plastics in Cooling Towers?”, that “conventional cooling tower materials undergo continual deterioration in service. The wood is attacked by microbiological organisms. Metals are subject to corrosion… In a constant battle to improve service life economically, cooling tower manufacturers recently have been investigating plastics.”[2]

In the 1960’s and 70’s, FRP laminates are introduced in many applications. “The ‘glass’ fishing rod…replaced other materials because of its properties. The Corvette automobile and accessory parts of many other automotive products are changed over to glass fiber and polyester laminates. The success of this material in small boats is a testimony of the resistance to outdoor weathering and water immersion. Chemical valves, pipe, and tanks, and combination insulators and guy lines are other examples of use of this material.”[3]

Long before the use of FRP pultrusions for structural framework in evaporative cooling, fan blades, fan cylinders, fill support grids, diagonal connectors, casing, louvers, pipe and other parts were successfully used in cooling tower applications.

Even as redwood and douglas fir were dominating the structural componentry for evaporative cooling towers, pioneers in the business recognized the useful properties of FRP for structural load transfer. Such observations were documented in John A. Nelson’s paper “Plastics and the Marley Cooling Tower Company”.[4]

John explains, “(Our)Company pioneered the use of plastic components in cooling tower construction. Marley engineers early recognized the unique, useful properties of plastics, particularly as they related to cooling tower environments.” “Fiberglass reinforced polyester was the first major plastics material to be introduced… It was generally described as glass reinforced polyester and was commonly referred to as GRP. GRP was registered as a trademark (of Marley Company) in 1960, but the trademark was not renewed after 1980.”.

“The earliest polyesters were based on orthophthalic acid… generally the least costly, but they have only moderate chemical resistance. In the early 50’s, polyester resins were introduced which were based on isophthalic acid. Those had markedly improved chemical and water resistance and were introduced in Marley tower components shortly after they became available. The isophthalic resins are still being used in critical components.”[4]

The First Structural FRP Parts

The Diagonal Connector became the earliest FRP structural component, introduced in 1957. “Diagonal bracing in the wood structure is necessary to resist lateral operational, wind and seismic loads, transferring these loads into the basin. The development of an optimized diagonal connector resulted from long study of numerous framing systems. Metal cables and rods for pure tension diagonals, as well as numerous metal devices for connecting wood diagonals, were investigated and found undesirable from standpoints of field erection, strength capacity, corrosion resistance or economy.”[3]

Again, as John Nelson explains, “Glass reinforced polyester appeared to be the proper material for this component so a design was generated utilizing compression molding of fiberglass rovings impregnated with polyester resins along with surface materials referred to as rovmat. After … revisions to the design and the tool, connectors of adequate strength were produced. … Because of the critical nature of the structural timber connectors a system of proof loading representative samples routinely was established … results of tests on the connectors from operating towers verified the adequacies of the early durability tests on resin/glass combinations.”[4]

Accelerated exposure tests in the form of boiling water tests and strength tests of various polyester resins were used to determine the proper formulation for this application. This program resulted in a minimum safety factor range of 2.82 to 4.10. In many cases, the safety factor was higher, because the maximum possible design loading is attained in only limited areas of towers as built. Proof testing was established as part of the quality control procedures for all connector production. For reference the typical loading capability of these structural connectors was 6250 lbs./pair, when installed for
TURN-KEY COOLING SOLUTIONS

AMERICAN COOLING TOWER, INC

Corporate Office:
6411 Maple Avenue
Westminster, California 92683

Since 1982 American Cooling Tower has provided services for:

Process & Power
Universities
Industrial
Commercial
Government
Military
And more...

National Offices:
San Francisco, CA
Springfield, MO
Greensboro, NC
Houston, TX

NEW TOWERS
- Counter Flow Designs
- Cross Flow Designs
- Pultruded Fiberglass Structure
- Wood Structure
- Concrete Structure
- Double Wall Construction

RENTAL TOWERS
- Nationwide depots
- Stainless Steel Units
- Open & Closed Loop design
- Contingency Planning
- Fast response time
- Quick Setup
- Accessories

SERVICE/REPAIR
- Rebuilds
- Tower Cleanings
- Thermal Upgrades
- Replacements
- Performance Testing
- Blast & Coats
- Mechanical Upgrades
- Fan Balancing
- Gear Box Maintenance
- Drive Shaft Alignments
- Maintenance Programs

PARTS
- Fill Media
- Drift Eliminators
- Spray Nozzles
- Distribution Systems
- Mechanical Components
- Coatings
- Structural
- Hardware
- Steel fabrication
- FRP, Wood, Steel

800-371-5959 • www.AmericanCoolingTower.com
balanced loading on both sides of a column. Over the years, many tests have also been carried out to verify acceptable fatigue strength and properties after time in service.

Following the structural connector, a number of FRP mechanical and distribution components were developed, tested, and introduced in evaporative cooling towers including: filament wound distribution piping in 1961, blades for the 336” diameter fan in 1963, Hollow rib fan cylinders in 1968, Cored 10 Meter FRP blades in 1977, and Glass reinforced epoxy (GRE) blades for 144” - 216” HP-7 fans 1980 and 1981.

Fiberglass Field-Erected Cooling Tower

By the 1990’s, FRP structural field erected towers became available. In 1992, Marley introduced a Fiberglass Counterflow Tower called the Class F400. Over the next two decades, 400+ towers and 1700+ cells were built by SPX/Marley. This workhorse tower was used in many applications, including base-load power, chemical process, refining, metals and mining, pulp and paper, gas separation, agricultural processing, geothermal power, high tech manufacturing, data center, hospital, commercial, comfort cooling. Tower conditions include exposure to high and low pH’s, and high temperatures, with 74 towers at 110 degF plus, and 17 towers at 120 degF plus. Other exposures include brackish water, seawater, and sewage effluent applications.(5)

One of the earliest of these F400 towers was built for a Missouri Municipal Utility. This tower was recently completely reviewed. The tower was in very good condition, structurally sound, and operating efficiently after 20 years. Pictures from that inspection are included below.
FRP offers light weight with high strength, corrosion resistance, impact resistance, dimensional stability, custom profiles, and a proven cooling tower track record as documented here. This FRP tower and component history is not intended to imply that there have been no problems with FRP materials in the evaporative cooling environment. There are always issues using novel materials for a given application. The problems, however, have been few and the replacement parts for these towers rare.

**A New Era: FRP’s Critical Properties Defined for Quality Material, Design, and Manufacturing**

As FRP use in structurally critical evaporative cooling designs increased, the need for defined standards became apparent. The Cooling Technology Institute’s Engineering Standards and Maintenance committee began work on FRP Standards, CTI STD-137 and 152, under the leadership of Glenn Barefoot, beginning about 2000. These documents represent formalized ‘Best Practices’ for lessons learned in Evaporative Cooling Tower Design and Manufacturing. The CTI engineering philosophy pertaining to FRP material is reflected in STD-137, Section 7.1, “Minimum mechanical properties (coupons)…, when tested at 77°F, are listed in Table(s). …These mechanical properties taken from the coupons are intended to be used as a proof test for the composite supplied and not to be used for design purposes. The purchaser should consult appropriate design manuals to obtain the necessary design data for agreed upon qualifying tests on full sections.”

This CTI philosophy depends on expertise developed by the evaporative cooling tower manufacturers in consultation with the pultrusion industry, using the threshold material coupon properties to qualify materials, and engineering skill in applying FRP to operating conditions. These applied structural engineering skills are not readily available, but must be sought and retained in the industry.

A number of reference standards and tests, most prominently ASTM’s, are listed in CTI STD-137 and 152. These include tests for tensile, flexural, and compression properties, along with other important features such as impact resistance and fire-retardancy.

The proof of competent engineering is the component and tower legacy reference the history section of this paper. FRP towers have proven to be durable structures with few repairs.

**FRP Material Testing**

Examining material capability is essential to judging its usefulness for application. In the cooling tower industry, preservative treated wood set the standard prior to FRP availability, with testing demonstrating its strength retention over tower lives stretching to 50 and even 60 years. FRP material underwent long-term water exposure and strength testing by individual companies and industry groups during development of FRP Tower designs. Several tests are discussed here.

SPX/Marley completed 5 tests of pultruded FRP products in hot water exposure between 1988 and 2008. The most extensive of these tests showed initial average FRP flexural strengths of 55,000 psi and initial average FRP tensile strengths of 66,000 psi. This testing duration was 3 years and the initial and long-term data supports strength requirements for engineered designs using FRP.

When drafting CTI Standard 137 began, pultrusion and cooling tower manufacturer’s saw fit to conduct a number of tests evaluating FRP column design requirements and strength retention. FRP column buckling and compression were an important focus. Buckling testing of 48” tall columns considered results for multiple FRP supplier’s showed an initial 43,900 psi buckling strength for all products and 95% strength retention over the 2 years. Compression properties of 12” columns averaged for multiple suppliers showed an initial strength of 71,400 psi and 80% retention over the 2 years. The study points out that “the 12” samples failed by crushing the ends while the 48” samples were subject to Euler buckling.”

These tests are representing important milestones in the application of FRP for structural in the evaporative cooling application.
The current ACMA-funded standards writing process for pultruded FRP structures represents a broad engineering recognition of the use of FRP industrial applications, such as evaporative cooling equipment. This is an ongoing process that the cooling industry will be monitoring.

Manufacturing Quality System

The Pultrusion Process

Pultrusion manufacturing is sophisticated processing. Figure 10 above shows a portion of the pultrusion processing equipment. Roving, mat, and veil are pulled in configured feed into a resin bath, exiting to lay-up handlers that bring the wet roving into a pre-mold configuration. The machine further configures the laminate into the final pre-cure shape and adds veil as the pultruded part goes into the die for cure. Good process control is essential to achieve the final part dimensions consistently. Quality checks of the resins and glass materials, reinforcement placement, wet out, surface treatment, and curing cycle insures that the part is manufactured “per specification”.

Review of the pultruder’s quality plan, observation of their process, and sampling measurements of the as built member should be adequate to assure laminates that will perform structurally in cooling towers. Use of process control verification techniques with visual indicators at this stage of supply will pay big dividends in the FRP finished product for the tower. These recommendations help the end user feel confident that FRP parts are right for their application. A competent FRP supplier should have in-house testing facilities to ensure specified performance and in-plant quality manual, verification, and documentation available for the cooling tower manufacturer and the end user.

Construction Techniques

Proper material handling and construction of a tower are the next objectives. FRP materials, inspected at the factory, should be reviewed at site prior to installation for signs of quality and shipping issues. Major issues should be handled by segregating material. Minor issues could arise from post-cure, cutting, drilling, loading, shipping, and site storage operations. Customer and supplier should work to allow sensible use of material.

Construction procedures should be in-place that provide for protection of bent members at hoisting, proper hoisting technique, expert placement of assemblies, and final alignment of structure per design while avoiding damage. 

Material Quality and Design

FRP material quality and design should be judged by a number of factors. Many of the most significant quality indicators are contained within the body of the laminate and are not discernible from external examination. Those include layup, reinforcement location, wetting, and cure. For that reason, adequate FRP manufacturing
process controls are essential to building good evaporative cooling tower projects.

The appearance of FRP material is also an indicator of care taken in manufacture. These visuals may or may not be representative of properties below the surface of the part. Defect descriptions are provided in ASTM D4385 paragraph 1.1.1, as “criteria for visual acceptance of (pultrusions)”. This is intended as a guide to monitor processing and make further checks and judgments, not as an absolute accept/reject categories for material. Many visual defect categories are “permitted, if product meets test requirements.”

From ASTM D4385 important definitions include: blister, crack, craze, delamination, dry fiber, folded reinforcement/resin richness, insufficient cure, and internal shrinkage crack. The standard is constructed to allow selection of the relevant items and various quality levels. ASTM D4385 paragraph 4.1 states that, “the inspection shall be concern with those defects described by the product specification, drawings, or contracts for the pultruded product.”

Certainly not all of the categories are relevant for cooling towers, as cooling towers are not generally aesthetic products. The customer should select items and levels here carefully, to insure a durable product, without substantial extra expense from exclusion of irrelevant laminate issues.

The material specification is critical. Review of vendor selection, manufacturing requirements, physical properties verification tests, quality procedures, and appearance all provide information to the user. These checks should be specified by the customer and then provided by the pultrusion and evaporative cooling tower manufacturer to the customer. Production stage quality checks are the most important arbiters of good material. Visual defects are a factor in evaluating a material like FRP.

Problems and Resolutions

Problems in FRP cooling tower structure have been rare. In this section a few of those problems are reviewed, as they may be instructive, and help customers and manufacturers sort out field issues. These problems can be divided into 2 categories, Structural and Non-structural.

Structural

Structural problems are typically obvious. When structural members, i.e. columns, girts, and diagonals, are moving in measurable amounts over short periods of time, the FRP tower frame is rearranging itself to accept or bear load. This process will continue until equilibrium is reached. These type observations mean that FRP members are incapable of bearing the load as originally configured, due to their initial strength, installation, and/or the safety factor used in the design. These problems are typically immediate, i.e. early in tower life. These problems are rare, judging based on FRP tower history.

Structural issues need to be resolved, as soon as reasonably possible. As a first step, the situation must be evaluated by methods including, initial and ongoing observation, design calculation review, and safety factor review in order to understand the problem. Replacement of overloaded parts should be undertaken when the proper solution can be identified and replacement design is verified. Alternate materials or redesigned bearing may be required to insure longevity. Replacement should be managed to minimize damage to additional and/or surrounding structure by added loading and coincide w/outages so as to insure tower operation with continued integrity. An example overloaded column is shown in Figure 12.

Non-structural

Visual imperfections in FRP members, where overloading is not apparent, are more difficult to judge. If design, manufacturing, and construction techniques were verified to minimize risk, the chance of significant structural FRP quality problem appearing at this stage in the overall process is low. If tower members are not ‘moving’, as described in the structural section, then there is a substantial time window for evaluation of the situation specifics. One should initially review the problem by methods including, observation, check of design calculation, and safety factor review, in order define the problem and its impact on the cooling tower design. Longer term observation, sampling, and testing are options in selecting a solution and can typically be employed for these type problems.

Visual indicators like crazes or resin-rich cracks can be confused with a more meaningful reinforcement separation that might affect strength. Without internal examination and/or destructive properties testing for the parts in question, the relevance of many of these visual indicators cannot be determined. A crack by ASTM D4385 definition is a “Visual separation …that penetrates down from the surface to the equivalent of one full ply or more of reinforcement”. Resin-rich areas can craze or separate within the resin layer, without penetrating reinforcement and without measurable effect on part strength.

As an example, the 3.5” square FRP tube shown in Figure 13 has resin rich areas displaying some crazing/cracking. Without removing sample sections, cutting crossections, and examining laminate internals the depth and extent of the imperfection could not have been known. Here specimens were cut and analyzed. Compressive strength, and compressive modulus tests were completed. Full 3.5” column cross sections were compression tested. In test, 4 samples
with the craze defects compression strength averaged 30,900 psi, while 4 non-defect samples tested at 29,400 psi. The crazed parts are acceptable structurally. In this case, the ASTM definition for a crack was not met and the compression strength for the column cross section was not reduced. These type parts do not need to be replaced for structural or long-term tower quality reasons.

Figure 13: Reinforcement Fold in Full Crosssection, Compression Tested

Figure 14: Reinforcement Fold

In another example, a number of 3.5” FRP columns developed blisters on the structure of a relatively new tower. Site and materials investigation could not conclusively determine whether material deficiency or site exposure were the cause. Without removing sample sections, cutting crossections, and examining part internals, the depth and extent of the imperfection could not have been known. Specimens were sampled, examined, cut, tested and analyzed for capability. Testing indicated no strength reduction or progression of these blisters at 1 and 2 years operation. Consultation with the resin vendor and pultrusion manufacturer yielded recommendations that the parts in question be monitored long-term, rather than replaced. A program to monitor the status of parts both visually and by properties testing has been undertaken.

The problem in both these cases was determining the nature of the “defect”. Such parts can be monitored without any structural risk to the tower, since no distress is indicated. Such problems could be dealt with on an ongoing basis at minimal cost or risk to either end user or manufacturer.

Recommended policy for suppliers is to be responsive in diagnosing problems, identifying failure mechanisms, and performing warranty repairs with FRP towers built, while implementing changes in design, manufacturing requirements, and construction techniques that reflect lessons learned from FRP tower experience.

Conclusions:
Substantial testing, application, and operational data indicates that FRP is a material well suited to the cooling tower environment. It is very durable in the various wet exposures. There have been few FRP replacement parts and no FRP tower failures. FRP has been in-use since the 1950’s in various forms, with strong structural roots in early wood tower designs.

John Nelson indicated in 1987, that “(a) review of records and calculations from the number of components produced indicate that more than 61 million pounds of FRP have been utilized in Marley cooling tower components through 1986. This number is particularly significant since virtually all of the material is still in service unless the towers have been retired. In other words, there have been extremely few failures of GRP components in service.”(4)
Specific Conclusions:

1. FRP is a material well suited to cooling tower application and very durable in the various wet cooling tower environments.

2. Competent Manufacturers:
   a. have capable Design Staff providing sound FRP designs for field-erected cooling towers,
   b. have Quality System to verify FRP material for their jobs,
   c. have Field Construction Procedures providing proper handling of FRP structure,
   d. stand behind their design, QC, and construction practices,
   e. and provide a long historic track record of sound FRP product.

3. Customers should take substantial care in specifying FRP Structural Tower specifics.

4. Customers should work with manufacturer’s in a practical way to attain FRP tower designs that meet long-term operating goals at a reasonable cost.

References:


5. Internal SPX/Marley Publication, F400 Installation Data, 2/12/10.

6. CTI STD-137

7. Internal SPX/Marley Publication, 3/12/12

8. ASTM D4385


10. Internal SPX/Marley Publication, 2/17/11

11. Update on the Impact of Water Immersion for Pultruded FRP, Clint Smith, Strongwell, CTI TP04-08.


Appendix - Additional Example and Information

For 5.2” square column, the size and thickness of the laminate seemed to create resin rich areas in the profile corners that can craze/crack, see Figure 14. Corners with reinforcement folds and crazes/cracks and those without are being tested in compression. A single sample of each type has been tested so far. That partial section containing corners without folds had ultimate compression strength of 70,000psi, while the partial section containing corners with folds was at 80,000psi. Testing continues.

For many of these parts the ASTM definition for a crack was not met. These crazes do not penetrate reinforcement. Many cannot be seen without magnification. Such parts can be monitored without any structural risk to the tower. No distress is indicated. Structural issues, although unlikely, could be dealt with on an ongoing basis at minimal cost or risk to either manufacturer or end user.
Cooling Tower Measurements?

We Do!

We do it all - sensors to measure vibration, acoustics, forces, pressure, load, strain, shock and torque - sure we do!

NEW!

LINEAR ADJUST

Mechanical Vibration Switch

Model 685A09

- Innovative, patent pending design outperforms traditional mechanical vibration switches
- Low cost protection for critical machinery
- Linear trip adjustment (∼1/4 turn per g)
- Better sensitivity repeatability on reset

Want Better Cooling Tower Protection?

IMI SENSORS
A PCB PIEZOTRONICS DIV.

Toll-Free in the USA 800-959-4464
Email imi@pcb.com
Website www.imi-sensors.com
How Sensor Mounting Affects Measurements

David A. Corelli
IMI Sensors

Abstract:
Sensor mounting can significantly affect both overall vibration and FFT (Fast Fourier Transform) data. This paper describes the differences and confusion in overall measurement techniques and shows how frequency response can affect these measurements. The frequency response of some common mounting methods, such as stud, 2-rail magnet, and flat magnet are measured under controlled laboratory conditions and the results presented. The laboratory data is then correlated with actual machinery data. The paper also shows the dramatic effect that mounting has on commonly used high frequency overall measurements such as Spike Energy™ and PeakVue® that are used for early warning of bearing and gear faults.

Note: Definitions are included at the end of the paper.

Overall Vibration Level
We often hear the term overall vibration level but what does it mean? It is certainly not a well defined term and one can make the case that it is not defined at all. There are many ways to measure overall vibration levels and many of today’s vibration data collectors can be setup to measure overall vibration levels using different techniques. Thus, it is hard to define or compare acceptable overall levels for machinery unless the measurement method is well defined. Below are several terms that describe overall vibration measurements.

- Amplitude
- RMS or true RMS
- Derived or calculated peak
- True peak
- “Full” bandwidth analog
- Filtered analog
- Band limited overall (computed from the FFT)

Measures
The typical measures used for overall vibration measurement and analysis (displacement, velocity, and acceleration) are useful for detecting different types of faults. The first three measures listed below are actual physical quantities that can be traced back to a standard, typically through NIST in the United States. Overall HFE (High Frequency Energy), on the other hand, is not a physical quantity, is measured using data outside the calibrated range of the accelerometer, and is thus not traceable. This adds another level of complexity not only in trying set vibration standards or limits for HFE measurements but also in trying to compare results.

- Displacement is used to measure very low frequency faults such as unbalance in slow speed machines like cooling tower fans. Unfortunately, this can be difficult to measure without non-contact (proximity) probes. It is also used to monitor relative shaft movement with fluid film (sleeve type) bearings using non-contact probes.
- Velocity is a primary measure used in most condition monitoring programs to monitor “Balance-of-Plant” faults such as unbalance, misalignment, and looseness.
- Acceleration is typically used to detect higher frequency faults such as gear mesh and broken rotor bars.
- High Frequency Energy (HFE) uses data collected above the calibrated range of the accelerometer, including data collected at sensor resonance, and provides early detection of high frequency and impulsive faults such as bearing defects, gear defects, and loss of lubrication (metal-to-metal contact).

GM Vibration Standard - I often hear vibration analysts complain that measurements made with new sensors don’t agree with the same measurements made with older sensors. They also are confused why another analyst is getting different results than they are when they are seemingly making the same measurements, particularly with overall measurements. To help address this problem, the General Motors Vibration Standards Committee defined “Band-Limited Overall Amplitude Acceptance Limits” to ensure consistency and repeatability of results in their Vibration Standard for the Purchase of New and Rebuilt Machinery and Equipment. Band-limited overall values are computed from a frequency spectrum (FFT) that must be within ±5% of the calibrated response of the accelerometer, including sensor mounting effects, over the selected frequency range. Further, when looking at the total energy in a peak, “a minimum of 5 lines of resolution must be used and the peak must be centered in the band.” The following equation is defined in the GM Standard to compute the band-limited overall when a specified Hanning window is used (the 1.5 factor)

\[
A = \sqrt{\frac{\sum A_i^2}{1.5}}
\]

Where:
- \(A\) = Overall vibration level in Band
- \(A_i\) = Amplitude in the \(i^{th}\) line of resolution in the Band
- (i=1) = The first line of resolution in the Band
- (i=N) = The last line of resolution in the Band
- N = the number of lines of resolution in the band

When this method is used to determine the overall vibration level, it is much more repeatable between analysts and “transportable” since the band-limited overall is calculated over a well defined frequency range and from a calibrated spectrum. However, a problem often arises when the analyst does not realize that their sensor mounting method is altering the frequency response in the selected frequency range so the spectrum is actually not calibrated.

HFE Problems - The problems of accuracy, consistency, and repeatability of data is worse when making HFE measurements because overall HFE levels are determined from data collected outside the calibrated range of the accelerometer, over a frequency range where
sensor mounting dynamics affect the measurements, and there is no physical quantity to trace it back to. Additionally, different accelerometers have different natural frequencies and amplification factors. Since HFE measurements include data collected at the sensor’s natural frequency, this further exacerbates the problem. If this isn’t bad enough, many if not most industrial accelerometers have built-in low pass filters to reduce the amplification effects (to reduce saturation) at the sensor resonance, which also changes the sensor’s high frequency response (above the specified range of the sensor). In the case of HFE, all bets are off on accuracy or transportability. In fact, who is to say what is accurate since there is no physical quantity to trace it back to?

Mounting Effects

Frequency response calibrations were run on two IMI Sensors, a Model 603C01 Low Cost Industrial Accelerometer and a Model 622B01 Precision Industrial Accelerometer. The 603C01 has about a 25 kHz natural frequency and a 2-pole internal filter while the 622B01 has about a 30 kHz natural frequency and a single-pole filter. Frequency response tests were run using step sine analysis on an NIST traceable accelerometer calibration system. The frequency response was tested with the following sensor mounts: stud, 35# pull flat magnet, 35# pull 2-rail (curved surface) magnet, ¼ twist mount, and 4” SS Probe (stinger). A typical test setup is shown in Figure 1. The lower sensor in Figure 1 is a back-to-back calibration standard. Figure 2 shows the stainless steel probe mounted to a 603C01 accelerometer. The results of the tests are shown in Table 1.

Since the frequency response of most industrial accelerometers are specified at their ±3dB point, it can be seen that the mounting method dramatically changes the calibrated range of the accelerometer system (sensor and mount). The flat frequency response of the 603C01 is reduced from about 12.5 kHz with a stud mount to about 3554 Hz with a 2-rail (curved surface) magnet under ideal conditions. It will be worse on a curved surface on a machine. The useful frequency range of the sensor with the stainless steel probe is only 750 Hz. When making overall measurements, significantly different values will be recorded with these different sensor mounting configurations and the analyst will probably not realize it.

Centrifugal Compressor and Traceable Measurements

The above example clearly shows how the sensor mount can affect the measured data. But how much variation is actually encountered under normal day-to-day measurement circumstances due to the different sensors and typical mounts?

Data was collected on the centrifugal compressor shown in Figure 3. The acceleration and velocity spectra collected with the various sensors and mounts are shown in Figures 4 and 5. Even though these are seemingly low frequency measurements, i.e., well within the specified range of the accelerometers, there are major differences in the spectral data in both acceleration and velocity. This is due to the effects of the sensor mount. For the 2-rail magnet, twist mount, and stinger, the differences are significant. This clearly shows that the mounting methods typically used in day-to-day data collection can have a large effect on the accuracy of routinely collected data. The plots also show the overall level as calculated from the spectrum. In velocity, it ranges from 0.0138 ips stud mounted to 0.0229 ips with the probe or a 65.9% difference. If the probe data is not considered, the difference is still 37.7%. For acceleration, the numbers run between 0.510 g to 0.983 g for a difference of 92.7% or almost 2 to 1. These are all huge errors and as the frequencies used in the overall level calculation goes higher, they get worse.

Combustion Air Fan and HFE Measurements

The data shown in Table 2 summarizes the overall Spike Energy™ readings (an HFE measurement) taken on a combustion air fan using an EntekIRD dataPACT™ 1500. The measurements were made with 1 kHz, 2 kHz, and 5 kHz High Pass (HP) Corner filters. The Low Pass Corner frequency of the data collector is fixed at 65 kHz. Thus, the data included in the overall Spike Energy™ measurements includes frequencies that are well outside of the specified range of the sensor including data near the sensor resonance. The table is sorted by Overall Spike Energy™ (gSE units) from highest to lowest. There is a 46 to 1 difference between the highest and lowest readings! In general, the sensor with the highest frequency response and best mount has the highest values. That does not mean, however, that the other readings are wrong. They are just different. Remember, there is no physical quantity to trace these readings back to.
It should be noted that magnetically mounted accelerometers are routinely used in condition monitoring programs using portable data collectors and that HFE measurements are generally collected as part of the route data. These measurements are effective in early detection of bearing problems even though the HFE is attenuated. As long as the sensor, mounting method, and location are consistent and trended, the measurements are effective; however, they generally can’t be compared to readings taken by someone else using a different sensor, mounting method or data collection system.

**HFE Measurements**

Even though there is no traceability for HFE measurements and it is nearly impossible to get the same results as someone else, why are they so popular. The simple answer is they work very well in identifying certain types of faults. The user just needs to know how to use them. These are typically high pass filtered measurements that are very sensitive to spikes in the data, as is typical with rolling element bearing faults. Since the measurements are not traceable, the data should be trended. And, it is up to the analyst to determine what amplitudes are acceptable and which are not based on historical data.

“The most meaningful use of Spike Energy™ is to trend gSE readings along with velocity and acceleration readings.”

“[PeakVue®] is a powerful complementary tool that can detect a range of faults and problem conditions such as vibration analysis alone might miss under certain conditions.”

The data in Figure 6 was taken using the IMI Sensors Echo® Wireless Vibration Monitoring System on a motor driving a centrifugal pump. The first plot is a trend of rms velocity, the second rms acceleration, and the third is a high pass filtered, 2k Hz HPF, true peak acceleration (an overall HFE measurement). It is clearly seen that the HFE measurement is far more sensitive to the bearing fault than the rms measurements. The motor was shut down, the bearing changed, and new levels established. Although there was a small change in the rms velocity and a bit more in the rms acceleration, they had not tripped their alarms yet. In slow speed machinery, the HFE reading is the most likely to pick up a bearing fault early.

**Conclusions**

In order to make accurate measurements, the frequency range must not only be within the specified range of the accelerometer but must also be within the flat range of the sensor mount. Knowing the range of the mount is a challenge and can only be determined through testing. When sophisticated calibration equipment is not available, it is possible to get an estimation of frequency response. Mount a sensor on a machine having high frequency content using various mounts. Comparing the results, as was done in the centrifugal compressor example, can provide useful information on about the sensor and mounting responses.

Even when accurate measurements are made, they may not agree with other accurate measurements. When trying to compare overall measurements with others, make sure you are using similar sensors, mounting methods, and measurement methodologies as in the GM Vibration Standard.

True high-frequency measurement such as HFE and demodulation (not covered in this paper) are not physical measures so the amplitudes are arbitrary. Data must be collected consistently and trended to make use of the amplitudes. These trends should be used as an indicator to look at other vibration data before diagnosing a problem. Demodulated time waveforms and spectra can often reveal impending faults, particularly in cases of impacting, much earlier than conventional analysis. They are a powerful complementary tool for the vibration analyst.

**Figures and Tables**

![Figure 1: Frequency response test setup](image1)

**Figure 1: Frequency response test setup**

![Figure 2: Stainless steel probe (stinger)](image2)

**Figure 2: Stainless steel probe (stinger)**

<table>
<thead>
<tr>
<th>Sensor &amp; Mount</th>
<th>3 dB Freq (Hz)</th>
<th>Resonant Freq (Hz)</th>
<th>Gain at Resonance</th>
<th>Total Mass (gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>622B01 + Stud</td>
<td>15000</td>
<td>30000</td>
<td>35 to 40 dB</td>
<td>94</td>
</tr>
<tr>
<td>603C01 + Stud</td>
<td>12500</td>
<td>25000</td>
<td>15 dB</td>
<td>51</td>
</tr>
<tr>
<td>603C01 + Flat Magnet</td>
<td>6000</td>
<td>11245</td>
<td>21.5 dB</td>
<td>100</td>
</tr>
<tr>
<td>622B01 + Flat Magnet</td>
<td>5000</td>
<td>8000</td>
<td>20 dB</td>
<td>143</td>
</tr>
<tr>
<td>603C01 + 2-Rail Magnet</td>
<td>3654</td>
<td>6322</td>
<td>27.3 dB</td>
<td>128.1</td>
</tr>
<tr>
<td>622B01 + 2-Rail Magnet</td>
<td>3308</td>
<td>6000</td>
<td>22.9 dB</td>
<td>171.1</td>
</tr>
<tr>
<td>603C01 + 4” SS Probe</td>
<td>720</td>
<td>1300</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1: Resonant frequency and 3 dB point for 2-sensors and 4-mounts**
Figure 3: Centrifugal compressor

Figure 4: In velocity spectra, where an analyst would typically expect consistent data, there are significant differences.

Figure 5: Acceleration spectra to 5000 Hz have significant differences.

Table 2: Overall Spike Energy™ for various sensors and mounts collected on the combustion air fan

<table>
<thead>
<tr>
<th>Pos</th>
<th>Sensor</th>
<th>Filter</th>
<th>Mount</th>
<th>Surface</th>
<th>1 kHz HPF</th>
<th>2 kHz HPF</th>
<th>5 kHz HPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>083</td>
<td>803A01</td>
<td>None</td>
<td>Flat Mag</td>
<td>Glue Base</td>
<td>6.95</td>
<td>6.54</td>
<td>6.46</td>
</tr>
<tr>
<td>063</td>
<td>803A01</td>
<td>None</td>
<td>Stud</td>
<td>Glue Base</td>
<td>6.85</td>
<td>6.36</td>
<td>6.45</td>
</tr>
<tr>
<td>023</td>
<td>803A01</td>
<td>None</td>
<td>Flat Mag</td>
<td>Bare</td>
<td>6.72</td>
<td>6.26</td>
<td>6.35</td>
</tr>
<tr>
<td>013</td>
<td>803A01</td>
<td>None</td>
<td>2 Pole Mag</td>
<td>Bare</td>
<td>3.79</td>
<td>3.50</td>
<td>3.49</td>
</tr>
<tr>
<td>073</td>
<td>803A01</td>
<td>None</td>
<td>2 Pole Mag</td>
<td>Glue Base</td>
<td>3.77</td>
<td>3.53</td>
<td>3.44</td>
</tr>
<tr>
<td>074</td>
<td>803C01</td>
<td>2-Pole</td>
<td>2 Pole Mag</td>
<td>Glue Base</td>
<td>2.85</td>
<td>2.63</td>
<td>2.51</td>
</tr>
<tr>
<td>014</td>
<td>803C01</td>
<td>2-Pole</td>
<td>2 Pole Mag</td>
<td>Bare</td>
<td>2.52</td>
<td>2.32</td>
<td>2.21</td>
</tr>
<tr>
<td>084</td>
<td>803C01</td>
<td>2-Pole</td>
<td>Flat Mag</td>
<td>Glue Base</td>
<td>2.24</td>
<td>2.05</td>
<td>2.02</td>
</tr>
<tr>
<td>024</td>
<td>803C01</td>
<td>2-Pole</td>
<td>Flat Mag</td>
<td>Bare</td>
<td>2.11</td>
<td>1.88</td>
<td>1.81</td>
</tr>
<tr>
<td>064</td>
<td>803C01</td>
<td>2-Pole</td>
<td>Stud</td>
<td>Glue Base</td>
<td>1.91</td>
<td>1.65</td>
<td>1.58</td>
</tr>
<tr>
<td>103</td>
<td>803A01</td>
<td>None</td>
<td>Stinger</td>
<td>Bare</td>
<td>0.64</td>
<td>0.42</td>
<td>0.40</td>
</tr>
<tr>
<td>104</td>
<td>803C01</td>
<td>2-Pole</td>
<td>Stinger</td>
<td>Bare</td>
<td>0.38</td>
<td>0.22</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Figure 6: RMS velocity, RMS acceleration, and true peak acceleration trend plots

Definitions

Amplification Factor – The gain or “Q” at the natural frequency (resonance) of the sensor. For a 100 mV/g accelerometer vibrating at 1 g, the output will be 100 mV. If there is a gain of 10 resonance, a 1 g vibration at the sensor’s natural frequency will yield a 1 V output making it appear the input is 10 g.

FFT – Fast Fourier Transform is the algorithm typically used to compute the Discrete Fourier Transform or frequency spectrum of a digitized time signal. This transforms the signal from the time domain (time waveform) to the frequency domain (frequency spectrum). In technical papers and publications, this frequency spectrum is often referred to simply as the FFT.

Frequency Response / Frequency Range of an industrial accelerometer is generally specified at the ±3 dB points. That means the low and high frequency limits for the accelerometer are determined when the nominal sensitivity (e.g., 100 mV/g) is either up 3 dB or down 3 dB. The following equation can be used to determine the actual sensitivity of the accelerometer at these points.
\[ dB = 20 \log \frac{S}{S_{REF}} \]

Rearranging to solve for \( S \)

\[ S = 10^{\frac{dB}{20}} \times S_{REF} \]

At +3 dB and a nominal sensitivity (\( S_{REF} \)) of 100 mV/g, the actual sensitivity (\( S \)) is 141 mV/g. At -3 dB, it’s 70.7 mV/g. This shows that when an industrial accelerometer is used at its upper or lower frequency limit, the deviation from nominal sensitivity is not trivial.

**HFE** – In vibration literature this can mean High Frequency Enveloping or High Frequency Energy, with Enveloping being most common. Since this paper deals primarily in overall measurement, it is used for High Frequency Energy, meaning, an overall measurement that filters out lower frequency content and includes very high frequency content that most often extends beyond the specified range of the accelerometer. This type of measurement is most typically used for early detection of rolling element bearing faults. Spike Energy™ and PeakVue® are examples of HFE type of measurements.

**Route** is a predefined set of machines, points, and measurements to be made on a regular basis. The route information is loaded into a portable data collector and an analyst walks around a plant making the preprogrammed measurements. Most routes include a variety of measurements including time waveform, velocity, acceleration, and HFE.

**Traceability** – The National Institute of Standards and Technology, NIST, defines traceability as “an unbroken record of documentation (“documentation traceability”) or an unbroken chain of measurement and associated uncertainties (”metrological traceability”). In the case of displacement, velocity, and acceleration (typical vibration measures) there is a well defined physical quantity that is being measured, can be quantified, and is therefore traceable. In the case of HFE measurements, there is no defined physical quantity, the measurements are made outside of the traceable range of accelerometers, and are therefore not traceable. In this case, data should be trended to look for changes.

**Transportable** – This is a term coined by the author meaning a measurement that is well defined, accurate, and repeatable and thus could be obtained by anyone making the same measurement.

**References:**


3. PeakVUE is a registered trademark of Computational Systems Incorporated.


Cooling Technology Institute
Licensed Testing Agencies

For nearly thirty years, the Cooling Technology Institute has provided a truly independent, third party, thermal performance testing service to the cooling tower industry. In 1995, the CTI also began providing an independent, third party, drift performance testing service as well. Both these services are administered through the CTI Multi-Agency Tower Performance Test Program and provide comparisons of the actual operating performance of a specific tower installation to the design performance. By providing such information on a specific tower installation, the CTI Multi-Agency Testing Program stands in contrast to the CTI Cooling Tower Certification Program which certifies all models of a specific manufacturer's line of cooling towers perform in accordance with their published thermal ratings.

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

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

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

### Licensed CTI Thermal Testing Agencies

<table>
<thead>
<tr>
<th>License Type</th>
<th>Agency Name</th>
<th>Address</th>
<th>Contact Person</th>
<th>Website / Email</th>
<th>Telephone</th>
<th>Fax</th>
</tr>
</thead>
<tbody>
<tr>
<td>A,B</td>
<td>Clean Air Engineering</td>
<td>7936 Conner Rd, Powell, TN 37849</td>
<td>Kenneth Hennon</td>
<td><a href="http://www.cleanair.com">www.cleanair.com</a>, <a href="mailto:khennon@cleanair.com">khennon@cleanair.com</a></td>
<td>800.208.6162</td>
<td>865.938.7569</td>
</tr>
<tr>
<td>A, B</td>
<td>Cooling Tower Technologies Pty Ltd</td>
<td>PO Box N157, Bexley North, NSW 2207, AUSTRALIA</td>
<td>Ronald Rayner</td>
<td><a href="mailto:coolingtwtech@bigpond.com">coolingtwtech@bigpond.com</a></td>
<td>61 2 9789 5900</td>
<td>61 2 9789 5922</td>
</tr>
<tr>
<td>A,B</td>
<td>Cooling Tower Test Associates, Inc.</td>
<td>15325 Melrose Dr, Sanley, KS 66221-9720</td>
<td>Thomas E. Weast</td>
<td><a href="http://www.ctttai.com">www.ctttai.com</a>, <a href="mailto:ettake@aol.com">ettake@aol.com</a></td>
<td>913.681.0027</td>
<td>913.681.0039</td>
</tr>
<tr>
<td>A, B</td>
<td>McHale &amp; Associates, Inc.</td>
<td>4700 Coster Road, Knoxville, TN 37912</td>
<td>Thomas Wheelock</td>
<td><a href="http://www.mchale.org">www.mchale.org</a>, <a href="mailto:tom.wheelock@mchale.org">tom.wheelock@mchale.org</a></td>
<td>865.588.2654</td>
<td>425.557.8377</td>
</tr>
</tbody>
</table>

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

### Licensed CTI Drift Testing Agencies

<table>
<thead>
<tr>
<th>Agency Name</th>
<th>Address</th>
<th>Contact Person</th>
<th>Website / Email</th>
<th>Telephone</th>
<th>Fax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Air Engineering</td>
<td>7936 Conner Rd, Powell, TN 37849</td>
<td>Kenneth Hennon</td>
<td><a href="http://www.cleanair.com">www.cleanair.com</a>, <a href="mailto:khennon@cleanair.com">khennon@cleanair.com</a></td>
<td>800.208.6162</td>
<td>865.938.7569</td>
</tr>
<tr>
<td>McHale &amp; Associates, Inc.</td>
<td>4700 Coster Road, Knoxville, TN 37912</td>
<td>Thomas Wheelock</td>
<td><a href="http://www.mchale.org">www.mchale.org</a>, <a href="mailto:tom.wheelock@mchale.org">tom.wheelock@mchale.org</a></td>
<td>865.588.2654</td>
<td>425.557.8377</td>
</tr>
</tbody>
</table>
CTI Toolkit Version 3.1
...now Windows 7 compatible

A great opportunity to upgrade your CTI Blue Book Version 1.0 and CTI Toolkit Version 2.0 Software

Key Features of CTI Toolkit Version 3.1:

- **Air Properties Calculator**: fully ASHRAE Compliant psychrometrics. Interactive.
- **Thermal Design Worksheet** in the “Demand Curve” Tab which can be saved to file and retrieved for later review. Now with printable and exportable graphs.
- **Performance Evaluator** in the “Performance Curve” Tab to evaluate induced draft or forced draft, crossflow or counterflow cooling tower performance. Now calculates percent performance or leaving water temperature deviation. Data can be entered manually or with an input file. Automatic Cross-Plotting. Now with printable and exportable graphs.
- **New and Improved Help Files** guide you through the software, explain performance evaluation techniques and offer tips for use.

Now works with Microsoft Windows 7 and all earlier Windows Operating Systems back to Windows 95

16 MB ram recommended, and 3 MB free disk space required.

*Upgrade Now! Only $25/per upgrade from 3.0 for CTI Members ($40 for Non-Members)*

To Order, Call (281) 583-4087 or visit CTI’s Website [www.cti.org](http://www.cti.org)
Order Today
Call 281-583-4087

“The Performance Curve method is widely recognized as a more accurate method of determining tower capability from measured test data. The new CTI ToolKit Tab Application provides a quick and easy method for anyone to evaluate a performance test using this more accurate method.”

- Rich Harrison, Jr. ATC-105 Task Group Chairman

<table>
<thead>
<tr>
<th>Product</th>
<th>Unit Price</th>
<th>Quantity</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTI ToolKit Version 3.1 (single user license)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI Member</td>
<td>$395</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-member</td>
<td>$450</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI ToolKit Version 3.1 (Upgrade from V1.0 and V2.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI Member</td>
<td>$ 95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-member</td>
<td>$120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI ToolKit Version 3.1 (Upgrade from V3.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI Member</td>
<td>$ 25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-member</td>
<td>$ 40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PerfCurv 3.1 (Stand alone Performance Curve application)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI Member</td>
<td>$195</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-member</td>
<td>$240</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Shipping for CD-Rom (from Texas):
Priority mail $6; 2nd Day Air $18; Overnight Domestic $28; International (DHL) TBA

Multi-user site licenses and educational institution pricing available on request

Bill to: ________________________________________________________________
         ________________________________________________________________
         ________________________________________________________________

Phone: ___________________________ Fax: ________________________________
Email Address: ___________________________

Ship to: ________________________________________________________________
         ________________________________________________________________
         ________________________________________________________________

Phone: ___________________________ Fax: ________________________________
Email Address: ___________________________

Charges can be made to Visa, MasterCard or American Express
Card No.: ___________________________ Expiration Date: ___________________________
Signature: ___________________________ CVV; CVC; CID Code: ___________________________

System Requirements:
Microsoft Windows® 95/98, 2000, XP, and Windows 7

Phone: 281.583.4087
Fax: 281.537.1721
Web: http://www.cti.org
As stated in its opening paragraph, CTI Standard 201... "sets forth a program whereby the Cooling Technology Institute will certify that all models of a line of water cooling towers offered for sale by a specific Manufacturer will perform thermally in accordance with the Manufacturer's published ratings..." By the purchase of a "certified" model, the Owner/Operator has assurance that the tower will perform as specified, provided that its circulating water is within acceptable limits and that its air supply is ample and unobstructed. Either that model, or one of its close design family members, will have been thoroughly tested by the single CTI-licensed testing agency for Certification and found to perform as claimed by the Manufacturer.

CTI Certification under STD-201 is limited to thermal operating conditions with entering wet bulb temperatures between 12.8°C and 32.2°C (55°F to 90°F), a maximum process fluid temperature of 51.7°C (125°F), a cooling range of 2.2°C (4°F) or greater, and a cooling approach of 2.8°C (5°F) or greater. The manufacturer may set more restrictive limits if desired or publish less restrictive limits if the CTI limits are clearly defined and noted in the publication. In addition, 7 of the manufacturers also market products as private brands through other companies. While in competition with each other, these manufacturers benefit from knowing that they each achieve their published performance capability and distinguish themselves by providing the Owner/Operator’s required thermal performance. The participating manufacturers currently have 76 product lines plus 12 product lines marketed as private brands which result in more than 12,500 cooling tower models with CTI STD-201 Thermal Performance Certification for cooling tower Owner/Operator’s to select from. The following table lists the currently active cooling tower manufacturers, their products with CTI STD-201 Thermal Performance Certification, and a brief description of the product lines.

Those Manufacturers who have not yet chosen to certify their product lines are invited to do so at the earliest opportunity. You can contact Virginia A. Manser, Cooling Technology Institute, PO Box 73383, Houston, TX 77273 for further information.
<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product Line</th>
<th>CTI Certification Validation Number</th>
<th>Revision Number</th>
<th>Date</th>
<th>Tower Type</th>
<th>Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggreko Cooling Tower Services</td>
<td>AG</td>
<td>08-34-01</td>
<td>1</td>
<td>July 24, 2019</td>
<td>Open Circuit</td>
<td>5</td>
</tr>
<tr>
<td>Amscot Cooling Tower Corporation</td>
<td>R-LC</td>
<td>11-20-05</td>
<td>1</td>
<td>March 4, 2013</td>
<td>Open Circuit</td>
<td>22</td>
</tr>
<tr>
<td>American Cooling Tower, Inc.</td>
<td>ACF</td>
<td>10-38-01</td>
<td>2</td>
<td>June 10, 2012</td>
<td>Open Circuit</td>
<td>195</td>
</tr>
<tr>
<td>AONE E &amp; G Corporation, Ltd.</td>
<td>ACT-C</td>
<td>09-28-02</td>
<td>0</td>
<td>August 25, 2012</td>
<td>Closed Circuit</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>ACT-R</td>
<td>05-28-01</td>
<td>2</td>
<td>August 25, 2012</td>
<td>Closed Circuit</td>
<td>22</td>
</tr>
<tr>
<td>Baltimore Aircoil Company, Inc.</td>
<td>ACT</td>
<td>08-11-12</td>
<td>2</td>
<td>November 30, 2011</td>
<td>Open Circuit</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>FXT</td>
<td>92-11-01</td>
<td>2</td>
<td>September 32, 2004</td>
<td>Open Circuit</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>FXV</td>
<td>98-11-09</td>
<td>9</td>
<td>November 11, 2012</td>
<td>Closed Circuit</td>
<td>741</td>
</tr>
<tr>
<td></td>
<td>PGT</td>
<td>10-11-13</td>
<td>0</td>
<td>April 10, 2010</td>
<td>Open Circuit</td>
<td>104</td>
</tr>
<tr>
<td></td>
<td>PF2</td>
<td>12-11-14</td>
<td>0</td>
<td>December 1, 2012</td>
<td>Closed Circuit</td>
<td>480</td>
</tr>
<tr>
<td></td>
<td>PT2</td>
<td>07-11-11</td>
<td>2</td>
<td>November 15, 2011</td>
<td>Open Circuit</td>
<td>324</td>
</tr>
<tr>
<td></td>
<td>Series V Closed</td>
<td>08-11-13</td>
<td>1</td>
<td>March 3, 2009</td>
<td>Closed Circuit</td>
<td>265 VF1 103 VFL</td>
</tr>
<tr>
<td></td>
<td>Series V Open</td>
<td>92-11-02</td>
<td>4</td>
<td>January 1, 2004</td>
<td>Closed Circuit</td>
<td>34 VF3 81 VT1 61 VTL</td>
</tr>
<tr>
<td></td>
<td>Series 1500</td>
<td>94-11-08</td>
<td>7</td>
<td>September 27, 2016</td>
<td>Open Circuit</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Series 3000</td>
<td>92-11-05</td>
<td>11</td>
<td>March 28, 2013</td>
<td>Open Circuit</td>
<td>352</td>
</tr>
<tr>
<td>Bell Cooling Tower Pvt Ltd</td>
<td>BGCTI</td>
<td>12-43-01</td>
<td>1</td>
<td>May 28, 2013</td>
<td>Open Circuit</td>
<td>78</td>
</tr>
<tr>
<td>Delta Cooling Tower, Inc.</td>
<td>TM Series</td>
<td>02-24-01</td>
<td>1</td>
<td>January 1, 2010</td>
<td>Open Circuit</td>
<td>96</td>
</tr>
<tr>
<td>Epsocs, Inc.</td>
<td>AT Series</td>
<td>99-13-01</td>
<td>13</td>
<td>August 26, 2012</td>
<td>Open Circuit</td>
<td>827</td>
</tr>
<tr>
<td></td>
<td>ATWLB</td>
<td>09-13-06</td>
<td>4</td>
<td>August 26, 2012</td>
<td>Closed Circuit</td>
<td>1,034 ATWB 825 eco-ATWB 319 eco-ATWE-E</td>
</tr>
<tr>
<td></td>
<td>ESWA</td>
<td>05-13-05</td>
<td>6</td>
<td>August 26, 2012</td>
<td>Closed Circuit</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>L Series Closed</td>
<td>09-13-07</td>
<td>1</td>
<td>September 17, 2016</td>
<td>Closed Circuit</td>
<td>216 LSWE 91 LRWB</td>
</tr>
<tr>
<td></td>
<td>L Series Open</td>
<td>05-13-03</td>
<td>3</td>
<td>April 17, 2012</td>
<td>Open Circuit</td>
<td>77 LSTE 45 LPT</td>
</tr>
<tr>
<td></td>
<td>PMTQ</td>
<td>10-13-09</td>
<td>0</td>
<td>September 17, 2016</td>
<td>Open Circuit</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>PMWQ</td>
<td>10-13-08</td>
<td>0</td>
<td>April 19, 2010</td>
<td>Closed Circuit</td>
<td>200</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Product Line</td>
<td>CTI Certification Validation Number</td>
<td>Revision Number</td>
<td>Date</td>
<td>Tower Type</td>
<td>Models</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>--------------</td>
<td>-------------------------------------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>---------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Elendoo Technology (Beijing) Co., Ltd.</td>
<td>ELH</td>
<td>13-50-01</td>
<td>0</td>
<td>January 30, 2013</td>
<td>Closed Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Foshan Juote Warm Ventilation Technology Company, Ltd.</td>
<td>ZXZ</td>
<td>12-47-01</td>
<td>0</td>
<td>November 28, 2012</td>
<td>Closed Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Guangzhou Laxun Technology Exploit Company, Ltd.</td>
<td>HMK</td>
<td>12-45-01</td>
<td>1</td>
<td>January 28, 2013</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Guangzhou Laxun Technology Exploit Company, Ltd.</td>
<td>LMB</td>
<td>12-45-02</td>
<td>0</td>
<td>October 28, 2012</td>
<td>Closed Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Hunan Yuanseng Technology Development Company, Ltd.</td>
<td>YHA</td>
<td>11-40-01</td>
<td>1</td>
<td>January 30, 2013</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>HVACR International, Inc.</td>
<td>Therflow Series TFC</td>
<td>09-28-02</td>
<td>0</td>
<td>January 4, 2010</td>
<td>Closed Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>HVACR International, Inc.</td>
<td>Therflow Series TFW</td>
<td>05-28-01</td>
<td>2</td>
<td>January 29, 2010</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Jacir</td>
<td>KS</td>
<td>12-46-01</td>
<td>0</td>
<td>November 13, 2012</td>
<td>Open Circuit</td>
<td>Centrifugal</td>
</tr>
<tr>
<td>KIMCO (Kyung In Machinery Company, Ltd.)</td>
<td>CKL</td>
<td>05-18-02</td>
<td>2</td>
<td>June 15, 2009</td>
<td>Closed Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>KIMCO (Kyung In Machinery Company, Ltd.)</td>
<td>Eco-Dyna Cool</td>
<td>09-18-03</td>
<td>0</td>
<td>September 14, 2009</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>KIMCO (Kyung In Machinery Company, Ltd.)</td>
<td>Endura Cool</td>
<td>93-18-01</td>
<td>6</td>
<td>May 17, 2007</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>King Sun Industry Company, Ltd.</td>
<td>HKB</td>
<td>09-35-01</td>
<td>2</td>
<td>March 16, 2013</td>
<td>Open Circuit</td>
<td>Centrifugal</td>
</tr>
<tr>
<td>King Sun Industry Company, Ltd.</td>
<td>HKD</td>
<td>09-35-02</td>
<td>2</td>
<td>March 16, 2013</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>King Sun Industry Company, Ltd.</td>
<td>KC</td>
<td>11-35-03</td>
<td>0</td>
<td>January 3, 2011</td>
<td>Closed Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Liang Chi Industry Company, Ltd.</td>
<td>C-LC</td>
<td>09-20-02</td>
<td>0</td>
<td>September 4, 2009</td>
<td>Closed Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Liang Chi Industry Company, Ltd.</td>
<td>R-LC</td>
<td>11-20-05</td>
<td>1</td>
<td>October 12, 2012</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Liang Chi Industry Company, Ltd.</td>
<td>U-LC</td>
<td>10-20-04</td>
<td>2</td>
<td>October 12, 2012</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Liang Chi Industry Company, Ltd.</td>
<td>V-LC</td>
<td>10-20-03</td>
<td>0</td>
<td>July 4, 2010</td>
<td>Open Circuit</td>
<td>Centrifugal</td>
</tr>
<tr>
<td>Marley (SPX Cooling Technologies)</td>
<td>Aquatower Series</td>
<td>01-14-05</td>
<td>2</td>
<td>July 18, 2009</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Marley (SPX Cooling Technologies)</td>
<td>AV Series</td>
<td>08-14-04</td>
<td>2</td>
<td>April 22, 2013</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Marley (SPX Cooling Technologies)</td>
<td>NCW Series</td>
<td>06-14-08</td>
<td>2</td>
<td>May 1, 2007</td>
<td>Open Circuit</td>
<td>Centrifugal</td>
</tr>
<tr>
<td>Marley (SPX Cooling Technologies)</td>
<td>MD Series</td>
<td>08-14-11</td>
<td>2</td>
<td>November 14, 2012</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Marley (SPX Cooling Technologies)</td>
<td>MHF Series</td>
<td>04-14-07</td>
<td>3</td>
<td>January 7, 2013</td>
<td>Closed Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Marley (SPX Cooling Technologies)</td>
<td>NC Series</td>
<td>92-14-01</td>
<td>16</td>
<td>January 23, 2009</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Marley (SPX Cooling Technologies)</td>
<td>Quadraflow</td>
<td>92-14-02</td>
<td>2</td>
<td>April 11, 2000</td>
<td>Open Circuit</td>
<td>Induced-draft</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Product Line</td>
<td>CTI Certification Validation Number</td>
<td>Revision Number</td>
<td>Date</td>
<td>Tower Type</td>
<td>Model</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------</td>
<td>-------------------------------------</td>
<td>-----------------</td>
<td>------</td>
<td>------------</td>
<td>-------</td>
</tr>
<tr>
<td>Mean Cooling Tower, Ltd.</td>
<td>NCC Series</td>
<td>12-26-07</td>
<td>0</td>
<td>December 1, 2012</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>MXC Series</td>
<td>12-26-08</td>
<td>0</td>
<td>December 1, 2012</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>MXL Series</td>
<td>12-26-36</td>
<td>0</td>
<td>December 1, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>MXR-KM Series</td>
<td>08-26-33</td>
<td>3</td>
<td>December 1, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Munters Corporation</td>
<td>Oasis PFC</td>
<td>12-48-41</td>
<td>0</td>
<td>November 28, 2012</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td>Nihon spindle Manufacturing Company, Ltd.</td>
<td>KG</td>
<td>12-33-82</td>
<td>0</td>
<td>December 1, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>OTT Company Ltd.</td>
<td>OTTC</td>
<td>12-44-41</td>
<td>0</td>
<td>October 9, 2012</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>OTTX</td>
<td>12-44-82</td>
<td>0</td>
<td>October 9, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Protec Cooling Towers, Inc.</td>
<td>FRS Series</td>
<td>05-27-43</td>
<td>2</td>
<td>October 5, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>FWS Series</td>
<td>04-27-31</td>
<td>4</td>
<td>October 5, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Reymaz Cooling Towers, Inc. (Fabrica Mexicana de Torres, SA de CV)</td>
<td>HFC</td>
<td>10-22-36</td>
<td>2</td>
<td>December 8, 2011</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>HRFG</td>
<td>04-22-33</td>
<td>2</td>
<td>August 6, 2011</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>LSGF</td>
<td>09-22-44</td>
<td>0</td>
<td>January 2, 2009</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>KT</td>
<td>13-22-97</td>
<td>0</td>
<td>May 26, 2013</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>SLSFG</td>
<td>09-22-85</td>
<td>0</td>
<td>January 2, 2009</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td>RSD Cooling Towers</td>
<td>RSS Series</td>
<td>08-32-31</td>
<td>0</td>
<td>April 28, 2008</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Shanghai Baofeng Machinery Manufacturing Company, Ltd.</td>
<td>FCS</td>
<td>10-27-34</td>
<td>0</td>
<td>February 22, 2010</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>FDC</td>
<td>11-27-35</td>
<td>0</td>
<td>October 1, 2011</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td>Ryowo (Holding) Company, Ltd.</td>
<td>FRS Series</td>
<td>05-27-33</td>
<td>2</td>
<td>October 5, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>FVS Series</td>
<td>12-27-36</td>
<td>0</td>
<td>October 5, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>FWS Series</td>
<td>04-27-31</td>
<td>4</td>
<td>October 5, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>FXS Series</td>
<td>05-27-92</td>
<td>3</td>
<td>October 5, 2012</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>BTC</td>
<td>12-49-31</td>
<td>0</td>
<td>December 1, 2012</td>
<td>Closed Circuit</td>
<td>Combined</td>
</tr>
</tbody>
</table>
# 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)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product Line</th>
<th>CTI Certification Validation Number</th>
<th>Revision Number</th>
<th>Date</th>
<th>Tower Type</th>
<th>Model(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinro Air-Conditioning (Fogang) Company Ltd.</td>
<td>CEF-A</td>
<td>11-37-32</td>
<td>0</td>
<td>July 1, 2011</td>
<td>Open Circuit</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>SC-B Series</td>
<td>11-37-33</td>
<td>0</td>
<td>October 20, 2011</td>
<td>Closed Circuit</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>SC-H Series</td>
<td>10-37-91</td>
<td>0</td>
<td>January 1, 2016</td>
<td>Open Circuit</td>
<td>15</td>
</tr>
<tr>
<td>Ta Shin F. R. P. Company, Ltd.</td>
<td>TSS Series</td>
<td>08-32-91</td>
<td>0</td>
<td>April 29, 2008</td>
<td>Open Circuit</td>
<td>6</td>
</tr>
<tr>
<td>The Cooling Tower Company, L. C.</td>
<td>Series TCI</td>
<td>06-29-91</td>
<td>1</td>
<td>January 3, 2011</td>
<td>Open Circuit</td>
<td>441</td>
</tr>
<tr>
<td>Thermal-Cooling bhd</td>
<td>TYH</td>
<td>11-40-91</td>
<td>1</td>
<td>January 30, 2013</td>
<td>Open Circuit</td>
<td>72</td>
</tr>
<tr>
<td>Tower Tech, Inc.</td>
<td>TTXL</td>
<td>08-17-96</td>
<td>3</td>
<td>December 7, 2011</td>
<td>Open Circuit</td>
<td>72</td>
</tr>
<tr>
<td>Truwater Cooling Towers, Inc.</td>
<td>EC-S Series</td>
<td>12-41-91</td>
<td>1</td>
<td>November 14, 2012</td>
<td>Open Circuit</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>EX-S Series</td>
<td>12-41-92</td>
<td>1</td>
<td>November 14, 2012</td>
<td>Open Circuit</td>
<td>44</td>
</tr>
<tr>
<td>Walco Systems</td>
<td>WGI</td>
<td>09-36-91</td>
<td>0</td>
<td>August 31, 2009</td>
<td>Open Circuit</td>
<td>236</td>
</tr>
<tr>
<td>York (By Johnson Controls)</td>
<td>AT Series</td>
<td>09-13-91</td>
<td>13</td>
<td>August 29, 2012</td>
<td>Open Circuit</td>
<td>827</td>
</tr>
<tr>
<td></td>
<td>ESWA</td>
<td>05-13-95</td>
<td>6</td>
<td>August 29, 2012</td>
<td>Closed Circuit</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>LSTE</td>
<td>05-13-93</td>
<td>3</td>
<td>April 17, 2012</td>
<td>Open Circuit</td>
<td>77</td>
</tr>
<tr>
<td>Zhejiang Jinting Refrigeration Engineering Company, Ltd.</td>
<td>JNC Series</td>
<td>09-28-32</td>
<td>0</td>
<td>January 5, 2009</td>
<td>Closed Circuit</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>JNT Series</td>
<td>05-28-31</td>
<td>2</td>
<td>January 29, 2010</td>
<td>Open Circuit</td>
<td>33</td>
</tr>
</tbody>
</table>

37 Participating Manufacturers  
38 CTI Certified Product Lines 
12577 CTI Certified Tower Models

---

**MANUFACTURER’S PUBLISHED THERMAL PERFORMANCE IS CERTIFIED BY THE COOLING TECHNOLOGY INSTITUTE UNDER THE PROVISIONS OF STD-201 (11)**

Certification Validation Number
Advntse GRP Cooling Towers Pvt Ltd (India) .29
Aggreko Cooling Tower Services .......... 40, 41
AHR Expo........................................ 63
Amarillo Gear Company.......................IBC
American Cooling Tower, Inc..............57
AMSA, Inc........................................11
BailSeco Blades & Castings, Inc...........53
Baldor Electric Company.....................51
Bedford Reinforced Plastics...............25
Brentwood Industries.......................31
ChemTreat, Inc..............................23
Composite Cooling Solutions, LP.........35
CTI Certified Towers.........................74
CTI License Testing Agencies.............71
CTI Tool Kit....................................72
Denso ...............................................19
Dynamic Fabricators..........................5
Gaiennie Lumber Company..................2
Glocon ............................................3
Hewitech...........................................27
Howden Cooling Fans.......................21
Hudson Products Corporation...............47
IMI Sensors.....................................65
Industrial Cooling Towers..................IFC, 6
International Chimney.....................45
Kipcon ............................................55
KIMCO .............................................43
Moore Fans ......................................33
Paharpur .........................................13
Power Gen.......................................49
Qualichem.......................................70
Research Cottrell Cooling..................4
Rexnord Industries...........................15
C.E. Shepherd Company, LP................17
Simpson Strong-Tie...........................39
SIPCO/MLS Service...........................54
Spraying Services, Inc.......................37
SPX Cooling Technologies..................OBC
Strongwell ......................................7
Taylor Technologies..........................12
Tower Performance, Inc......................67, 80
OVER 95 YEARS QUALITY BUILT HERE

AMARILLO Gear Company has built a worldwide reputation for building quality gear drives and composite drive shaft assemblies during its 95 year history. While others farm-out and piecemeal, Amarillo still designs and manufactures its gears and builds them in Amarillo, Texas.

Amarillo is ISO 9001:2008 quality certified and stands behind their extensive line of right angle spiral bevel cooling tower fan drives, including single and double reduction models. They also 100% manufacture the high quality A Series drives for drop-in replacement of other manufacturer’s models, complete with the backing of Amarillo’s warranty.


Want to know more? Please contact or staff of sales representatives or gear engineers for a quick response to your fan drive needs.

www.amarillogear.com (806) 622-1273
info@amarillogear.com

A Amarillo Gear Company LLC
A Marmon Water/Berkshire Hathaway Company
SOMETIMES YOU JUST CAN’T COMPROMISE.

THE MARLEY® GEAREDUCER

Getting a Geareducer from an industry leader in cooling towers will put you at an advantage from the start. Quality gears provide longer life and over 30% lower sound compared to lower class gear sets. Marley Geareducer bearings have twice the L10k service life for input and intermediate shafts that require half the maintenance costs. Marley Geareducers have a 100,000-hour service interval on input and intermediate shaft bearings compared to the 50,000-hour service interval of other manufacturers. All of this, and more, will make you glad you didn't compromise.

And now, SPX is offering rebuilt Marley Geareducers, as well as OEM repair service for your well worn Marley Geareducer. Go to spxcooling.com/geareducer to find the Geareducer Solution that is right for you.