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CTI Journal
The Official Publication of The Cooling Technology Institute
Vol. 35 No. 2 Summer 2014

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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
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February 8-12, 2015
Sheraton
New Orleans, LA

Committee Workshop
July 12-15, 2015
Tradewinds Island Resort
St. Pete Beach, FL

February 7-11, 2016
Hilton Houston North
Houston, Texas

For Immediate Release
Contact: Chairman, CTI Multi-Agency Testing Committee
Houston, Texas, 3-May-2014
The Cooling Technology Institute announces its annual invitation for interested drift testing agencies to apply for potential Licensing as CTI Drift Testing Agencies. CTI provides an independent third party drift testing program to service the industry. Interested agencies are required to declare their interest by July 1, 2014 at the CTI address listed.

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I want to thank all attendees and participants to the ‘2014 Annual CTI Conference in Houston. By all measures, it was a very successful conference. Attendance was over 425, with many new members and a total of 21 Countries being represented. Continuing education, fellowship, networking, important progress on authoring and editing/updating Codes & Standards were all accomplished during the conference. A special thanks to the 50 Exhibitors that participated in the Conference.

The CTI Committee Workshop is fast approaching. This year will be held July 12-16 at the Sheraton Resort in Steamboat Springs, Colorado. This is the meeting in which the three standing technical committees of Performance & Technology, Water Treating and Engineering Standards & Maintenance review progress on developing and editing/updating CTI Codes and Standards. This meeting is very important in order to keep CTI and its members current with today’s cooling technology issues to better serve the industry. I encourage participation in the Workshop Committee meetings, especially from our Owner Operators. Everybody’s input is greatly needed and all who participate will find it rewarding and educational. The agendas for meetings planned by the standing committees are on the CTI website (www.CTI.org) under 2014 Summer Committee Workshop page.

If you have any ideas, suggestions and/or concerns about CTI that you would like to discuss, please feel free to contact me. I look forward to seeing each of you in Steamboat Springs.

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Dear Journal Reader,

2014 is an eventful year for CTI, this is an update to the January editorial.

Mike Womack of CleanAir now has been working as the CTI Thermal Certification Administrator for multiple months. The overlap of Tom Weast, the former CTI Thermal Certification Administrator, with Mike has worked out very well to position Mike for his ongoing role. We are very grateful for Tom’s willingness to provide this support. Tom’s company (CTTA) will also continue to provide licensed thermal certification testing services. Once we are able to extend the licensed testing program for thermal certification testing to additional existing CTI Licensed Thermal Certification testers later this year, with CTTA continuing as well, we will be much better positioned to accommodate the growth in the Thermal Certification Program. Please take an opportunity to thank Tom Weast for his many years as CTI Thermal Certification Administrator, and also to thank Mike Womack and CleanAir Engineering for coming on with the Thermal Certification Program.

The first publication of CTI Licensed Thermal Test results by participant name was included in the January 2014 CTI Journal for the three participants in the new CTI STD-202 program. It is also published on the CTI Website. (http://www.cti.org/downloads/STD-202StandardCustomTowers.pdf) Data for last year’s results were reported. Next year the results will cover 2 years, and the year after that will begin to report a three year rolling set of results. This is a very significant step for CTI, giving visibility for Owner/Operators and EPCs to the success of testing results by the participating manufacturers. STD-202 enables Owner/Operators and EPCs to specify that bidders be Participating Manufacturers in the program based on STD-202, who have subjected their test results to public scrutiny. In the past, CTI has only published the aggregate results of that testing with no identification of manufacturers. This writer is, again, very pleased to congratulate the participants on their willingness to join the program, and I am sure many other CTI members join in that expression.

The volunteers involved in the activities that enabled these steps are to be congratulated for their efforts in bringing them to happen.

Respectfully,

Paul Lindahl, CTI Journal Editor
Powering Innovation

Since 1984, Brentwood has worked to meet the ever-increasing demands of the power industry and drive cooling tower innovation. With over 100 million cubic feet of plastic media supplied, we continue to develop products and process enhancements that optimize cooling and maximize tower performance.
ABSTRACT

Water treatment chemists have long observed that some scale inhibitors work better at high pH rather than low pH, and that some inhibitors have little, if any, activity at very low pH. Examples would be the effectiveness of polyacrylic acid at high pH as a calcium carbonate inhibitor, as in ash sluice and some mining applications, mediocre performance near a neutral pH, as in cooling water applications, and very low activity in an acid pH range, as in gypsum control in the pH range from 2 to 4. This paper provides a framework for evaluating relative inhibitor activity using dissociation profiles for common inhibitors and calculating the distribution of inhibitor species versus pH. The use of dissociation constants for inhibitors provides a valuable tool for matching inhibitors to a specific application range pH, and as an aid in scale inhibitor selection. It can also provide a tool for evaluating and comparing new molecules. The paper, and the concept of active versus inactive (or less active) inhibitor forms, offers explanations for what appeared to be anomalies during the modeling of inhibitor performance data, and field observations, such as:

- Why is the minimum dosage requirement for calcium phosphate inhibition by some polymers so much lower than the requirement for others?
- Why does the addition of pH as a variable for correlation dramatically improve the correlation coefficient (niceness of fit) for some inhibitors, even for scales whose solubility is for all practical purposes independent of pH?
- Why can many phosphonates’ performance in the cooling water pH range be modeled without incorporating inhibitor speciation or pH as a variable?

BACKGROUND

The impact of pH and protonation state on treatment efficacy is observed in many areas of water treatment. Chlorination provides an example with the protonated form of hypochlorous acid being observed to have much more biocidal activity than the dissociated alkaline hypochlorite form. Adsorption studies of inhibitors used as squeeze treatments in oil field applications provide another example of the efficacy of dissociated versus protonated inhibitor forms (Breen 1990). In some cases, such as bromination, the impact of dissociation state on efficacy is arguably negligible.

Similar observations have been made concerning the impact of pH and protonation state on efficacy in the case of scale inhibition by phosphonates and polymers, (Griffiths, 1979, Ramsey, 1985, Tomson, 2002, Hunter, 1993).

Scale inhibitors dissociate like other acids as in Equation 1:

(Eq. 1) \[ \text{H-Inhibitor} \leftrightarrow \text{H}^+ \text{ + Inhibitor}^- \]

with a dissociation constant that might be generalized as:

(Eq. 2) \[ K_a = [\text{H}^+] \cdot [\text{Inhibitor}^-]/[\text{H-Inhibitor}] \]

and a pKa defined as:

(Eq. 3) \[ pK_a = -\log10(K_a) \]

By definition, pK_a is the pH where 50% of the acid for a given dissociation step will be in the protonated form, and 50% in the dissociated form. Knowing the pK_a for the final dissociation step of an inhibitor can be critical when the dissociated and protonated forms have significantly different efficacy as inhibitors. A conservative method for employing the dissociation state is to assume that the dissociated inhibitor concentration for the final step is the active species.

Understanding the impact of pH upon the relative efficacy of an inhibitor can be key to providing the optimum inhibitor dosage and in assuring that the minimum effective active inhibitor is present.

In the simplest case, an inhibitor may have almost 100% efficacy in a pH range where it is almost completely dissociated, and close to 0% efficacy in a pH range where the inhibitor is almost completely protonated. This scenario has been reported for simple phosphonates such as HEDP (1-hydroxyethylidene-1,1-diphosphonic acid). Profiles comparing the protonation state and inhibitor efficacy for the simple phosphonates indicate that the final dissociation constant (pK_a) is a controlling factor with minor, if any, contribution from lower dissociation states. In a more complex case, such as HDTMPA (hexamethylene diaminetetra(methylene phosphonic) acid), the various protonation states appear to have significant efficacy, so their combined efficacy is greater than might be expected based upon experience with a simpler inhibitor.

Griffiths et al. developed dissociation profiles for common phosphonates and compared them to inhibition studies over the same pH range. They summarized their laboratory results for simple phosphonates as follows:

“The general trend … is an improvement in performance with increasing pH. The improvement runs parallel to the titration curve with full activity occurring only at a pH value that approaches the final phosphonic acid pKa value.” (Griffiths, 1979)

Figures 1, 2 and 3 profile the protonation state (fraction) for the phosphonates HEDP, ATMP (amino tris(methylene phosphonic) acid), and HDTMPA versus pH. The red lines depict the active form.
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ages and models for speciation was in the development of a model for calcium phosphate scale inhibition by AA-AMPS (copolymer of acrylic acid and 2-acrylamido-2-methylpropanesulfonic acid). The data of minimum effective dosage versus saturation ratio and temperature was developed at three (3) distinct pH values in the cooling water range of 7.0 to 9.0.

Three distinct scatter plots resulted from the first model attempted, a correlation of dosage as a function of driving force, induction time, and temperature (Eq. 4) Dosage = f(SR, time, temperature)

Where
- SR is the ion association model saturation ratio for tricalcium phosphate;
- dosage is the active AA-AMPS concentration in the test solution;
- temperature is the absolute temperature; and
- time is the last time before failure.

Figure 4 profiles the distribution of species for the AA-AMPS copolymer. The pKₐ for its final dissociation step is at a significantly higher pH than the comparable pKₐ’s for the phosphonates profiled in Figures 1, 2, and 3. The red line indicates the high activity dissociated form.

It can be seen that only a small percentage of the copolymer is in the active form (red line) in the typical cooling water pH range of 7 to 9, while a majority of the phosphonate concentration is in the active form for the same pH range.

Figure 5 profiles the predicted versus observed values for this correlation with a low coefficient of definition (R²) of 0.31.

Adding pH to the parameters modeled reduced the scatter plot to one zone, and increased the correlation to an R² of 0.81, as depicted in Figure 6. pH had a negative coefficient, indicating that dosage, when treated independently of saturation ratio, decreased with increasing pH (Ferguson, 1993). The pH factor in this case followed the dissociation fraction and corrected for the speciation at the various pHs studied.

The final correlation calculated the speciation of the inhibitor and used the active concentration of the unprotonated form, rather than the total polymer dosage. Figure 7 depicts the correlation improvement when the dissociated inhibitor concentration is used for the model.

**APPLICATION**

A knowledge of inhibitor speciation and activity versus pH is useful in selecting and matching inhibitors to a specific application, for developing performance test experimental design to develop inhibitor performance models against specific scales, and for optimizing dosages.

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The polymer performed at approximately a fifth the dosage of AA-AMPS copolymer under comparable conditions. Yet the model developed initially for the polymer using the relationship of equation 4 yielded r-squared correlation coefficient of only 0.02 (figure 8). Adding pH as a variable increased the correlation coefficient to an acceptable value for experimental data. Using the dissociated inhibitor form in the model, as calculated from the terpolymer’s $pK_a$, increased the correlation coefficient to 0.99 (figure 9). The performance increase might be attributed to the decrease in $pK_a$ from 10.5 for the copolymer to 9.7 for the terpolymer.

Selecting Inhibitors: A knowledge of dissociation profiles is useful in selecting inhibitors for an application. For a low pH application, select an inhibitor with a low $pK_a$, preferably below or within the pH range for the application. This assures that the maximum amount of inhibitor will be in the active form in the application pH range.

Optimizing Dosages: Tomson et al (Tomson, 2002) recommend the use of a factor to correct dosage models for the active species concentration expected. They incorporated the correction into models for minimum effective dosage. For example, if the minimum effective dosage calculated from a model is $D_{min}$ and the alpha (fraction) for the final dissociation species is $\alpha$, the use dosage, $D_{use}$, would be:

(Eq. 5) $D_{use} = D_{min} / \alpha$

For a optimized dosage $D_{min}$ of 1.0 mg/L and a dissociation fraction $\alpha$ of 0.8, this reduces to:

(Eq. 6) $D_{use} = 1.0 / 0.8 = 1.25$ mg/L

This method provides a simple, reasonably conservative, approach to correcting for active species versus total inhibitor concentration. It assumes that the final dissociation species is the only active material.

Developing New Models: Ideally, the experimental design for developing inhibitor models (Ferguson, 1992) would allow the researcher to calculate the relative efficacy of each inhibitor form in relation to the final dissociated form. An experimental design with a broad range of pH and saturation ratio would allow the researcher to calculate the relative efficacy for each significant species from the inhibitor dissociation profile.

Once the relative efficacies are calculated, the dosage model expands to:

(Eq. 7) $D_{use} = D_{min} / (\alpha_1\cdot eff_1 + \alpha_2\cdot eff_2 + \ldots + \alpha_n\cdot eff_n)$

This equation reduces to equation 5 when only the final dissociated form is significant.

SUMMARY

pH can affect the efficacy of scale inhibitors. Some species of inhibitors are more active than others. The dissociated form, at the highest pH, tends to be the active species. An understanding of the relative efficacy of inhibitor species versus pH can greatly improve models developed for calculating the minimum effective dosage, and for selecting the optimum inhibitor for a specific application.

FURTHER WORK

Laboratory studies are planned to develop dissociation profiles for commercial phosphonate and polymeric scale inhibitors, followed by inhibitor optimization studies over a broad pH range. The objective of the application research is to quantify the impact of pH on the efficacy of commercial inhibitors, with initial tests studying BaSO$_4$, CaSO$_4$, and CaCO$_3$ inhibition. This paper provides background information and the rationale for the work.

REFERENCES


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Understanding Vibration Switches

Abstract: The paper presents the basics of both Mechanical and Electronic Vibration Switches, explains how they are designed, how they work, and show where they are effective and where they are not. It also discusses their frequency responses along with the major differences in the responses of mechanical and electronic switches. Finally, it shows how the various switches meet or do not meet the new CTI Vibration Standard. A video is also included in the presentation that shows how the various vibration switches respond to unbalance using a long-stroke vibration shaker.

Why Vibration Switches - Vibration switches are simple devices used to protect rotating machinery against catastrophic failure, particularly large fans as found on cooling towers. They continuously monitor vibration on a machine and provide an alert and/or shutdown of the machine when vibration levels become too high. Figure 1 shows a large fan that failed catastrophically due to high vibration.

Types of Vibration Switches - There are two basic types of vibration switches mechanical and electronic, however; with today’s microprocessor technology, electronic vibration switches can be further subdivided into two types, traditional electronic and programmable electronic vibration switches.
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Mechanical Vibration Switches - A mechanical vibration switch is a fairly simple device consisting of a magnet mounted on a spring loaded arm, which in turn is attached to a mechanically activated electrical switch, Figures 5 and 6. The switch is held in an armed position when the position of a magnetic plate is adjusted so it is close enough to the magnet to overcome the force in the spring loaded arm.

The gap between the magnet and magnetic plate can be adjusted by an external screw adjustment to increase or decrease the magnetic force holding the spring loaded arm in an armed position. Unfortunately, not all mechanical switches have the same maximum gap or force adjustment per turn. Some switches have a maximum gap of 0.017 to 0.020 inches (4.3 to 5.1 mm) beyond which the magnetic force is not strong enough to overcome the spring force. Some mechanical switches can have gaps as high as 0.080 inches (2 mm).

The sensitivity adjustment is also a function of the thread on the adjusting screw, some have fine and some have course threads. Thus, the typical procedure for setting a mechanical screw, about ¼ turn from the point where the switch trips on startup can vary widely.

When motion occurs, the magnet on the spring loaded arm and the sprung mass generate inertial forces that to oppose the magnetic force as governed by Newton’s Second Law of Motion. When the acceleration level is high enough to generate an inertial force that is greater than the magnetic force, the switch trips. The spring loaded arm rests against a sprung mass that can move in three directions as shown in Figure 7 and thus mechanical switches are sensitive in all three axes, albeit not equally as will be shown. The sprung mass was moved for this photo to show functionality. Note: the sprung mass does not move in the negative X direction, thus there is a large difference in the shock required to trip the switch in the plus and minus X directions.

Figure 7: The sprung mass is sensitive to motion in three axes.

The above discussion highlights a key problem with mechanical vibration switches. At low operating speeds, as seen for example in large cooling towers, the acceleration is so low that the inertial forces never get high enough to trip the switch in a pure unbalance condition, but, they do trip, so what’s happening. If the unbalance gets high enough, there are secondary effects, typically impacting, that generate enough acceleration to cause the switch to trip.

Advantages and Disadvantages – The advantages of mechanical vibration switches are cost, simplicity, and two-wire operation unless a remote reset is required. It is also sensitive to vibration in all three planes of motion, although not equally as is often believed by users. The following test, Figure 8, was set up to determine the difference in sensitivity in the X, Y, and Z directions.

![Figure 8: Impact test for mechanical vibration switches](image)

The switch was set to a somewhat arbitrary trip level but fairly low. The switch was armed and then impacted using a calibrated impact hammer in four directions: plus X, minus X, Y, and Z. The force levels required to trip the switch were recorded for each direction.

This was done for both the traditional mechanical vibration switch and the new linear adjust mechanical vibration switch. The results are shown in Table 1. It is clear that in the X direction, it takes about half the shock or impact to trip the switch depending on the direction. Also, it takes about 3 times the shock or vibration to trip the traditional switch in the Y or Z axes. The directionality of the linear adjust switch seems to be much better.

<table>
<thead>
<tr>
<th>Force Required to Trip Switch (pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switch</td>
</tr>
<tr>
<td>Traditional</td>
</tr>
<tr>
<td>Linear Adjust</td>
</tr>
</tbody>
</table>

Table 1: Force required to trip the switches in three axes
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tion switch because the inertial force due to shock and vibration is acting on both the inertial mass and the magnet in that direction. Since the inertia of the magnet from a shock in the -X direction helps to “open” the switch and one in the +X direction to close it, the vibration required to trip the switch is less in the -X than in the +X direction.

The major disadvantages to a mechanical vibration switch are there is no accuracy in setting a trip level, it has different sensitivities in the various directions, it is not very repeatable, it will not trip due to a pure unbalance condition without secondary effects, and environmental sealing can be an issue due to the mechanical adjustment screw. Poor or no sealing compounds the problem due to moisture ingress causing corrosion and a change in switch sensitivity, often making it less sensitive to shock and vibration.

CTI Standard - Section 4.2 of the proposed CTI Standard for Vibration Limits in Water Cooling Towers states the primary Fan Rotational Speed for cooling towers is 70 to 400 RPM (1.2 to 6.7 Hz). The “C” Zone Classification (unacceptable) balance limits in the Fan Speed Displacement Tables run from about 11.5 mils on slower speed, 70 RPM, concrete cooling towers with pedestal mounting to about 15 mils on wood and fiberglass towers. On higher speed units, 400 RPM, it runs from about 4.1 mils on the concrete towers to about 6 mils on the wood and fiberglass units. When those displacement limits are used and the associated accelerations computed, they are found to be incredibly small as shown in Table 2 below that use the worst case displacements at each speed.

### Table 2: Acceleration and velocity levels corresponding to unacceptable balance conditions in the CTI Standard on cooling towers

<table>
<thead>
<tr>
<th>Fan Speed</th>
<th>1X</th>
<th>1x</th>
<th>&quot;C&quot; Limit</th>
<th>Alarm</th>
<th>Alarm</th>
</tr>
</thead>
<tbody>
<tr>
<td>rpm</td>
<td>Hz</td>
<td>mils p-p</td>
<td>ips pk</td>
<td>g pk</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>1.2</td>
<td>15</td>
<td>0.0550</td>
<td>0.0010</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>1.7</td>
<td>15</td>
<td>0.0785</td>
<td>0.0021</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>2.5</td>
<td>15</td>
<td>0.1178</td>
<td>0.0048</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>3.3</td>
<td>9</td>
<td>0.0942</td>
<td>0.0051</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>4.2</td>
<td>6</td>
<td>0.1178</td>
<td>0.0080</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>5.0</td>
<td>6</td>
<td>0.0942</td>
<td>0.0077</td>
<td></td>
</tr>
<tr>
<td>350</td>
<td>5.8</td>
<td>6</td>
<td>0.1100</td>
<td>0.0104</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>6.7</td>
<td>6</td>
<td>0.1257</td>
<td>0.0136</td>
<td></td>
</tr>
</tbody>
</table>

Using the highest displacement, unbalance for each fan speed, it is clearly seen that the acceleration levels are too low to cause enough inertial force on the mechanical switch lever or inertial mass mechanisms to trip the switch. Thus, in a pure unbalance condition, a mechanical switch cannot trip the tower. The velocity levels, however, are measureable with modern piezoelectric accelerometers (PE) and thus an electronic switch that uses a PE accelerometer will catch a balance condition in most cases.

### Electronic Vibration Switches

Electronic vibration switches, Figure 9, are much more accurate and repeatable than mechanical vibration switches. They utilize a calibrated piezoelectric accelerometer, typically embedded in the switch housing, for sensing vibration and can integrate the signal to get velocity and in some cases displacement. As shown in the Table 2 above, unlike the mechanical switch, the electronic switch can, in most cases, accurately measure the balance condition of the fan and respond based on its amplitude.

---

CTI Vibration Standard – The table below is taken from the proposed CTI Standard for Vibration Limits in Water Cooling Towers and shows the “Broadband Vibration Limits” (overall vibration amplitudes) for field erected wood, fiberglass framed, factory assembled steel and fiberglass cooling towers. The shutdown limit for these types of towers is specified at 0.7 ips (17.8 mm/s) peak velocity. This is the vibration shutdown level that the electronic vibration switch should be set to. It should also be noted that this specification cannot be met with a mechanical vibration switch. That is not to say that a machine or cooling tower cannot be protected with a mechanical switch, it just implies that greater accuracy can be achieved with an electronic switch and the Standard can be met. A word of caution, be sure to look at the frequency response of the electronic switch, most are accurate down to 2 to 3 Hz (120 to 180 RPM). Below those frequencies, the sensitivity of the switch drops off.

Many electronic vibration switches have some or all of the following options available making them more versatile, effective, and providing better protection than mechanical vibration switches.

- Warning and critical (shutdown) alarms
- Time delays
- Latching and non-latching switch operation
- Raw vibration output
- 4-20 mA output

### Table 1 - Broadband Vibration Limits from proposed CTI Standard for Field Erected Wood or Fiberglass Framed Cooling Towers and Factory Assembled Steel or Fiberglass Cooling Towers

<table>
<thead>
<tr>
<th>Severity Zone</th>
<th>Condition</th>
<th>Velocity in/sec Peak</th>
<th>Velocity in/sec rms</th>
<th>Velocity mm/sec Peak</th>
<th>Velocity mm/sec rms</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Low</td>
<td>0.35</td>
<td>0.25</td>
<td>8.9</td>
<td>6.4</td>
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<tr>
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<td>Acceptable</td>
<td>0.50</td>
<td>0.36</td>
<td>12.7</td>
<td>9.1</td>
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<tr>
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<td>0.43</td>
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<td>10.9</td>
</tr>
<tr>
<td>D</td>
<td>Shutdown</td>
<td>0.70</td>
<td>0.50</td>
<td>17.8</td>
<td>12.7</td>
</tr>
</tbody>
</table>

### Table 3: Broadband vibration limits for cooling towers from Table 1 of the proposed CTI Vibration Standard

**Dual Alarms** - When a vibration switch shuts down a machine, it will more than likely come at an inopportune time. By having two alarm levels and associated relays, a warning level can be specified that will trip a relay and provide an indication in the form of a light, audible sound, or annunciator that will warn the user that the machine is getting close to a shutdown level allowing them time to react prior to an unexpected shutdown.

**Time Delays** - Time delays are a big advantage of electronic vibration switches. There can be one or more delay types in electronic vibration switches with the most common being start up and alarm delays. The startup delay allows a fixed or programmable (depending...
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on the switch) amount of time where the vibration level is ignored to allow the machine to startup where it may have higher vibration prior to steady state operation. The alarm delay will require that the vibration level be above the alarm level for a certain amount of time prior to tripping. This would avoid a shut down for some random transient event like bumping into the machine. Additionally, some electronic vibration switches allow a maximum vibration level to be set during the startup delay, higher than the normal running level, but still protecting the unit should the levels get excessively high.

Latching and Non-latching – Mechanical vibration switches, by default, are latching, meaning once they trip they stay tripped until reset by someone. An electronic vibration switch can operate this way as well but can also be set to non-latching. This means that after a relay is tripped, it will automatically reset itself when the vibration level drops below the alarm level.

Raw Vibration Output – This provides the broadband analog time waveform directly from the embedded piezoelectric accelerometer for diagnostic purposes. A vibration data collector or other analysis device can be connected to the output for analysis.

4-20 mA Output – While the switch is providing protection, a 4-20 mA signal proportional to the overall vibration level can be sent to a PLC or other plant monitoring device in a control room for vibration monitoring purposes.

Accuracy – As can be seen in Figure 9, alarm levels and time delays in traditional electronic vibration switches are often set using potentiometers and thus have some degree of uncertainty, ≥10%. As will be shown with the newer programmable electronic vibration switches, setting are done via USB programming and are quite accurate.

Programmable Electronic Vibration Switches

Programmable electronic vibration switches generally have a little better accuracy and provide better control over trip levels and delays than traditional electronic vibration switches allowing the user to tailor the response as desired. However, they may not have all of the other features of traditional switches. Figure 4 shows a hermetically sealed USB programmable electronic vibration switch mounted on a motor. Figure 10 shows the programming screen and the large number of options there are for tailoring the alarm levels and delays.

Conclusion

Any vibration switch offers protection against damaging vibrations if set and used properly. Electronic vibration switches are more accurate, can directly protect against a pure unbalance condition, and many can meet the newly proposed CTI Standard for Vibration Limits in Water Cooling Towers. Traditional electronic vibration switches currently have more options than programmable units but also cost more. It is up to the user to determine what vibration switch is best for their application.

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Ice blockage of a power plant’s water intake is of paramount importance since it can lead to an unplanned shutdown of the intake compromising water supply and plant operation. American Electric Power’s (AEP) Conesville Power Plant historically controlled ice accumulation at the river intake by routing to the intake a portion of the warm water return from the condenser on the only operating “once-through” unit’s circulating water system. The unit operating with this once-through cooling system was retired at the end of 2012; thus, the plant lost the use of the condenser outlet/warm water return deicing flow at the river intake. A numerical study was conducted to evaluate design alternatives to alleviate ice accumulation at the river intake. A numerical model to predict the ice transport and accumulation at the river intake was developed. The model was then used to understand the main phenomenon leading to ice transport to the intake and potential blockage. The effectiveness of several mitigation measures was evaluated with the model. Based on model results, a mitigation plan consisting of intake modifications to be implemented during several phases was developed. In the first phase, large pipe openings are cut in the walls separating intake pump wells of previously retired units at the facility. In the second phase, a number of control vanes previously placed in front of the intake to control sediments are removed to facilitate downstream ice transport. A third phase, if needed to be implemented, involves removing additional sediment control vanes and cutting holes in the pump wells on the operating units. The paper describes the model, discusses numerical results and presents the field experience after implementation of phase one.

Introduction

Ice accumulation on an intake trash rack can be abrupt, leading in extreme cases to a complete blockage of the trash rack and an unplanned shutdown of the intake facility. The complete blockage of water supply will severely impact the plant operation and power generation.

The AEP Conesville coal-fired power plant, located on the Muskingum River in Ohio, initially operated with three small boilers (Units 1 & 2 – 125 MW/ea and Unit 3 – 165 MW) using once-through cooling to condense the steam. In the 1970s three additional tangentially fired boilers were added (Unit 4 – 780 MW and Units 5 & 6 – 375 MW/ea), all using cooling towers.

Figure 1 shows the water intake in the AEP Conesville Power Plant. Historically, the plant routed a portion of warm water from the once-through cooling system to the intake area during winter months to control ice accumulation in the river intake. Unit 3, the last unit operating with this once-through cooling system, was retired at the end of 2012. The remaining units only require cooling tower makeup water. As a result, the amount of water needed for cooling was drastically reduced to one third of past amounts. However, with the retirement of unit 3, the plant lost the ability to control ice buildup in the intake.

According to field observations in the Muskingum River near the water intake, transport of ice from the river upstream is the primary cause of ice accumulation at the intake. Ice transported by surface water to the intake structure adheres to and accumulates in the trash racks when sustained ambient temperature is below freezing. Figure 2 shows the Conesville Plant water intake partially blocked with ice during a typical winter day. Ice accumulates first on the upstream end of the intake and then gradually spreads to the downstream sections if enough ice is transported to the intake. A significant ice cover is formed upstream of the intake. Note that the ice cover is not attached to the shore or on the bank, which suggest that it is originally created from the ice accumulated in the intake.

The river hydraulics near the Conesville Plant water intake is strongly influenced by sediment control structures (SCS) built in 2000 to control riverbed sediment ingestion at the intake [1]. The structures comprise a guide wall upstream of the intake, thirteen submerged vanes arranged in two rows, and a skimming wall [2]. These structures had been very effective in maintaining a protective barrier against sediments during the first six years of operation. However,
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in 2006 sedimentation started to build up around the downstream vanes, and in 2009 a complete dredging of the area was necessary. It is believed that extreme flooding river conditions and reduction of the plant’s intake flow due to retirement of “once-through” Units 1& 2 at Conesville Plant have contributed to the sediment build-up. Little is known about the effect of the sediment structures on the flow pattern and ice transport to the intakes. A better understanding of reasons that reduced the effectiveness of the SCS is also needed. A model capable of predicting the hydrodynamics and ice transport in the river is important to better comprehend the physical process leading to intake blockage or sediment accumulation.

Mathematical models have been developed in the last several decades to describe river ice processes [3]. Current computer resources have made possible the use of Computational Fluid Dynamics (CFD) tools for modeling ice transport and accumulation in intakes. In this study, a three-dimensional (3D) numerical model based on the incompressible Reynolds Average Navier Stokes (RANS) equations together with a k-epsilon model for turbulence closure are used. The RANS equations are appropriate to obtain time-averaged solutions to the Navier Stokes equations for turbulent flows [4]. An energy equation is used to predict temperature distribution. A particle tracking technique is incorporated in the model to obtain ice trajectories. Buoyancy, drag, and turbulent dispersion forces are included. The pressure drop due to accumulation of ice in the trash racks is modeled, including a porous media with a porosity function of accumulated ice. The model was used to: (1) evaluate possible ice accumulation with present operations, (2) assess the effect of the SCS on the hydrodynamics and transport of ice to the intake region, and (3) analyze some possible mitigation measures.

Study Area
The modeled domain extended approximately 1,000 ft upstream of the intake (Figure 3). Bathymetric NAVD88 data collected in 2009 and 2010 were used in the model.
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The drag coefficient depends on the flow regime and particle shape. In this study, ice particles with diameter smaller than 10 mm are considered spherical with a drag coefficient given by:

\[
C_D = \begin{cases} 
\frac{24}{Re} & \text{Re} < 0.1 \\
\frac{a_1}{Re} + \frac{a_2}{Re^2} + \frac{a_3}{Re^3} & 0.1 < \text{Re} < 10000 \\
0.4 & \text{Re} > 10000 
\end{cases}
\]

where the particle Reynolds number is \( \text{Re} = \frac{\rho_d d_p |\mathbf{u}_p - \mathbf{u}|}{\mu} \).

Bigger particles are approximated by perfect discs with constant thickness. The diameter-to-thickness ratio of ice crystal discs is assumed to be 15:1 [5], and the drag coefficient is modeled as:

\[
C_D = \frac{24}{Re}(1 + b_1 \text{Re}^{b_2}) + \frac{b_3 \text{Re}}{b_4 + \text{Re}}
\]

where coefficients \( b_1, b_2, b_3 \), and \( b_4 \) are functions of the shape factor, \( \frac{a}{A} \), with \( a \) as the surface area of a sphere having the same volume as the particle, and \( A \) as the actual surface area of the particle. A Random Walk Model (RWM) is used to account for the dispersion of particles due to turbulence. Turbulent dispersion is taken into account using the instantaneous fluid velocity \( \mathbf{u} + \mathbf{u}'(t) \) instead of the mean velocity \( \mathbf{u} \), \( \mathbf{u}'(t) \), being the fluctuating velocity. The RWM assumes that \( \mathbf{u}'(t) \) conforms to a Gaussian probability distribution [6]:

\[
\mathbf{u}'(t) = \xi \sqrt{\frac{u'}{2}}
\]

where \( \xi \) is a Gaussian distributed random number having zero mean and unity variance.

The pressure drop through the trash racks without ice is modeled as a one-dimensional (1D) porous media. The pressure change across the trash racks can be modeled considering an inertial loss term:

\[
\Delta p = -1.04(\phi_i^2 - 1) \frac{\rho \mathbf{u}^2}{2}
\]

A 3D porous media in the trash racks is included in the model to account for the pressure drop due to accumulated ice in the intake. The model assumes that all ice particles in contact with the screen will adhere to the rack, neglecting growth/decay of crystals due to heat transfer. The momentum sink in Eq. (2) due to ice accumulation can be modeled as:

\[
r S = -1.04(\phi_i^2 - 1) \frac{1}{2} \rho \mathbf{u}^2 r
\]

The porosity of the trash rack considering the accumulated ice can be calculated considering the ratio between the volume available for flow of water and the total porous media volume \( \phi_i = \frac{V - V_{ice}}{V} \).

Before any ice accumulation the porosity is one, and when a complete blockage occurs, \( \phi_i = 0 \).

**Numerical Model**

**Model Grids**

The commercial grid generator Gridgen, was used to create the numerical grids. The river and water intake areas, with and without the SCS, were meshed with multi-block grids containing only hexahedral elements. Gridgen allows grid quality control near structures, river bed and free surface by projection in databases and selection of node distribution. Water surface elevation was considered flat. Grid points were clustered, and nodes were highly concentrated near the free surface and intake structure to resolve flow fields near the interest area. Figure 4 shows a general view of the entire grid with boundary conditions. Details (a) and (b) show the grid near the intake at the water surface elevation and river bed, respectively. Two grids, with and without the SCS, were created. The same grid topology was used for both configurations to avoid any effect of the grid on the results.

**Boundary Conditions**

Free Surface: the water surface is modeled using a rigid-lid approach imposing zero shear stress. The heat flux at the free surface is calculated from:

\[
q = h(T - T_w)
\]

where \( h \) is the heat transfer coefficient. In this study \( h = 2.5 \text{ BTU/ft}^2\text{h}^\circ\text{F} \) [7].

Walls and River Bed: non-slip condition and zero heat flux are used for the river banks and bed.

Outflows: zero gradients for all variables with the exception of pressure are imposed at the downstream end of the river and at the intake units. Pressure is adjusted to satisfy the specific discharge.

Inflow: the total river flowrate and measured temperature are specified at the upstream section. Turbulent variables are assumed to be zero.

**Numerical Method**

The commercial code Fluent 12.1 was used in this study. User Defined Functions were programmed to include the pressure drop due to ice accumulation in the intakes (Eq. 12).
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The SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) algorithm was used to couple pressure and velocity. The standard discretization method was applied to pressure, and first-order upwind schemes were used for momentum and turbulent variables. Unsteady solutions were obtained using a fixed time step of 1 s. Unsteady ice trajectories were computed integrating Eq. (7) with a fixed time step of 0.08 s. Implicit and trapezoidal schemes were chosen as low- and high-order schemes for the discrete phase model based on Fluent accuracy requirements and stability range for each scheme.

Simulation Conditions

The river flow was determined based on historic analysis of water discharges during winter, available on http://waterdata.usgs.gov/usa/nwis/sw at Coshocton Station, Station No. 03140500. Average and most frequent flows were analyzed to select a representative flow for the simulations. The average flow rate for the past seven years during winter was approximately 9,900 cfs. Figure 5 is a frequency plot summarizing distributional information of the river flow rate. Most of the year river flows are in the lower flow range between 1,000 and 8,000 cfs. Since ice accumulation is more critical during low flow events in the winter, simulations were run at a river flow of 6,000 cfs. For this flow rate, the water surface elevation calculated using USGS gauge readings at the Muskingum River Coshocton Station was 721.6 ft. For this condition, the top of sediment vanes are located 9.6 ft beneath the free surface. Based on air and water temperatures measured during the winter of 2010, a low air temperature of 8.6°F was used to compute the heat flux at the free surface (Eq. 13). An average river water temperature of 34.4°F was used at the model inlet.

The amount and size of ice in the model inlet are needed as boundary conditions. These variables depend on the site and time. Ideally, field data collected during several years would be used to determine the mean variables required as inputs to the model. Since a field study to determine ice characteristics was not carried out in the Muskingum River, ice concentration at the upper Niagara River was scaled and used in the simulations [8]. Ice size distribution was assumed to be the same as that measured in the St. Claire River [9, 10]. Both the Niagara and St. Claire Rivers are in comparable climates to the Muskingum River. Note that the scaling performed in this study is not valid to accurately calculate the amount of ice in the Muskingum River. Rather it provides a model input to evaluate different structural alternatives related to ice transport and accumulation in the intake area.

Effect Of Operational Conditions And Sediment Control Structures

Four simulations were performed to investigate the effect of the intake operation and SCS on the flow pattern and ice transport to the intake facility. Table 1 describes intake operation conditions. Simulations S1 and S2 represent past operations, and S3 and S4 current operations after the last unit operating with the once-through cooling system was decommissioned. Note that there are eight intake wells, with 1A and 1B for unit 1, 2A and 2B for unit 2, 3A and 3B for unit 3, and 4A and 4B for units 4-6, which only need makeup water for cooling towers.

<table>
<thead>
<tr>
<th>SCS</th>
<th>Intake Operation (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4A</td>
</tr>
<tr>
<td>S1</td>
<td>No</td>
</tr>
<tr>
<td>S2</td>
<td>Yes</td>
</tr>
<tr>
<td>S3</td>
<td>No</td>
</tr>
<tr>
<td>S4</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Figures 6(a) and 6(b) respectively show 3D streamlines colored by velocity magnitude without and with the SCS for the past operation. The length of the dashes in the streamlines is proportional to the velocity magnitude. As observed in the field, the model predicts a big eddy with low velocity at the shallow region in front of the intakes near the west opposite shore. Vanes create flow resistance that decrease streamwise velocities, inducing a small counterclockwise eddy upstream of the intake entrance.

![Figure 5. Muskingum River flow frequency plot.](image)

![Figure 6. Streamlines for S1 (a) and S2 (b)](image)
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Figure 7 is a top view with streamlines colored by elevation, showing vortices at the trailing edge of the vanes. Vanes create a secondary circulation in the flow, inducing helicoidal vortices that induce scouring and control bed elevation [11]. If the intake is not operating, vane-induced vortices are not created and sediment accumulation is not prevented. This is consistent with the recent bathymetric data. When units 1 and 2 were shut down and intakes 1 and 2 stopped operating, sediment deposition started to occur, and the bed rose to such a level that some vanes were covered. Note that, in this case, the vanes are no longer functional.

Figure 8 shows velocity vectors near the intake at 0.1 ft beneath the free surface, with and without the sediment control structures. For all the simulated operations, the sediment control structures increase the transverse velocity near the free surface (velocity in the intake direction), which facilitates the transport of ice to the intake entrance.

Near the free surface, the eddy upstream of the intakes is stronger when vanes are in place. This eddy decreases the streamwise velocity upstream of the intake entrance with potential of reverse flow near the intakes. The reduction of streamwise velocity decreases the downstream ice transport with potential to draw more surface frazil and pulverized ice into the intake. This condition is more critical for past operation, where water is flowing to the central region of the intake.

Without the SCS, ice moves downstream near the intake region, and small particles turn back to the intake entrance. Medium and large size particles move downstream with the river flow.

Without the vanes, warmer water from lower elevations is drawn to the intakes. The upstream eddy is located deeper and extends further downstream into the intake region than that predicted with the vanes in place.

Larger transverse velocities with the SCS favor the transport of bigger ice particles to the intake entrances. The accumulation of ice starts near the free surface, where most of the ice particles are found. Ice accumulation occurs first at the upstream end of the intake structure and then extends toward the downstream side. The upstream eddy traps ice particles, facilitating their accumulation and the creation of a stationary ice cover upstream of the intakes. The ice cover grows in size due to further accumulation of ice particles.

The rate of intake blockage is measured with the porosity of the porous media used to model ice accumulation in the intake. A value of one indicates an intake without any ice. It is assumed that when the porosity is 0.1, a complete blockage occurs and the intake is no longer functional. For comparison purposes, the porosity of the intake is plotted against non-dimensional time $t^*$, which is the time divided by the time at which total blockage occurs. Figure 9 shows the evolution of porosity with and without the SCS for past and current operations. With past operation (simulations S1 and S2), more water is drawn into the intakes. Without the SCS, ice can turn back more easily after the recirculation. These ice particles are then transported to the intake area. According to the model, intakes 3A and 3B are blocked when $t^* \sim 0.1$. However, the intake 4A is not blocked during the simulated time. For present operation without the
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SCS (simulation S3), only a small amount of small ice particles are transported to the intake entrance, and the intakes are not blocked. With the SCS (simulation S4), all intakes are blocked in a relatively short period of time due to the accumulation of ice particles. Contrary to what is predicted in the simulations without the vanes, the blockage occurs first in the upstream intakes, consistent with field observations. The most critical condition takes place under current operation, where water is drawn from the upstream intake. According to the model, at t*~ 0.05 the intake is completely blocked. For past operation, intakes 3A and 3B operate longer than intake 4A. However, they are also blocked in a relatively short time (t*~ 0.2).

**Evaluation Of Mitigation Measures**

According to the model, the accumulation of ice particles with current operation is comparable with past operation, and therefore there is an important risk of intake blockage by ice. Structural modifications in the intake were proposed to reduce the potential of blockage (Figure 10). The modifications consist of thirty-inch pipe openings in the existing walls that separate the pump wells. A knife gate shut off valve was installed to enable isolation of the 2B Intake Pump well for maintenance. Two options were proposed: 1) connecting all intakes, and 2) connecting intakes of retired units 1 and 2. Since partially or totally covered sediment control vanes are not functional, the removal of the downstream vanes was recommended. The 2B Emergency Booster Pump which can supply make-up water to the plant when the normal make-up pumps, 4A & 4B, are not operable will be placed in service on a weekly basis to help prevent sedimentation and verify operability of the equipment.

Eight numerical simulations were performed to evaluate the effectiveness of the proposed intake modifications, as described in Table 2. The effects of removing four and eight downstream vanes were studied. A pump capacity of 89.12 cfs was used. This is a conservative assumption, since normal system demand is about half of that value. Three operational conditions were evaluated: 1) pumps 4A and 4B operating at 44.56 cfs/each, 2) pump 4A at 89.12 cfs, and 3) pump 4A operating at 89.12 cfs until plugged, and then switching to pump 2B operating at 89.12 cfs.

<table>
<thead>
<tr>
<th>Vanes Removed</th>
<th>Intake Pipe</th>
<th>Intake Operation (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4A</td>
<td>4B</td>
</tr>
<tr>
<td>S5</td>
<td>4</td>
<td>All</td>
</tr>
<tr>
<td>S6</td>
<td>8</td>
<td>All</td>
</tr>
<tr>
<td>S7</td>
<td>0</td>
<td>All</td>
</tr>
<tr>
<td>S8</td>
<td>4</td>
<td>All</td>
</tr>
<tr>
<td>S9</td>
<td>4</td>
<td>1 and 2</td>
</tr>
<tr>
<td>S10</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Figure 11 shows ice distribution predicted with the particle tracking technique near the intakes at a time corresponding with 50% of total blockage. Details (a), (b) and (c) show the results when all intakes are drawing water with four, eight and zero vanes removed, respectively. Detail (d) shows the particles when operating with pump 4A. Details (e) and (f) show the results obtained when connecting intakes 1 and 2 with four and zero vanes removed, respectively. No significant difference is observed in the predicted flow pattern with all vanes in place or removing four downstream vanes. The flow pattern upstream of the intake is mainly affected by upstream vanes, and therefore removal of downstream vanes only has a marginal effect on the upstream eddy and ice transport to the intake area. When water is drawn with only one pump, higher velocities are predicted near intake 4A. However, this phenomenon is extremely local and does not affect the general flow pattern in the intake area. According to the model, the ice particles accumulate farther downstream as the number of vanes removed increases. Reducing the number of upstream vanes results in less flow resistance favoring downstream ice accumulation.
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The model cannot predict actual time to blockage, since the amount of ice upstream in the river is unknown. However, under the same river conditions, it can be used to compare different geometries or mitigation measures using the operation time of an intake. The operation time of an intake is defined as the time before 50% blockage. The operation time for the projected operation with water being drawn from intake 4A and the current intake geometry is $t_{\text{op}} \approx 0.025$. Table 3 shows the dimensionless operation time with the proposed structural modifications. In order to evaluate the effectiveness of a structural modification, the ratio between operation times under different conditions, $X_{\text{op}}$, can be calculated as:

$$X_{\text{op}} = \frac{t_{\text{op}}}{t_{\text{op}}^*}$$  \hspace{1cm} (14)

where $t_{\text{op}}$ is the operation time with the proposed modification and $t_{\text{op}}^*$ the time with the original intake. Table 3 summarizes operation time and for simulations S5 to S10. can be used to calculate the increment in operation time due to a proposed modification. For example, connecting all intakes and removing four vanes (simulation S5) results in operation 16 times longer (before 50% intake blockage) than the current system.

Numerical results indicate that connecting all intakes results in longer time before intake blockage. The difference in intake operation time when removing four downstream vanes is not significant. However, ice particles are less attracted to the intake region when upstream vanes, i.e., vanes in front of intake 3, are also removed. The proposed modifications help to alleviate ice accumulation in the intakes. However, ice transport to the intake entrance is not fully prevented.

<table>
<thead>
<tr>
<th>Intake Modifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intake Modifications</strong></td>
</tr>
<tr>
<td>Based on model results, a mitigation plan to be implemented in several phases was prepared. In the first phase, 36 inch-diameter pipe openings are cut in the walls separating intake pump wells 1 and 2. Figure 12 shows the openings in the pump pit walls. An isolation valve is installed to enable dewatering the 2B intake pump pit (Figure 13). A pipe opening larger than simulated was constructed. This pipe with 36 inch-diameter in lieu of 30 inch-diameter is expected to result in longer intake operation time. In the second phase, sediment control vanes placed in front of non-operating intake units will be removed to facilitate downstream ice transport. A third phase involving removal of additional sedimentation control vanes and cutting holes in all pump wells will be implemented if needed.</td>
</tr>
</tbody>
</table>
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screens tripped and remained out of service to prevent additional ice accumulation by the sprays from the screen wash system. As planned, the emergency booster pump 2B was used for meeting plant intake flow requirements. Having the downstream intakes interconnected ensured a reliable supply of water to the booster pump suction and for the plant needs.

**Figure 14. Ice in Muskingum River on Jan. 2014**

**Conclusions**

Ice transport and accumulation at the water intake in the AEP Conesville power plant were analyzed with a numerical model. Numerical simulations were performed for a typical river flow during winter months.

The model predicted vane-induced vortices and the general flow pattern observed in the field. According to the model, observed sediment deposition was caused by the shutdown of units 1 and 2. When these units stopped operating, secondary recirculations were not present and sediment was deposited.

The model predicts that ice accumulation occurs first in the upstream intake and then in the downstream part, as observed in the field. Sediment control structures create hydrodynamic conditions that facilitate ice transport to the intake and attract bigger ice particles.

The intake blockage time for the past and current operations is comparable. According to the model, ice buildup in the trash racks could result in complete blockage of the intake facility, compromising water supply during the months of freezing.

An intake modification based on distributing the flow to reduce surface velocities and eliminating some vanes was proposed. Numerical results indicate that including pipe openings in the existing walls results in less ice attraction to the intake and longer time before blockage. The difference in intake operation time when removing four downstream vanes is not significant. However, ice particles are less attracted to the intake region when upstream vanes were also removed.

A mitigation plan was developed and is currently being implemented. The first phase of the plan consists of connecting the retired intake units and the 2B Emergency Booster Pump intake. A second phase, comprising the removal of five vanes in front of retired units, will be effected after phase 1. A final phase, implemented if necessary, includes the removal of three additional vanes and connection of all intake units/pump pits.

During the winter of 2014, temperature was well below freezing for an extended period of time and ice transported from the river upstream accumulated at the intake structure. Ice behavior and accumulations at the intake closely matched the predictions from the model. AEP will monitor the icing characteristics during following winters to determine if additional (i.e., second phase) modifications are necessary/warranted. The 2014 Winter field experience seems to indicate that the implemented intake modifications may be enough to ensure continuous, reliable water supply to the plant during extreme cold weather.

**Nomenclature**

- \( a \)  surface area of a sphere having the same volume as the particle
- \( A \)  surface area of the particle
- \( b \)  shape factor coefficient
- \( C_D \)  drag coefficient
- \( C_p \)  specific heat
- \( C_{1\varepsilon} = 1.44, \ C_{2\varepsilon} = 1.92, \ C_\mu = 0.09 \) model constants
- \( d_p \)  particle diameter
- \( F_D \)  drag function
- \( g \)  gravitational acceleration
- \( G_k \)  generation of turbulent kinetic energy
- \( h \)  heat transfer coefficient
- \( H \)  roughness height
- \( \rho \)  pressure
- \( q \)  heat flux at the free surface
- \( s \)  second
- \( S \)  momentum source
- \( S_{ij} \)  modulus of the mean rate-of-strain tensor
- \( t^* \)  dimensionless operation time
- \( T \)  temperature
- \( T_a \)  air temperature
- \( T_o \)  reference temperature
- \( \nu \)  velocity
- \( u \)  the velocity normal to the trash racks
- \( V \)  trash rack volume
- \( V_{ice} \)  volume of ice accumulated in the trash rack
- \( X_{op} \)  ratio between intake operation times

**Greek letters**

- \( \alpha \)  molecular thermal conductivity
- \( \alpha_{eff} \)  effective thermal conductivity
- \( \alpha_t \)  eddy thermal conductivity
- \( \varepsilon \)  turbulent dissipation rate
φ  shape factor
κ  turbulent kinetic energy
μ_eff  effective viscosity
μ  molecular viscosity
μ_t = ρ_o C_p κ^2 eddy viscosity
ρ_o  water density at
σ_k = 1, σ_ε = 1.2  turbulent Prandtl number for k and α
φ_i  trash rack porosity
φ_s  screen porosity

Subscript
b  ice particle

Acknowledgments
The authors would like to acknowledge Marian Muste from IIHR – Hydroscience & Engineering, Kathy Dober from AEP Engineering Services, Charlie Dannemiller from AEP Region Engineering and Conesville Plant personnel for their valuable contributions to the study.

References

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Role of Mass of the Structure

Damaging and/or catastrophic effects resulting from earthquakes within an active seismic zone are directly proportional to the total mass of the structure built within the confines of mentioned zone. Thus, using of materials with lower densities and stiffer and stronger than the traditional materials (what allows to decrease cross-sectional areas) has to be the priority in the materials selection for the structures built in the seismic zone.

Critical Parameters

The total weight of structure is determined by densities $\rho$ of materials and by cross-sectional areas of elements $A$, which are inverse proportional to the strength $\Pi$ of the materials. As a result, the total weight of the structure is proportional to the ratio $\rho/\Pi$ or inverse proportional to the ratio $\Pi/\rho$. The first task of the design for a structure in a seismic area is to decrease the weight of the structure. Structural members made from composites having specific strength $\Pi/\rho$ decimal order higher than the traditional materials are ideal candidates from this point of view (see Table 1). Not only is a decrease of the total mass of a structure important, but so too is the distribution of its mass. Current research indicates that the best combination comprises that which incorporates a heavily reinforced foundation in conjunction with a structure made from light-weight materials provided the flexible response on sudden loads. Tantamount to these requirements is the necessity to establish a strong connection between the structure and its foundation.

Flexural vibrations of the structure depend on the parameter

$$\alpha = \left( \frac{\omega^2 \rho A}{\Pi E J} \right)^{1/4}$$

where $E$ – is the Young modulus of material, $\omega$ – is the frequency of vibrations, $J$ – is the moment of inertia of the cross-section, and $A$ – is the cross-sectional area. In regards to improving ability of the structure to withstand seismic stresses this parameter has to be decreased. The specific stiffness $E/\rho$ of composites (which is participating in the denominator of the parameter $\alpha$) is much higher than in traditional materials and as a result their vibrational performance is better.

Energy absorption is the key characteristic of any structure in dynamic loading. Energy absorption ability of material is mainly determined by the “area under stress-strain curve”. Sometimes this characteristic is called “material toughness”. However, it creates a confusion with established terminus “fracture toughness” characterizing resistance to the crack propagation. It should be noted that the strong but brittle material can absorb much less energy than not so strong materials with greater ultimate strain. For linearly elastic materials energy absorption per unit of volume is equal to $\frac{\Pi^2}{2E} = \frac{1}{2} \Pi \epsilon_{ult}$ but for ideally plastic materials it is equal to $[\Pi \epsilon_{ult}]$. For majority of materials the energy absorption per unit of volume is $k \Pi \epsilon_{ult}$ where coefficient $k$ is characterized the shape of the stress-strain diagram and which in majority of cases has the value between $\frac{1}{2}$ and 1. Energy absorption per unit of mass is determined by $\frac{k \Pi \epsilon_{ult}}{\rho}$.

Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density $\rho$ (lb/ft$^3$)</th>
<th>Young modulus $E$ (GPa)</th>
<th>Specific stiffness $E/\rho$ (GPa ft$^2$/lb)</th>
<th>Tensile strength $\Pi$ (GPa)</th>
<th>Specific strength $\Pi/\rho$</th>
<th>Ultimate tensile strain $\epsilon_{ult}$</th>
<th>Energy absorption per volume $\frac{\Pi^2}{2E} = \frac{1}{2} \Pi \epsilon_{ult}$ (BTU/lb$^3$)</th>
<th>Energy absorption per mass $\frac{k \Pi \epsilon_{ult}}{\rho}$ (BTU/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-glass fiber</td>
<td>0.0904</td>
<td>72.4</td>
<td>328</td>
<td>4.5</td>
<td>1.8</td>
<td>0.10</td>
<td>4.7</td>
<td>32</td>
</tr>
<tr>
<td>S-2 glass fiber</td>
<td>0.135</td>
<td>58.5</td>
<td>341</td>
<td>4.5</td>
<td>1.8</td>
<td>0.10</td>
<td>3.3</td>
<td>25</td>
</tr>
<tr>
<td>Carbon fiber, IM</td>
<td>0.175</td>
<td>83.0</td>
<td>368</td>
<td>2.4</td>
<td>1.1</td>
<td>0.09</td>
<td>1.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Carbon fiber, HS</td>
<td>0.136</td>
<td>82.6</td>
<td>341</td>
<td>2.4</td>
<td>1.1</td>
<td>0.09</td>
<td>1.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Kevlar-49</td>
<td>0.120</td>
<td>152</td>
<td>413</td>
<td>2.4</td>
<td>1.1</td>
<td>0.09</td>
<td>1.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Zylon</td>
<td>0.110</td>
<td>152</td>
<td>413</td>
<td>2.4</td>
<td>1.1</td>
<td>0.09</td>
<td>1.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Sand A1S- 9000 series</td>
<td>0.284</td>
<td>30.5</td>
<td>32.3</td>
<td>0.6</td>
<td>0.06</td>
<td>0.06</td>
<td>0.6</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Structures manufactured from high grades of armor steel absorb a lot of energy per unit of volume due to their combination of high strength and plasticity. However, composites are replacing steel even in such traditional dynamic applications such as armoured fighting machines and military tanks armor because composites have better energy absorption per unit of mass. Other important characteristics such as specific strength and specific stiffness are much higher in composites than in steel. Comparison of the stress-strain diagrams of different materials is shown in the Fig. 1.

Additional Properties Important for Dynamic Applications

The key to success in the design of structures for dynamic applications is the ability to redistribute the peak of stresses in the time and in the constituents’ area/space. Reaction on suddenly applied load is better if structure is more flexible (see Fig. 2). It allows redistributing stress peak in time, decreasing the maximal stress, and avoiding the fracture. This is well known from an observation of
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fishing rods behavior. Also, because sudden load is applied on some part of the structure surface not in the whole volume of structure, the ability to involve as much material as possible in the resistance and as quick as possible provides opportunity to avoid sharp peaks of the stresses. The velocities of the elastic waves are proportional to the square root from the specific stiffness. Even in glass fibers the velocity of the elastic waves is higher than in steel, in Kevlar it is 1.7 times higher, in carbon fibers it is up to 3.8 times higher. Materials with higher elastic speed velocities are preferable for dynamic applications.

Figure 2. Schematic comparison of the reaction on suddenly applied load in two types of structures.

Besides energy absorption, the energy dissipation is extremely important in reaction of the structure on suddenly applied loads. Whole absorbed energy can be subdivided to stored energy and to dissipated energy. The ratio of dissipated energy to stored energy in the material is called “tangent delta” (because it is studied experimentally in cyclic loading and is determined via phase shift between load and displacement). In steel the energy dissipation is related to the plastic deformation. In composites the energy dissipation happens due to viscoelastic deformation of polymeric matrix. Also, polymeric fibers, such as Kevlar, Spectra, Zylon are characterized by nonlinear viscoelasticity. Spectrum of relaxation times in polymers is very wide. From one side, it results in creep in long-time loading. From another side, in very short time dynamic processes part of energy dissipates and as a result, the peak stress is much lower than in the case of absence of energy dissipation. This is the second mechanism of the stress redistribution during the time. It is the reason, why Kevlar fibers are more effective in bullet-proof vests than the carbon fibers despite the mechanical characteristics of carbon fibers are better than in Kevlar fibers.

Resistance to the Crack Propagation
There are other characteristics of materials to take into account. Fracture toughness and ductility are important also, however, there are different concepts hidden under these terms: J-integral, stress intensity factor, crack extension force, etc. Depending on fiber architecture, the resistance of composites to the crack propagation can vary in wide ranges. When bigger number of fibers the crack needs to cut in the process of its propagation, the higher fracture toughness of composite is observed.

About Use Of Concrete In Seismic Areas
Concrete is used in dynamic applications such as protective bunkers against artillery shells and bombs. However, its application in seismic areas has to be done with some precautions. Concrete has relatively high compressive strength and low tensile strength. As a result, because the pure shear can be represented as a combination of tension in one diagonal direction and compression in other diagonal direction, the resistance of concrete to pure shear is very low too. When shear is acting simultaneously with hydrostatic pressure, the resistance of concrete is increasing significantly. This idea is used in dome-shaped bunkers. However, the pure shear is one of the most typical seismic stresses. It means that concrete has to be not only reinforced but also well-pre-stressed. Using composites for reinforcement of concrete was the subject of investigations during last sixty years. Initially there were rebars made from glass-fiber reinforced plastic. These rebars have high strength but insufficient stiffness. As a result, it is necessary to use much bigger volume concentration of the reinforcement in comparison with steel rebars. However, for the high level of pre-stress of the concrete, the glass-fiber reinforced plastics are preferable in comparison with steel because the maximal elastic strain is much higher in glass fibers than in steel. Carbon-fiber reinforced plastics having higher strength and stiffness than steel are much more expensive than the glass-fiber reinforced plastics. Despite this restriction carbon-fiber reinforced plastics are used more and more for reinforcing concrete in unique structures. There are some problems with secure gripping composite rebars in concrete until complete fracture of the material with static fatigue of rebars, etc. Nevertheless, more and more composite rebars are used for concrete now and their much bigger role in the reinforced concrete structures for seismic areas is expected.

Cooling Towers For The Seismic Areas
Application of composites for cooling towers structures was started by the first author of this report with the firm Ceramic Cooling Towers Inc. (Fort Worth). Now the Composite Cooling Solutions Inc. constructs cooling towers from composites on regular basis. These types of the structures are more appropriate for the seismic areas than the traditional ones. However, there are some adjustments in the design has to be made specifically targeting structure performance under seismic loads. Fan blades vibration due to possible deflections of the axis of the rotation during seismic activity is an example of the problem to be solved. Composite Cooling Solutions Inc. is collaborating with Lamar University (Beaumont, TX) in research and development.

Conclusions
Authors experience in such structures as racing cars (Chaparral) or commercial cars (springs for Corvette and Camaro), helicopter blades, all-composite buildings (Apple, AT&T), bridges, fishing rods, yachts, airspace and other structures (Green), in airspace, electrical machinery, shipbuilding, wind turbines, and defense (blast-resistant structures) (Beyle) is convincing that the composites are the exceptional materials for cooling tower construction in seismic zones.
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Lessons Learned from a High Recovery RO - Based ZLD System

Brad Buecker  
Kiewit Power Engineers

A critical topic that continues to be discussed at CTI meetings is the need for water conservation across a broad spectrum of industries and municipal applications. Major contributing factors in many cases are increasingly stringent wastewater discharge regulations, as outlined in this paper. More and more, plant personnel are looking at cooling tower blowdown recycle and recovery as a method to conserve water, with the ultimate scenario being zero liquid discharge (ZLD). An emerging technology is water recovery based on high-recovery reverse osmosis technology. This process includes ultrafiltration, softening, and reverse osmosis. However, the concentrating nature of cooling towers combined with chemical treatment programs subjects blowdown treatment systems to chemistry that may significantly influence performance. The final sections of this paper examine lessons learned from actual operation at an existing power plant. Difficulties included poor performance of an upstream multi-media filter, fouling of ultrafilter membranes from standard cooling tower treatment chemicals, and the somewhat belated realization that feed of a cationic polymer ahead of membrane systems is typically not a good idea.

Increasingly Strict Regulations for Cooling Tower Blowdown

Subsequent to the passage of the Clean Water Act in the late 1960s, the U.S. Environmental Protection Agency (EPA) began controlling industrial plant wastewater discharges per National Pollutant Discharge Elimination System (NPDES) guidelines. In many cases, NPDES guidelines focused upon a small core of primary impurities in wastewater discharge streams. These included total suspended solids (TSS), oil and grease (O&G), pH, and free chlorine (or other oxidizing biocide). A once-common guideline is shown below in abbreviated form.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Monthly Average (Limit or Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Available Chlorine</td>
<td>0.2 mg/l</td>
</tr>
<tr>
<td>O&amp;G</td>
<td>15 mg/l</td>
</tr>
<tr>
<td>pH (range)</td>
<td>6.0 – 9.0</td>
</tr>
<tr>
<td>TSS</td>
<td>30 mg/l</td>
</tr>
</tbody>
</table>

Table 1 – An Abbreviated NPDES Example

At many plants constructed in the previous century, once-through cooling systems were common, and these limits were often easy to achieve. The majority of problems arose at coal-fired power plants from impurities in the discharge of coal pile runoff ponds and wet ash disposal ponds. The constituents in these particular streams that required the most oversight tended to be TSS and pH, but straightforward methods were available to control this chemistry. Now, increasingly stringent air quality regulations and the availability of cheap natural gas have led to significant growth of simple- and especially combined-cycle units for new power generation. But due to pending 316b water regulations, which are designed to protect marine life from destruction in cooling water intakes, virtually all new combined-cycle project specifications call for a cooling tower, or in some instances an air-cooled condenser. Complicating these developments is that NPDES guidelines are tightening, but not necessarily in a uniform manner.

The EPA is currently preparing new national guidelines that will place limits on additional power plant cooling tower blowdown constituents. These include the heavy metals chromium and zinc, with projected limits of 0.2 and 1 part-per-million (ppm), respectively. However, some individual state regulators have begun to place limits on some or all of the following additional constituents:

- Total dissolved solids (TDS)
- Sulfate
- Copper
- Phosphate
- Ammonia
- Quantity of discharge

Concurrently, regulators are pushing some plants to use alternatives to fresh water for makeup. (This trend is particularly evident in California.) These sources include reclaim water from municipal wastewater treatment plants and poor quality groundwater. In the case of the former, ammonia and phosphate are often problematic constituents, and thus the cooling tower makeup might require treatment such as ammonia stripping and phosphate precipitation by clarification to protect the discharge. Groundwater may contain high concentrations of hardness, alkalinity, chlorides and sulfates, and silica.

As an example of changing NPDES regulations, consider the new guidelines at a power plant in one of our southern states, where cooling tower blowdown constitutes nearly all of the plant’s liquid discharge. Prior to 2013, the plant’s NPDES permit primarily focused upon the items outlined in Table 1. The new permit now imposes an average monthly limit of 1,200 mg/l TDS. Given that the makeup water TDS concentration sometimes reaches 400 mg/l TDS, the tower cycles of concentration (COC) may be limited to three under the new regulations, whereas previously the tower had been operated at a significantly higher COC.

Another impurity receiving more scrutiny is sulfate (SO₄). This issue can be problematic with regard to process chemistry, as sulfuric
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acid feed to cooling tower makeup has been a common method to remove bicarbonate alkalinity and thus minimize calcium carbonate \((\text{CaCO}_3)\) scaling in the condenser and cooling system.

\[ \text{H}_2\text{SO}_4 + \text{Ca(HCO}_3\text{)} \rightarrow \text{CaSO}_4 + 2\text{H}_2\text{O} + 2\text{CO}_2 \]

Tighter regulations on sulfate in the discharge stream may curtail or eliminate this straightforward method of scale control at some plants. Indeed at the plant outlined in this first case history, the new guideline limits the sulfate concentration to 400 mg/l. Also as touched upon above, phosphate is being banned in some waste streams. [2] Phosphate serves as a primary nutrient for plant growth, and when released to open bodies of water can often initiate and propagate algae blooms. The difficulty is that a very common cooling tower treatment method relies on the use of organic and inorganic phosphates for corrosion and scale control. New, all-polymer programs are emerging to minimize phosphate use.

As has been noted, zinc and chromium are on the proposed new NPDES list. State regulations may be more comprehensive or stringent with regard to metals discharge. For the power plant mentioned above, in 2015 copper will be incorporated into the discharge guidelines, where the limit will be less than 30 parts-per-billion (ppb). Some plants in the country have even lower copper discharge guidelines. At these very low limits, copper discharge can potentially be a problem from units equipped with copper-alloy condenser tubes. However, another copper source, sometimes from older wooden cooling towers, comes from copper compounds utilized as a wood preservative. One possible solution is replacement of the old cooling tower with a modern, fiberglass tower. Another possibility is installation of a wastewater treatment plant with a heavy metal precipitation process.

The upshot of this discussion is that at existing plants costs to comply with new liquid effluent guidelines may be significant. A switch to all-polymer chemistry in a large cooling tower to eliminate phosphate in the discharge may result in significant annual O&M cost increases. Alternatively, the capital cost for installation of a treatment system to remove newly-regulated impurities from the discharge stream may reach or exceed one million dollars. Plus, a waste treatment system adds complexity and operational costs of its own to the plant.

**Moving to ZLD**

In addition to the impurities mentioned above, there is every possibility that additional wastewater contaminants may be regulated in the future. For this reason, some experts recommend that plants consider ZLD at the very beginning of the project. This process is often rather complex. Perhaps the most straightforward disposal technique, but with a large caveat, is deep well injection. The wells may be several thousand feet deep to avoid any discharge into shallow groundwater used for domestic purposes. While this concept sounds simple, experience has shown that some wastewaters can generate scale within the well shaft, particularly as the water warms further underground. High-pressure is generally required for this process, and if scale formation occurs, capacity may decrease.

At plants in arid locations with a large land area, evaporation ponds may be sufficient to handle the wastewater discharge. However, these ponds must be properly lined to prevent seepage of the wastewater with its impurities into the underlying soil. Permitting may or may not be granted for evaporation ponds. Another alternative at sites strategically located is to have the wastewater trucked off-site to a waste disposal company. But this technique can be expensive because obviously the vast bulk of the material is simply water, and also because waste remediation is high-priced commodity.

If none of the above options are acceptable, thermal evaporation of the waste stream may be the only choice. At a recent visit to a plant in the southwestern U.S., the author observed a brine concentrator/crystallizer system that treats the entire cooling tower discharge. While the system is reliable, the inlet flow rate at full load is nearly 1000 gpm. Thus, energy requirements are quite large, as are the regular maintenance costs to remove accumulated solids from the evaporation equipment.

For these reasons, becoming popular are treatment methods to reduce the volume of the plant waste stream before final treatment. A notable example is high-recovery reverse osmosis, as outlined generically below.

![Fig. 1. Generic outline of an emerging wastewater treatment technology.](image-url)

Keys to the process are:

- Microfiltration (MF) or ultrafiltration (UF) to remove suspended solids in the waste stream. This is a critical process to prevent suspended solids from fouling reverse osmosis (RO) membranes.
- Sodium bisulfite \((\text{NaHSO}_3)\) feed to remove residual oxidizing biocides. This is also critical to remove oxidizing biocides that would degrade softener resin and RO membranes.
- A sodium softener to remove calcium and magnesium. Otherwise the downstream equipment would suffer from calcium carbonate and magnesium silicate scaling.
- Sodium hydroxide injection to elevate the pH above 10. (The combination of hardness removal and pH elevation keeps silica in solution.)
- Two-pass reverse osmosis (RO) treatment.

Under proper conditions, a 90-percent RO recovery rate is possible. The RO permeate recycles to the plant high-purity makeup water system or other locations. However, while the process appears straightforward, a number of lessons-learned have emerged regarding this technology in actual application. The following lessons are taken from a high-recovery RO system operating at a power plant in the Pacific Northwest. One of the most notable is that some standard water treatment chemicals may foul the UF membranes. Operating experience indicates that the membrane manufacturer and type greatly influence this phenomenon. Fouling may be caused by the fact that most membranes carry a negative surface charge while cationic polymers are usually employed for flocculation. Residual
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polymer will coat the membranes. (A very similar phenomenon has been observed with MF or UF systems installed in makeup water systems downstream of a clarifier. Inexperienced designers and/or plant personnel have not always recognized that MF or UF should generally serve as a replacement for clarification, not a polishing process for the clarifier.)

A straightforward solution that has significantly improved the reliability of this particular system is conversion of the ultrafilter from an inside-out process flow path to outside-in. Typical micro- and ultrafilter systems consist of multiple, parallel flow modules containing thousands of spaghetti-like, hollow-fiber membranes.

The membranes must be regularly backwashed every 10 to 20 minutes or thereabouts to remove particulates. The backwash flow path is the reverse of the normal flow path. In this case, conversion of the membranes from inside-out to outside-in normal flow path has significantly improved the backwash efficiency, perhaps due to greater ability for the supplemental air scour to better contact the membrane surfaces.

Another interesting initial difficulty was noted with the UF backwash process. Typically with these systems, a small portion of the permeate is collected in a separate tank at the beginning of each process cycle for use in backwash. So far, so good. But most modern MF and UF units are now equipped with automatic chemically-enhanced backwash (CEB) systems. After a certain number of cycles, a CEB backwash kicks in where first the membranes are cleaned with a dilute caustic/bleach solution to remove organics and microbiological organisms, followed by rinsing and then a dilute citric acid wash to remove iron particulates. When this particular UF was first commissioned, the membranes developed a layer of calcium silicate during the CEB caustic stage. The driving force was the higher pH generated by the caustic, which in turn greatly reduced the silicate solubility. The solution to this problem was a switch to softened water for the backwash supply.

Yet another lesson learned from this application involved treatment of the reject stream from the RO unit. It has an elevated pH due to the caustic injection for silicate scale control, but “simple” acid injection to lower the pH was not that simple. The original configuration had direct sulfuric acid injection into the discharge pipe via a basic mixing tee. However, concentrated sulfuric acid is a viscous liquid that takes some time to dissolve. Residual acid flowing along the pipe wall downstream of the mixing tee has caused significant corrosion of the discharge pipe. A re-design of the neutralization process is currently underway.

The upshot of this case history is that pilot testing with the proposed cooling tower chemistry is very important for analyzing membrane performance. Some water treatment equipment vendors have suggested upstream multi-media filters to help remove the chemicals from the blowdown stream, but direct observation has shown that these filters may be ineffective in preventing chemical fouling of membranes.

An important factor in general with these systems regards redundancy, either via storage capacity or standby equipment. With a properly operating system, the final waste stream is obviously very much reduced. But if the system comes off line, the entire blowdown and additional plant wastewater streams can be too taxing for the final treatment process, particularly if it involves thermal evaporation.

A Potential Reclaim Water Scenario

Very recently, the author became involved in a project where reclaim water will be used as the makeup to a power plant cooling tower, but where the entire blowdown will be recycled to the wastewater treatment plant. Another plant in the area is already doing so.

At first glance, the natural inclination is to believe that complete blowdown recovery would cause a continual increase in solids within the system. However, if one examines this schematic using a control volume diagram, the issue becomes clear.
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The recycle of blowdown is an internal process, and after startup of the system as the blowdown solids concentration increases, at a certain point the amount of solids exiting the process balances the amount entering. The author has prepared an iterative program in Excel that demonstrates this calculation. It should be noted that a blowdown treatment system, perhaps a lime softener, may be needed to prevent excess accumulation of scale-forming solids in the WWTP. Such a system, with equipment to generate a solid sludge, can establish ZLD conditions.

Summary

Once-through cooling is no longer an option for new power plants. In many cases, cooling towers are the preferred choice, although air-cooled condensers are appearing more frequently. For new and existing plants with cooling towers, increasingly stringent effluent guidelines are requiring plant owners, operators, and technical personnel to evaluate water and wastewater treatment modifications and additions. Many factors are influencing these decisions, and they include:

- States may impose guidelines beyond those of the USEPA.
- Regulations are appearing for such wastewater constituents as total dissolved solids, sulfate, phosphate, ammonia, and some heavy metals.
- Restrictions on discharge of some of these impurities, such as phosphate, can greatly influence the choice of cooling tower treatment program. All-polymer programs are emerging.
- Discharge chemistry control may, in part at least, have to be addressed by modifications to makeup water treatment.
- Increasingly, plants in some areas of the country, either from mandate or necessity, are selecting reclaim (gray) water for makeup. These supplies often have quite variable water quality, which greatly influences cooling tower operation and blowdown chemistry.
- Installation of wastewater treatment systems may be required to comply with new guidelines.
- It is quite possible that other wastewater constituents may be regulated in the future. These might include additional salts and heavy metals. The author has heard recent comments that chloride and bromide concentrations may be limited in some plant discharges. Selection of ZLD as a proactive measure can prepare a plant for future eventualities.

- Installation and operation of a wastewater treatment system up to ZLD is not a simple process. Many factors can influence system performance, including:
  - Variable influent water quality, particularly if the plant makeup quality is inconsistent.
  - Potential for fouling of the wastewater treatment system from some chemicals utilized for cooling water treatment.
  - Change of influent flow rate due to a change in cooling tower cycles of concentration per chemistry modifications.
  - Dealing with the final waste stream that comes from the primary treatment process. If techniques such as evaporation ponds or deep-well injection are not possible, thermal evaporation may be the only choice.

References


Brad Buecker is a Process Specialist with Kiewit Power Engineers, Lenexa, KS. He has over 33 years of experience in the power industry much of it with City Water, Light & Power in Springfield, IL and at Kansas City Power & Light Company’s La Cygne, KS generating station. Buecker has written many articles and three books on steam generation topics, and he is a member of the American Chemical Society, the American Institute of Chemical Engineers, the American Society of Mechanical Engineers, the Cooling Technology Institute, and the National Association of Corrosion Engineers. He has a B.S. in chemistry from Iowa State University, with additional course work in fluid mechanics, heat and material balances, and advanced inorganic chemistry.
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Emerging Phosphorus

Regulations

Recently, US regulations have begun to restrict the industrial discharge of phosphorus as an undesirable aquatic nutrient for cyanobacteria and algae in the environment. Controlling algae growth by restricting phosphorus can be traced to Justus Von Liebig, a 19th century German chemist considered to be the “father of the fertilizer industry”. He is credited with popularizing Liebig’s “Law of the Minimum” which states that growth is controlled not by the total amount of resources available, but by the scarcest resource. Phosphorus is generally the limiting nutrient for cyanobacteria and algae growth, not only in the environment but also in many cooling tower systems. Algae and cyanobacteria derive energy from abundant sunlight, and carbon for cellular growth from abundant bicarbonate in the water. Cyanobacteria and many species of algae can “fix” atmospheric nitrogen into water. They colonize water bodies in thick mats and produce cyanotoxins that are hazardous to aquatic mammals, fish, shellfish, and even humans. In the environment, the periodic die-offs of algae and cyanobacteria cause dissolved oxygen “sags” that adversely affect aquatic life. According to USEPA, phosphorus and nitrogen nutrients are the cause of degradation in half of impaired water bodies and are associated with fish kills, sediment accumulation, unhealthful trihalomethanes (THMs) in chlorinated drinking water, and a 6,000 square mile low dissolved oxygen “dead zone” in the Mississippi River delta drainage area. USEPA’s strategy for regulating nutrients under the Clean Water Act is based on the concept of a Total Maximum Daily Load (TMDL) for a particular nutrient or pollutant entering a watershed. If a watershed is deemed to be impaired, a Waste Load Allocation (WLA) must be developed for that pollutant which restricts the amount entering the watershed to an amount that is below its assimilative capacity. At this point in time, an inventory of all the impaired water bodies in the US has been compiled, along with the pollutants responsible for the impairment. If the watershed is impaired by phosphorus, a more stringent limit for phosphorus discharge is likely to be incorporated into the site’s NPDES permit at the time of renewal. Figure 1 illustrates this water quality based TMDL approach.

Abstract

Phosphate based corrosion and scale inhibitor programs emerged as the cooling water treatment technology of choice when the industry was strongly encouraged to eliminate chromates some 35 years ago. At that time, we were certainly aware of the many troublesome issues associated with phosphate based programs: the precise control required to prevent phosphate deposits on hot bundles, inadequate admiralty brass corrosion using only azoles, escalating dispersant demand due to phosphate precipitation with well water iron and aluminum carryover, and excessive algae growth on the towers and the associated chlorine demand. Although we were aware of impending phosphorus regulations we continued to perfect phosphate based cooling water programs because there simply was no reasonable alternative …until now. This paper describes the development of a promising phosphorus free corrosion and deposit control program, including laboratory and field application performance data from several challenging applications.

Background

Cooling water treatment from the 1930s through the early 1980s relied primarily upon 5-500 ppm hexavalent chromium to inhibit corrosion of steel and copper alloys in conjunction with acid to maintain the pH of the system in the 6.0-7.0 range to control scale formation. In the last decades of the chromate era, zinc and polyphosphate supplements were added to support lower levels of chromate. Chromate proved to be an excellent steel and copper corrosion inhibitor, but its greatest attribute was its forgiving nature. A dosage of 50 ppm provided excellent performance and 500 ppm performed even better across the broad pH 6.0-7.0 range. An overfeed did not lead to fouling, and more corrosive conditions, even brines, could always be overcome with higher treatment levels.

As chromate was phased out due to human health concerns and zinc has been mostly phased out due to aquatic toxicity, the cooling water treatment industry in the United States and Western Europe focused primarily on phosphate-based chemistries for both corrosion and scale control. Progressive advances have led to polymers that are more efficient in maintaining higher levels of orthophosphate in solution. Organic phosphate components provide both scale inhibition and cathodic corrosion inhibition for steel. Aromatic azole supplements are used to overcome phosphate’s deficiency in protecting copper alloys.

Today’s phosphate chemistries perform adequately in most circumstances but demand precise control. The concentration of phosphate must be balanced carefully with calcium, polymeric dispersant, pH, and temperature. If all five factors are not perfectly balanced at all times and at all points in the system, either corrosion or fouling will occur. This is particularly problematic in the chemical industry due to the prevalence of high temperature, low flow bundles together with steel piping operating at much lower temperature.

Apart from unforgiving control requirements, phosphate has several additional weaknesses. Phosphate by itself is an effective inhibitor only for steel and a marginal inhibitor for galvanized surfaces. It has little or no beneficial effect on copper or aluminum corrosion. Phosphate programs often perform poorly in soft or low hardness waters, requiring much higher levels of phosphate to form an effective calcium phosphate film. Phosphate will also precipitate with well-water iron and aluminum clarifier carryover, forming deposits and causing excessive polymeric dispersant demand.
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In cooling towers, algae and cyanobacteria convert inorganic bicarbonate into organic carbon which support the growth of bacteria. The dense algae mats that form on cooling tower decks and exposed areas support higher life forms such as protozoa and amoeba which can harbor and amplify Legionella bacteria. As shown in Figure 2, halogen demand is directly proportional to chlorophyll concentration. According to Liebig’s Law of the Minimum*, restricting phosphorus entering the cooling system is an effective means for reducing algae growth and chlorine demand.

**Objective**

Considering emerging environmental restrictions on phosphorus discharge and the many shortcomings of phosphorus based cooling water treatment technologies, a multi-year research effort was undertaken to develop a versatile and totally phosphorus and zinc free cooling water treatment technology. The requirements for the program were to have no orthophosphate, polyphosphate, or organic phosphonates or phosphinates, yet be cost competitive with traditional phosphorus programs. The program also had to be non-toxic to aquatic life at 10x the nominal use concentration, with an overall Environmental Health and Safety (EH&S) profile similar to or better than current phosphorus-based programs.

**Laboratory Studies**

**Scale Inhibitor Development**

Organic phosphates have been the primary calcium carbonate scale inhibitors used by the industry since the mid-1970’s. They also serve an additional role as cathodic corrosion inhibitors for steel. Our first goal was to identify and evaluate non-phosphorus chemistries for calcium carbonate scale inhibition. Initial screening studies were conducted in heated beakers, and the most promising candidates were evaluated more carefully in a matched pair of fully instrumented pilot cooling towers (Figures 3-5).
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cial water velocity in the annular flow space was maintained at 4 fps (1.2 m/s). The test methodology was to add the scale inhibitor chemistry and cycle up the makeup water (Table 1) gradually over a three week period until a “crash point” was reached, as indicated by scale formation on the heat exchanger tubes (Figure 6). Figure 7 indicates that the best of the non-phosphorus scale inhibitors could achieve an LSI of 2.96, corresponding to 5.5 cycles of concentration on the test water.

Table 1. Makeup water used for non-P moderate alkalinity pilot cooling tower study

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
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<tr>
<td>Conductivity, μmhos</td>
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<td>P-Alk, as CaCO₃, mg/L</td>
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<tr>
<td>M-Alk, as CaCO₃, mg/L</td>
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<tr>
<td>Ca, as CaCO₃, mg/L</td>
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<td>Mg, as CaCO₃, mg/L</td>
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<td>SO₄, mg/L</td>
<td>54</td>
</tr>
<tr>
<td>SiO₂, mg/L</td>
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</table>

Corrosion Inhibitor Development

Initial screening for non-phosphorus corrosion inhibitors took place using spinner baths and electrochemical tests. The spinner bath units were operated so as to achieve a superficial velocity of 1 ft/sec at a controlled temperature. The solutions were aerated to maintain oxygen saturation. Most spinner bath tests were conducted at a bulk water temperature of 50 °C (122 °F). Corrosion inhibitor performance was also determined through Linear Polarization Resistance (LPR) measurements in cells containing rotating as well as static corrosion coupons. Most of the testing was conducted using the water chemistries shown in Table 2. Additional testing was conducted to evaluate more severe conditions by addition of supplemental chlorides and sulfates, as well as under conditions simulating field evaluation sites.

The testing focused on mild steel corrosion control. Several hundred non-phosphorus candidates were screened over a four-year period. Although many chemistries demonstrated efficacy in reducing corrosion, only a few were considered adequate phosphate replace-

ments when dosage, commercial availability, and usage cost were considered.

Figures 8 and 9 show the corrosion coupons exposed for 3 days to the untreated baseline water compared to the best performing non-phosphorus program. The baseline corrosion rate for this corrosive, ultra-soft water was found to be 60 mpy at 40 °C for mild steel. The best-performing non-P program achieved <1 mpy on mild steel and <0.1 mpy on copper.

One major drawback to conventional phosphate and zinc programs is that they can be very unforgiving in terms of deposition. In general, the only negative consequence of an overfeed of a non-P inhibitor is an increase in treatment cost. More corrosive conditions can be handled by simply increasing dosage.

Figure 5. Pilot cooling towers

Figure 6. Appearance of test heat exchanger surfaces before and after scale development “crash point”

Figure 7. Pilot cooling tower study – Calcium achieved vs. cycles of concentration
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Table 2. Water composition used for development of soft water program

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Value</th>
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<tr>
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<tr>
<td>Copper, as Cu, mg/L</td>
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<tr>
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<tr>
<td>Larson Skold index</td>
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</table>

Table 2. Water composition used for development of soft water program

Copper alloy corrosion inhibition

One weakness of phosphate is its inability to protect non-ferrous alloys. Aromatic azoles, typically TTA and BZT, must be added to the phosphate programs to protect copper alloys. This chemistry does not offer the same degree of protection for copper alloys as the heritage chromate programs under stressed conditions. Cooling programs operating in the pH 7.0-7.8 "stabilized phosphate" chemistry range frequently experience difficulties obtaining adequate copper corrosion protection especially during periods of heavy chlorination. The preferred non-P program was evaluated against the baseline stabilized phosphate-azole program in the laboratory using linear polarization resistance measurements. The test water was simulated 8-cycle Sabine River water containing 0.5 ppm free available halogen developed from sodium hypochlorite and sodium bromide. The pH of the water was maintained at 8.0-8.2 with 160 ppm alkalinity and 200 ppm calcium (as CaCO₃). As shown in Figure 10, the conventional 3 ppm azole program (red line) performed adequately at <0.1 mpy. However, the non-P program with no azole (blue line) outperformed azole alone. The combination of non-P program in conjunction with 2 ppm azole (green line) demonstrated synergistic behavior in providing the best performance at <0.01 mpy.

Figure 10. Copper corrosion inhibition comparing azole, the non-P inhibitor, and combination azole with non-P inhibitor

The electrochemical tests were confirmed in the laboratory using 3-day "spinner bath" studies (Table 3). The studies indicate that the non-P program can produce results equivalent to the baseline phosphate-azole program on both steel and copper at the same 100 ppm product dosage. However, the non-P program is more flexible. The dosage can be dialed up by 30% to produce better corrosion and deposit control protection or reduced by 35% to reduce costs with a slight sacrifice in performance.

Aluminum Corrosion Inhibition

Aluminum corrosion has been of increasing concern due to the more widespread use of aluminum alloys, particularly in closed cooling systems. Unlike steel, which becomes immune to corrosion at high pH, aluminum is an amphoteric metal that corrodes rapidly under alkaline conditions.

A 3-day spinner bath study was conducted in aerated 50 °C (122 °F) tap water to which additional 300 ppm chloride and 100 ppm additional alkalinity were added to provide more challenging conditions. The pH of the water was allowed to fluctuate in the 8.0-8.7 range.
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Corrosion coupon appearance and aluminum concentration in the test solution were used as an indication of corrosion, since aluminum coupons actually gain weight as they corrode due to precipitation. The non-P formulated product was evaluated at 100, 200, and 300 ppm product. Results are shown in Table 4. Corrosion on aluminum occurs when the protective aluminum oxide layer is damaged either mechanically or chemically. Pits on the baseline coupons were surrounded by white precipitate, suggesting that anodic sites developed in the absence of effective treatment. The non-P treatment program completely eliminated anodic pitting at the 300 ppm product concentration.

**Table 3. Results of baseline phosphate vs. non-P programs in a 3-day spinner study**

<table>
<thead>
<tr>
<th>Treatment Program</th>
<th>Coupons Copper / Steel</th>
<th>Corrosion (mpy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline PO₄ 100 ppm Products</td>
<td>AdminAl 0.32</td>
<td>Steel: 2.1</td>
</tr>
<tr>
<td>Non-P 65 ppm Product</td>
<td>AdminAl 0.35</td>
<td>Steel: 4.05</td>
</tr>
<tr>
<td>Non-P 100 ppm Product</td>
<td>AdminAl 0.13</td>
<td>Steel: 1.21</td>
</tr>
<tr>
<td>Non-P 130 ppm Product</td>
<td>AdminAl 0.07</td>
<td>Steel: 0.85</td>
</tr>
</tbody>
</table>

**Table 4. Effectiveness of non-P chemistry on aluminum corrosion**

<table>
<thead>
<tr>
<th>Treatment Program</th>
<th>Coupons AI / AI</th>
<th>Aluminum ion in water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>2 ppm</td>
<td></td>
</tr>
<tr>
<td>Non-P 100 ppm Product</td>
<td>0.31 ppm</td>
<td></td>
</tr>
<tr>
<td>Non-P 200 ppm Product</td>
<td>0.07 ppm</td>
<td></td>
</tr>
<tr>
<td>Non-P 300 ppm Product</td>
<td>&lt;0.05 ppm</td>
<td></td>
</tr>
</tbody>
</table>

**Corrosion Control Mechanism**

Electrochemistry studies were used to elucidate the corrosion inhibition mechanism of the new treatment chemistry on steel. As shown in Figure 11, the corrosion inhibitor package inhibits both the anodic and cathodic corrosion processes, showing the tendency to form a particularly strong passive film on the anodic region.

**Figure 11. Electrochemical study of non-P inhibitor on steel**

**Field applications of non-P Programs**

1. **Low hardness, Low alkalinity Corrosive Water Application**

The best performing non-P program in the laboratory was formulated as a commercial product and taken to a field evaluation in a corrosive water application where phosphate discharge was becoming a concern. The small 2-cell Evapco cooling tower servicing a HVAC system was using a conventional phosphate-based program and obtaining marginal results of 3.4 - 4.6 mpy on mild steel. Process conditions made it difficult to obtain the consistent chemistry required by phosphate-based programs, and the small size of the system made it difficult to justify automating the chemical dosing systems. The non-P program improved performance to 1.4 mpy on mild steel and <0.01 mpy on copper. Thermal performance of
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critical heat exchangers has shown no decline in performance since transitioning to the non-P treatment program. Figures 12 and 13 show the copper and steel coupons after a 64-day exposure.

2. High Hardness, High Sulfate Corrosive Water Application

A Midwest cogeneration plant faced stringent phosphate discharge regulations. The unclarified makeup water was high in calcium and alkalinity, requiring sulfuric acid for pH control. The resulting cooling water was relatively corrosive due to high sulfates from the use of acid. The circulating water is shown in Table 6.

Steel corrosion rates on the baseline low-phosphorus program were averaging about 10 mpy (Figure 14). Upon changing to the non-P chemistry, corrosion rates have been reduced to a 2 mpy average on steel (Figure 15) and 0.1 - 0.2 mpy on copper.

3. Gulf Coast Chemical Plant

The formulated product was evaluated at a Gulf Coast chemical plant cooling tower operating at 9 cycles on clarified Sabine River water. The water is relatively corrosive and several heat exchangers with high temperatures have been prone to deposition over the years. Although the corrosion results have been excellent in the past, the plant wanted to use a more forgiving, non-fouling program. Corrosion coupon results have been excellent, with steel coupons showing rates of 1.07 mpy for the first 35 days, 0.89 mpy for the second 32 days, 0.80 mpy for the third 32 days, and 0.32 mpy for the first 99-days. Critical heat exchanger approach temperatures have remained flat. Figure 16 shows the appearance of the initial steel coupon after 35 days before and after cleaning.

4. High iron in well water application

Well water iron poses a special challenge for phosphate-based treatment programs. The reactive iron precipitates the phosphate corrosion inhibitor, rendering the phosphate ineffective and creating a sticky iron phosphate precipitate that creates additional polymer demand and tends to precipitate on heat transfer surfaces. Non-phosphorus treatment programs are particularly suited to such applications because the corrosion inhibitor does not react with the iron and the dispersant is only required to disperse the iron itself.
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rather than precipitated iron phosphate. A Gulf Coast air separation plant with 2-5 ppm iron in its well water was experiencing heat exchanger fouling problems on a phosphate based treatment program. The problems were severe enough to require shutdowns to clean the exchangers. Figure 17 shows the last set of coupons removed from the phosphate program with heavy deposition and obvious corrosion.

The treatment program was converted to the non-phosphorus program with the addition of a non-P supplemental dispersant for iron. Results on both corrosion and fouling have improved substantially. Figure 18 shows the first coupon set removed after 35 days.

Table 8. Cooling water chemistry
A Gulf Coast chemical plant was experiencing elevated steel corrosion rates in their jacket water cooling system, typical for a phosphate program. The corrosion rate was 6.8 mpy on steel coupons, resulting in nearly 4 ppm iron in the cooling tower water. The phosphate based program was overlaid with the non-P corrosion inhibitor program. Iron levels in the tower dropped to 0.5 ppm as shown in Figure 21, and the corrosion rate on the first 28-day coupon was reduced to 1.34 mpy.
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<table>
<thead>
<tr>
<th>Feature</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inherent Corrosion Resistance</td>
<td>ATEX Certified</td>
</tr>
<tr>
<td>Smoother Operation</td>
<td>High Misalignment Capability</td>
</tr>
<tr>
<td>UV Stabilized</td>
<td>Easy Installation</td>
</tr>
<tr>
<td>Superior Fatigue Life</td>
<td>High Strength to Weight Ratio</td>
</tr>
</tbody>
</table>

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Figure 20. Approach temperature trend on the non-P program system transitioning to non-P program overlay.

Figure 21. Cooling tower iron level for jacketed vessel cooling.

Table 9. Cooling Tower Chemistry for Jacketed Vessel

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.0</td>
</tr>
<tr>
<td>Conductivity (µhmhos)</td>
<td>1500</td>
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<tr>
<td>Ca, as CaCO₃, mg/L</td>
<td>150</td>
</tr>
<tr>
<td>&quot;M&quot;-Alk, as CaCO₃, mg/L</td>
<td>175</td>
</tr>
<tr>
<td>Sodium, as Na, mg/L</td>
<td>225</td>
</tr>
<tr>
<td>Chloride, as Cl, mg/L</td>
<td>270</td>
</tr>
<tr>
<td>Sulfate, as SO₄, mg/L</td>
<td>150</td>
</tr>
<tr>
<td>Total P, as PO₄, mg/L</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 9. Cooling Tower Chemistry for Jacketed Vessel.
Aquatic Effects and EH&S Since the initial goal of the program was to develop an environmentally sound alternative to phosphate treatment programs, one of the major criteria was to have minimal aquatic effects, including mortality to EPA marker organisms, minimal human exposure hazards, no zinc, and no phosphorous in any form. A range of formulated products have been developed around the basic non-P corrosion inhibitor technology. Most are formulated at a mildly acidic pH. This is considerably less hazardous than most of the products it replaces, which must be formulated under strongly caustic or strongly acidic pH. The cautionary wording is considerably less onerous, and the HMIS rating is typically 1-0-0-0. The basic formulated product is applied at a nominal dosage of 100 ppm. The LD50 acute effect concentration is approximately 3,000 mg/L for both Ceriodaphnia and fathead minnow, and the 7-day chronic no-effect level for fathead minnow is 3,500 mg/L. Another version of the formulated product is also totally nitrogen free, including no azole and no acrylamide or AMPS containing polymers. The LD50’s of that non-N and non-P product are 3,700 mg/L for Ceriodaphnia and 6,300 mg/L for fathead minnow. The significant safety margin between application dosage and aquatic effect concentration, the total absence of phosphorus and even nitrogen, and the mildly acid formulation should enable the products to be applied safely and discharged under current US regulations.

Conclusions
Practical non-phosphorus cooling water treatment programs have been developed to comply with emerging regulatory restrictions. Non-phosphorus chemistry offers several key benefits in addition to environmental compliance. Most importantly, these non-P programs:

- Are non-fouling with a broad control band
- Do not contribute to algae growth either in the environment or in the cooling tower, thus resulting in lower chlorine demand
- Are effective in zero hardness or high hardness waters
- Effective on steel, copper, and aluminum
- Are not affected by well-water iron or aluminum carryover
- Form a more persistent film, treating the surfaces rather than the bulk water
- Have minimal aquatic effects and a favorable EH&S profile
- Provide superior performance to phosphate based programs.

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1. Introduction
A new cooling power plant subservient to the “Accident & Emergency” building with replacement of the existing cooling towers to be built at the Catholic University General hospital “Agostino Gemelli” in Rome, in largo Agostino Gemelli, n. 8. The client wants to evaluate compliance with the specifications and regulations of the new air conditioning systems that will be installed, from the point of view of noise.

The contract includes installation of new machines, resulting in a noise reduction of at least 8 dBA compared to the noise of the existing plants.

Various sound level measurement has been carried out in the hospital area during the night to characterize the existing refrigeration cooling tower units and to detect the residual noise of the area.

The first data recorded is considered a reference for comparison with the results of the estimates, while the residual noise was used in order to build the prediction emission scenario.

The noise model prediction is created using the software CADNA and appropriate algorithms.

The new source emission data has been provided by the water cooling tower manufacturer.

The estimation of environmental noise expected as a result of the installation of four new towers and new fridge plants, resulting from the noise scenario, was compared with the sound levels currently present, also in order to verify compliance with the noise limits established by applicable Laws.

2. Work activity description
The work includes three phases: 1) Construction of a new cooling power plan, 2) Replacement of cooling towers; 3) local generator enlargement

2.1 Construction of a new cooling power plant
The new plant includes the installation of three new absorption chillers.

The installation of pump assembly for the chilled water circuit and the circuit water tower have been planned as service of new absorption units.

Hot water pumps are also provided. Connections to existing pipelines will be carried out by the construction of a tunnel installation inspection that will be installed in the basement of the Accidents & Emergency building.

2.2 Replacement of cooling towers
The project involves the replacement of the five existing towers with four new towers, which should allow 8 dBA noise reduction.

The new configuration includes:
- Three cooling towers (TR1-TR2-TR3 Figure 1) engines 15 kW, with modules equipped with three fans;
- A cooling tower operating on two groups dedicated to the refrigerator after cooling batteries, motors 5.5 kW and module equipped with two fans.

2.3 Local generator enlargement
The project also includes expansion of the existing space and the installation of a new electric generator.

3 Sources noise emission
The machines that will be installed are characterized, from the noise point of view, to the acoustic emission data provided by the manufacturer (table 1).

This data shows the noise measured at 1.5 meters and at a height of 4 metres above ground level.

The data in Table 1 shows the number of machines installed, brand name, series, and acronyms, in reference to Figure 1.

4 Characterization measurements of the current sources and residual noise
The sources analyzed are of the current cooling towers TE1, TE2, TE3, TE4, TE5 subservient to the Accident & Emergency building of The General Hospital A. Gemelli.

During the noise surveys: no. 7 pumps, 9 large tower fans, (TE1, TE2 and TE3) and 4 small tower fans (TE4 and TE5) were put in operation.

The evaporation tower noise is characterized by the contribution of two types of sound sources (figure 7):

1) Fan noise;
2) Water Noise.

The first contribution, "fan noise", is the sound of low / mid frequencies and longer frequencies passing through walls and obstacles, that it is difficult to mitigate, and propagates from the top.

The second contribution "water noise" is a noise at height frequencies, depending on water loading (Q/A), that naturally attenuates with distance, that is masked easily with simple barriers, and propagates from below.

Regarding the above situation, in order to better the sound source characteristics in the 3 survey points, two measurements of LeAq are carried out contemporaneously, both at a height of 1.5 meters to
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better emphasize the contribution of the "water noise", at a height of 4 meters for the contribution of the "fan noise".

The measurement taken at 4 meters was carried out in order to eliminate the source of wind uncertainty, with the microphone outside the discharge zone at high air velocity, also in reference to the specific standard ATC-128 (Cooling Technology Institute Standard).

4.1 Measuring points

The choice of measuring points was established in reference positions that showed the best accessibility condition during the inspection, also considering the future space destination project, necessary for post work measurements and the receptor location. Therefore, 3 points were chosen around the evaporation towers (Figure 9-10).

- Point 1: Next to stairs - location northeast, about 6.5 m from the center of TE2
- Point 2: Next to local QE - Southeast location about 7.5 m from the center TE2;
- Point 3: Next to path Heliport - location north - west, about 5 m from the center TE2.

4.2 Working conditions during the measurements

The sound level measurements took place during the night (from 10:00 pm to 6:00 am). The measurements were made at two heights to better characterize the source.

During the measurement there were: n. 7 pumps, n. 9 fans large towers and n. 4 small towers fans in operation.

From the data of the measurements performed, as expected, there was a higher sound level of the measurements performed at 4 meters, compared to 1.5 meters (Figures 11-13), the latter are characterized by a greater contribution of low frequencies (Figures 14).

The sound measurements with current cooling towers were carried out in order to compare the sound levels obtained, with those expected as a result of the replacement with four new Super silent towers.

5 Acoustic Municipal classification

The legislation establishing the criterion of zoning, each municipality must divide its territory into six classes, each subject to a different noise limit.

The hospital area acoustic class, is class I acoustic zoning of the City of Rome: "special protect-ed areas".

This class includes the areas where tranquillity is a basic element for: hospitals areas, schools, relax and leisure areas, rural residential areas, areas of particular interest in urban planning, public parks, etc..

The noise limits are very low especially at night-time (10.00 pm to 6:00 am) when the input value must not exceed 40 dBA at the receptor.

6 Provisional scenarios

For the acoustic modelling a calculation software based on the principle of ray tracing has been used. A ray tracing algorithm discretization was employed to calculate energy emitted by a source and it is used to calculate the sound field at a point as a superposition contribution of the various rays that pass through the same point. The rays traced during their path undergo an energy attenuation content due to geometric divergence, because of the reflection effects, attenuation due to dissipation in the middle, effect of the soil and of any obstacles, weather effects and effects related to the diffraction phenomena. The path of each individual beam shows how much the incident wave is attenuated from a given source of noise.

For the study of the noise source emission and noise propagation, the software has the main algorithms validated on a national and international level. Among these, those recommended by the Euro- pean Commission are included, in particular the methods of calculating "NMPB - Routes 96 - Guide du bruit" for vehicular traffic; the norm "ISO 9613-2" for the calculation of the noise from industrial sources, and the method of calculation Dutch "RMR" for rail traffic noise.

Operating conditions specified in the model (Figure 15):

- Water tower pumps as a function 6 of 9 (2 for each tower): E1 to E6;
- Chilled water pumps in operation depending on n. 3 to 6 (1 for each refrigeration unit): E15 to E17;
- Superheated water pumps running 1 of 3: S1;
- Evaporation Tower in operation n. 4 of 4: TR1 to TR4;
- All 3 Chillers running: AS1 to AS3.

6.1 Estimated noise and measured values Comparison

The results obtained by calculation software CADNA 4.0 for environmental noise (LA'), (represented in the scenario fig. 15), are compared with environmental noise measurements (LA) carried out at the same reference points, on the 18th day / April 19, 2013 on the existing towers (table 2).

7 Noise Reduction

According to the results of table 2, to ensure the noise reduction of 8 dBA it is necessary to take some action, such as cover panels of refrigerator groups and silencer installations.

7.1 Refrigerator group cover panels

Internal sound absorbing panelling will be installed to the chillers as shown in table 3. PGB PWD-F sound-absorbing and sound-insulating mineral wool panels.

The panels are made of two layers of steel enclosed between a mineral wool insulation with staggered joints oriented fibres and high density.

The panels for the roof are of curved type insulation: CTD5 roofing system insulated panels "Mar-cegaglia" a single span, double-hinged arch (Figure 16).

7.2 Silencer Installation

In order to reduce the tower noises optional abatement systems must be installed, circular absorbing silencers with nose cone, installable in expulsion to the fan.

The circular silencers, SLN used in expulsion, are mounted above the diffuser using threaded inserts on the heads of the same mufflers. They are characterized by optimum noise attenuation, low pressure drop and high strength construction (figure 17). These types of silencers are available in two series: SLN without nose cone (N), and with SLN nose cone (O), with lengths equal to one or two times the diameter.
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In this case study silencer nose cone models are used, 1400 mm nominal diameter, because they have a stronger ability of noise attenuation compared to models without a nose cone (table 4). The standard construction is galvanized steel and the special sound-absorbing material is mineral fibre protected by perforated sheet metal.

8 Conclusions
This paper concerns the forecast evaluation of noise impact in order to establish compliance with terms of contract and the currently applicable laws on noise, about new air conditioning systems that will be installed following the construction of a modern refrigeration system subservient to the Accident & Emergency building at the General Hospital A. Gemelli in Rome.

We have described the different actions of the project showing the lay-out of the machines (Figure 1), and their emission sound levels at a distance of 1.5 m and 4 m above ground level (table 1).

To characterize the existing cooling towers of the refrigeration unit and to detect the residual noise of the area, various sound level measurements were carried out during the night.

The measurements of the residual noise and emission data of the new sources (certified by the manufacturer) are combined to build the emission prediction model, using the software CADNA DataKustik vers. 4.0, and appropriate algorithms.

The acoustic modeling of the area, has produced a scenario for the weekly night-day period (fig. 15), where sound isolevel surfaces (equal loudness) with colors representing the various noise levels are shown as indicated in the key. The model shows numeric text boxes of the noise levels expected of the control points placed exactly in the same positions of the measurement points used on the current machines.

The estimated values of environmental noise, obtained from this prognosis study, concerning the installation of four new towers and new fridge plants are compared with the actual sound levels measured.

This comparison shows a reduction in the three control points ranging from 5.1 to 6.4 dBA with an average of about 5.8 dBA, therefore less than 8 dBA guaranteed by contract.

Therefore, to ensure the right noise reduction some mitigation is required:

1. Coverage of the refrigeration unit, panels of insulating materials;
2. Install additional abatement systems for cooling towers, such as sound-absorbing circular silencers with nose cone.

These actions will ensure a certain reduction of more than 3 remaining dB to comply with the agreements (estimated at least 5-6 dB). Unfortunately up to now the silencers have not yet been installed, and so it is not yet possible to perform measurements of the actual noise abatement. But thanks to our provisional acoustic study it could help the manufacturer indicate the necessary action to ensure compliance in the contract of the client.

9 References
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2 Papa A, Mariconte R., Metodologie di valutazione dell’immissione di rumore a bassa frequenza, 39° Congegno Nazionale dell’ Associazione Italiana di Acustica, Roma (2012);
3 Papa A, Mariconte R., Le valutazioni di clima e di impatto acustico: strumenti e problematiche connesse, 10° Congresso Nazionale CIRIAF, Perugia (2010);
4 Papa A, Mariconte R., Impiego dei modelli previsionali per la valutazione del clima ed dell’impatto acustico, 1° Congresso Nazionale sulla Governance del Rumore Ambientale; Ischia (2009);

10 Figure and Table Attached
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Figure 14: P3 measuring point - environmental noise level Spectrum Comparison

Figure 15: Post-work night environmental noise Scenario with equal loudness curves and Marker sound levels in the control points

Figure 16: Cover panels CTD5 schematic representation

Figure 17: Silencer scheme

Figure 18: Silencer Photo

Table 1: Acoustic emissions certified by the manufacturers of new sound sources

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<tr>
<th>Reference/measure point</th>
<th>LA pre-work measured</th>
<th>LA’ post-work estimated</th>
<th>LA - DB</th>
<th>Noise reduction</th>
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<td>1</td>
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<td>72,2 dBA</td>
<td>6,4</td>
<td>6,4 &lt; 8</td>
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<tr>
<td>3</td>
<td>79,8 dBA</td>
<td>74,0 dBA</td>
<td>5,8</td>
<td>5,8 &lt; 8</td>
</tr>
</tbody>
</table>

Table 2: Points of reference/measure expected values Differential level

<table>
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<tr>
<th>Spessore Thickness (mm)</th>
<th>a (medio average)</th>
<th>Δ La</th>
<th>Rw (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0,87</td>
<td>13,35</td>
<td>33</td>
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<td>80</td>
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</tr>
<tr>
<td>100</td>
<td>1,03</td>
<td>20,12</td>
<td>34</td>
</tr>
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</table>

Table 3: Acoustic characteristics cooling unit coverage area paneling PGB PWD-F

<table>
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<tr>
<th>Nominal Diameter</th>
<th>Type</th>
<th>Length</th>
<th>Octaves (Hz)</th>
<th>Dynamic insertion loss (dB)</th>
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<td>6 13 21 18 12 11 10</td>
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<tr>
<td>SLN/1400(D)</td>
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<td>4</td>
<td>4 6 11 20 19 15 13 11</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Silencer Acoustic performance
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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 insure CTI Tests are conducted in a fair, unbiased manner. Cooling tower owners and manufacturers are strongly encouraged to utilize the services of the licensed CTI Cooling Tower Performance Test Agencies. The currently licensed agencies are listed below.

**Licensed CTI Thermal Testing Agencies**

<table>
<thead>
<tr>
<th>License Type*</th>
<th>Agency Name</th>
<th>Contact Person</th>
<th>Telephone</th>
<th>Fax</th>
</tr>
</thead>
<tbody>
<tr>
<td>A,B</td>
<td>Clean Air Engineering</td>
<td>Kenneth Hennon</td>
<td>800.208.6162</td>
<td>885.938.7569</td>
</tr>
<tr>
<td></td>
<td>7936 Conner Rd</td>
<td><a href="http://www.cleanair.com">www.cleanair.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Powell, TN 37849</td>
<td><a href="mailto:knennon@cleanair.com">knennon@cleanair.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A, B</td>
<td>Cooling Tower Technologies Pty Ltd</td>
<td>Ronald Rayner</td>
<td>61 2 9789 5900</td>
<td>61 2 9789 5922</td>
</tr>
<tr>
<td></td>
<td>PO Box N157</td>
<td><a href="mailto:coolingtwttech@bgpond.com">coolingtwttech@bgpond.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bexley North, NSW 2207</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AUSTRALIA</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>A, B</td>
<td>Cooling Tower Test Associates, Inc.</td>
<td>Thomas E. Weast</td>
<td>913.681.0027</td>
<td>913.681.0039</td>
</tr>
<tr>
<td></td>
<td>15325 Melrose Dr</td>
<td><a href="http://www.cttai.com">www.cttai.com</a></td>
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</tr>
<tr>
<td></td>
<td>Stanley, KS 66221-9720</td>
<td><a href="mailto:cttai@ao.com">cttai@ao.com</a></td>
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<tr>
<td></td>
<td>4700 Coster Road</td>
<td><a href="http://www.mchale.org">www.mchale.org</a></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Knoxville, TN 37912</td>
<td><a href="mailto:bernie.pastorik@mchale.org">bernie.pastorik@mchale.org</a></td>
<td></td>
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* Type A license is for the use of mercury in glass thermometers typically used for smaller towers.

**Licensed CTI Drift Testing Agencies**

<table>
<thead>
<tr>
<th>Agency Name</th>
<th>Contact Person</th>
<th>Telephone</th>
<th>Fax</th>
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<tbody>
<tr>
<td>Clean Air Engineering</td>
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<tr>
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<td><a href="mailto:knennon@cleanair.com">knennon@cleanair.com</a></td>
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<tr>
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<tr>
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<td><a href="http://www.mchale.org">www.mchale.org</a></td>
<td><a href="mailto:bernie.pastorik@mchale.org">bernie.pastorik@mchale.org</a></td>
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<tr>
<td>Knoxville, TN 37912</td>
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STD-202: Standard for Publication of Custom Cooling Tower Thermal Performance Test Results

In the past, more than half of custom field-erected cooling towers have been tested at less than 100% thermal capacity. CTI has developed Standard STD-202 to encourage cooling tower capacity of 100% or better.

Custom cooling towers built by the Participating Manufacturers are field tested for thermal performance by CTI Licensed Test Agencies and the results are published in accordance with this Standard.

This program provides specific benefits to owners/operators of custom field-erected cooling towers. Performance testing will highlight the difference between the specified thermal performance guarantee and actual performance, increased power generation due to proper cooling tower performance, increased heat exchanger efficiency due to lower entering temperatures and lower energy consumption of the entire system.

This is a voluntary program. For the period of this publication of results, the Participating Manufacturers are:

- Composite Cooling Solutions, L.P.
- EvapTech, Inc.
- SPX Cooling Technologies, Inc.

SPECIFY CTI STD-202 FOR YOUR COOLING TOWERS PER RECOMMENDATIONS IN THE STANDARD:

PM in CTI STD-202. The cooling tower vendor shall be a Participating Manufacturer (PM) in the Cooling Technology Institute (CTI) STD-202 program for Publication of Custom Tower Thermal Performance Test Results, as validated by listing as such on www.cti.org.

Thermal Performance Acceptance Testing. The cooling tower shall be subject to acceptance testing conducted by a CTI Licensed Thermal Performance Testing Agency, according to the latest edition of CTI ATC-105. Such testing shall occur within one year of commercial operation of the cooling tower.

<table>
<thead>
<tr>
<th>Participating Manufacturer</th>
<th>Composite Cooling Solutions, L.P.</th>
<th>EvapTech, Inc.</th>
<th>SPX Cooling Technologies</th>
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<td>From 11/1/2012 to 10/31/2013</td>
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<td>% of tests ≥ 100% Capacity</td>
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<td>100</td>
<td>100</td>
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N.A. = At the time of this publication the minimum number of CTI licensed tests required by STD-202 have not been performed.
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.

The history of the CTI STD-201 Thermal Performance Certification Program since 1983 is shown in the following graphs. A total of 36 cooling tower manufacturers are currently active in the program. In addition, 8 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 89 product lines plus 13 product lines marketed as private brands which result in more than 18,029 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.
NUMBER OF CTI CERTIFIED PRODUCT LINES

Through 6/30/2014

Private Brands
Manufacturer Brands

NUMBER OF CTI CERTIFIED TOWER MODELS

Through 6/30/2014

Private Brands
Manufacturer Brands

YEAR
NUMBER OF CTI CERTIFIED TOWER MODELS

YEAR
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<th>Manufacturer</th>
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<th>Revision Number</th>
<th>Date</th>
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<td>Aggreko Cooling Tower Services</td>
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<td>Amot Cooling Tower Corporation</td>
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<td>American Cooling Tower Inc.</td>
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<td>Delta Cooling Tower, Inc.</td>
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<tr>
<td>Bell Cooling Tower Pvt Ltd</td>
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<td>Devsa</td>
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<td>Elemeco Technologies (Beijing) Co., Ltd.</td>
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<td>GEA Polecil Cooling Towers B. V.</td>
<td>CF Line</td>
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<td>Guangzhou Laxun Technology Export Company, Ltd.</td>
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<td>Hunan Yuanheng Technology Development Company, Ltd.</td>
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<tr>
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<td>Vertico Systems</td>
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<td>York (By Johnson Controls)</td>
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<td>Zhejiang Wuxingang Science and Technology Company, Ltd.</td>
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<td>September 9, 2013</td>
<td>Closed Circuit</td>
<td>8</td>
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</tbody>
</table>
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<th>Unit Price</th>
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<td>CTI Member</td>
<td>$395</td>
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