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CTI Journal

Summer Vol. 40, No. 2

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The CTI Journal

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It is CTI's objective to: 1) Maintain and expand a broad base membership of individuals and organizations interested in Evaporative Heat Transfer Systems (EHTS), 2) Identify and address emerging and evolving issues concerning EHTS, 3) Encourage and support educational programs in various formats to enhance the capabilities and competence of the industry to realize the maximum benefit of EHTS, 4) Encourage and support cooperative research to improve EHTS Technology and efficiency for the long-term benefit of the environment, 5) Assure acceptable minimum quality levels and performance of EHTS and their components by establishing standard specifications, guidelines, and certification programs, 6) Establish standard testing and performance analysis systems and prcedures for EHTS, 7) Communicate with and influence governmental entities regarding the environmentally responsible technologies, benefits, and issues associated with EHTS, and 8) Encourage and support forums and methods for exchanging technical information on EHTS.

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Letters to the editor and manuscripts for publication should be sent to: The Cooling Technology Institute, PO Box # 681807 Houston, TX 77268.

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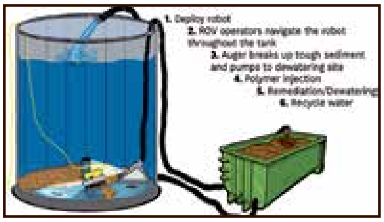

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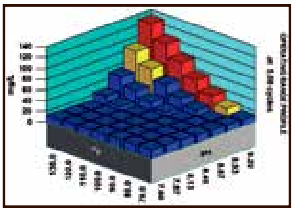

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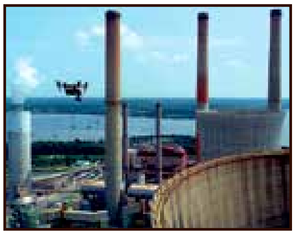

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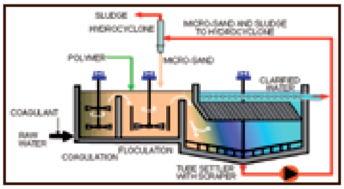

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For Immediate Release
Contact: Chairman, CTI
Multi-Agency Testing Committee
Houston, Texas

2-September-2019

Cooling Technology Institute, PO Box 681807, Houston, Texas 77268 – The Cooling Technology Institute announces its annual invitation for interested thermal testing agencies to apply for potential Licensing as CTI Thermal Testing Agencies. CTI provides an independent third party thermal testing program to service the industry. Interested agencies are required to declare their interest by March 1, 2019, at the CTI address listed.

Future Meeting Dates

Committee Workshop	Annual Conference
July 12-15, 2020 Steamboat Grand Steamboat Springs, CO	February 9-13, 2020 The Westin Galleria Houston, TX
July 11-14, 2021 The Inn at Loretto Santa Fe, NM	February 7-11, 2021 Sheraton New Orleans, LA
	February 7-11, 2022 The Westin Galleria Houston, TX

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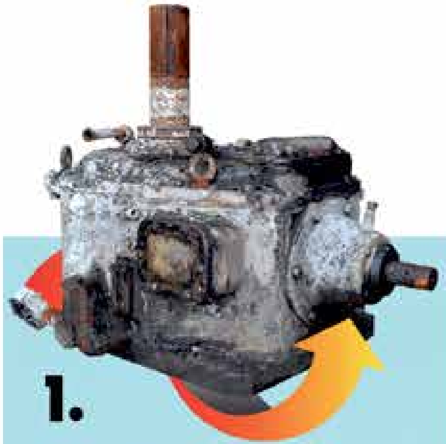

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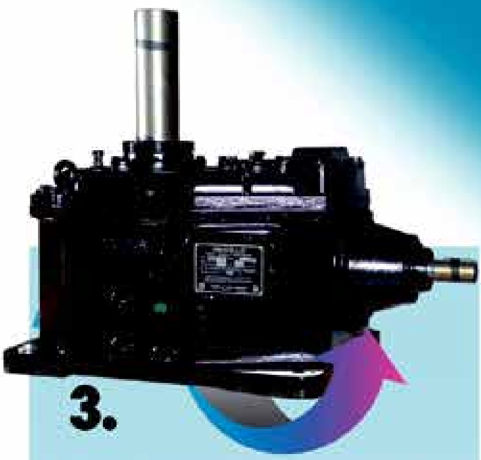

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View From The Tower

Part of CTI's mission includes "advocacy and dialog on the benefits of cooling technologies with government agencies and other organizations with shared interests". In this issue, the Editor's Corner highlights some of the advocacy that CTI has been performing. On behalf of the CTI members, I thank those advocates who spend hours on phone conferences, attendance at outside organizations or government meetings, and developing response documents in support of our CTI interests.

We are all familiar with continuous improvement. CTI recognizes this and is working to make improvements through all segments of the organization. We are actively upgrading our website and working on a members' area. We are developing a regulatory update publication focusing on activity that impacts cooling technologies. To keep up with a fast-paced world, both the Long-Range Planning Committee (LRPC) and Strategic Issues Task Force (SITF) will be meeting every other year before the October Board of Directors meeting. This will increase the speed and processing of new ideas and action items. Previously, these two groups met in brain storming sessions about every five years in addition to the quarterly conference calls which will continue. We look to expand our outreach with other organizations through presentations and reciprocal attendance. The Product and Materials Certification Committee is proceeding with selection of the FRP Certification Process as we finalize the testing protocols.

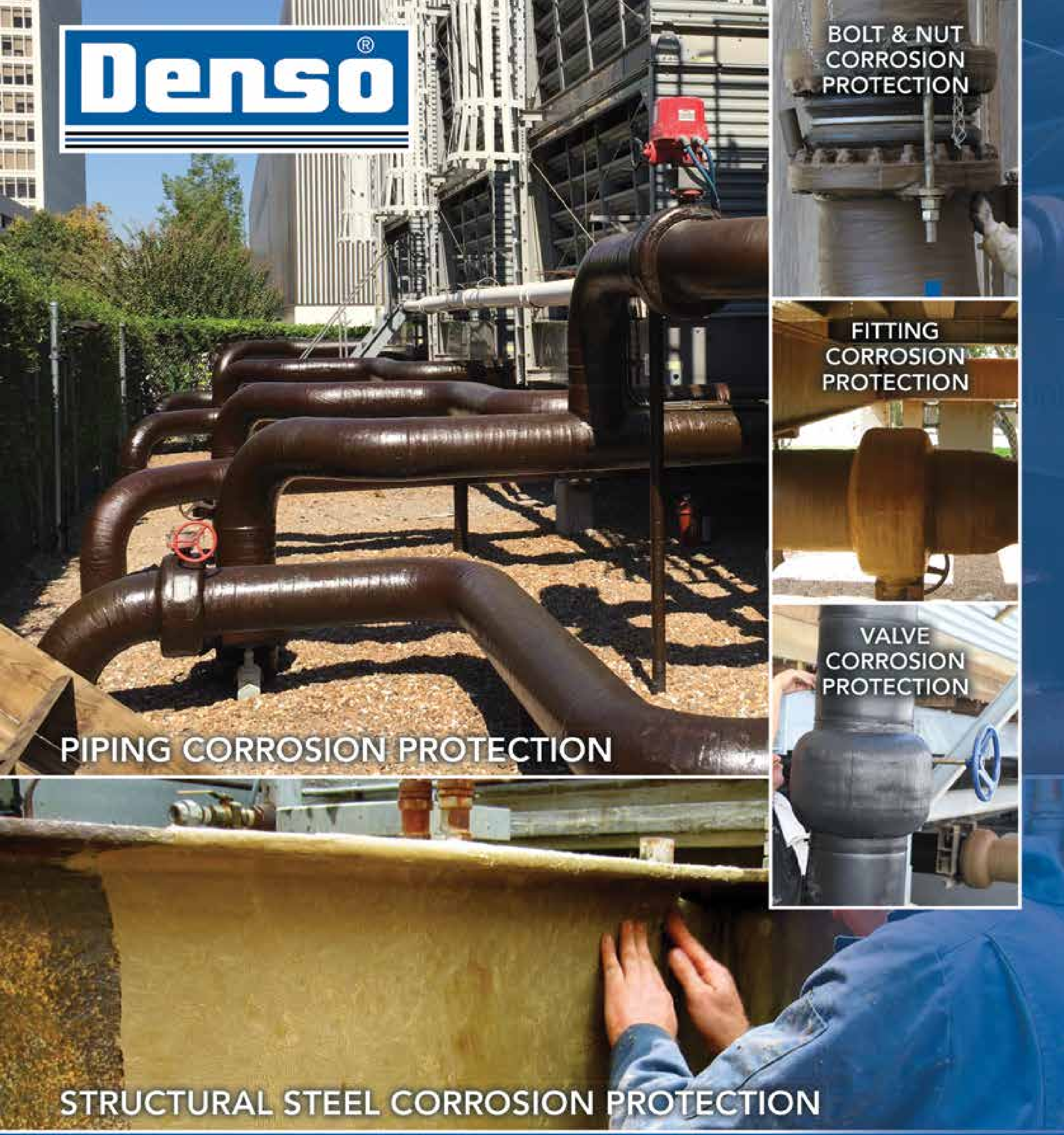
I thank all those who participate in the above-mentioned activities and those who contribute to CTI's continued success, which could not be possible without the past contributions of others. I note the passing of Paul Puckorius, a pioneer in our industry, one of the first water treating members of CTI, Past President, and Honorary Life Member. We will miss Paul's participation during our program sessions as we recognize all his contributions to the organization. I extend sincere condolences to his family and friends. We recognized Ed Schinner with a Lifetime Honorary Member award at our meeting in New Orleans. In his remarks, he noted significant events of the CTI from broadening our organizational scope to establishing the thermal certification program which leveled the playing field for the industry. It was informative to hear Ed's perspective of the CTI's history, including that of all his professional organizations, he enjoyed CTI the most – "the meetings were always fun, good people, social gatherings, mutual respect and friendships".

Let's keep that atmosphere going and establish more significant events!

I hope to see you in Memphis and again February 9-13, 2020 at the Westin Galleria in Houston!

Respectfully,

Helen Cerra
CTI President 2018-2019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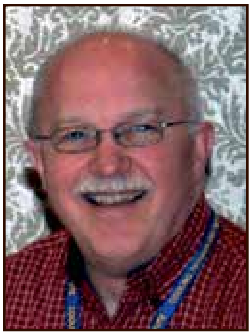
Editor's Corner

Dear Journal Reader,

CTI meets in Memphis this July. We look forward to seeing you there.



Following the recent Editor's Corner format, some of the highlights of recent activity are as follows:

So far, California has, after input from CTI and other organizations, stayed true to the term sheet with DOE in which heat rejection equipment is excluded from their fan regulations per the CTI definitions (Title 20). Title 24 covers building energy efficiency, and we expect them to re-open pursuit of increased minimum efficiency for cooling towers, with which CTI is engaged.

ASME proposed a change to remove the exemption for small diameter tubing and equipment to the Boiler and Pressure Vessel Code. For many years, this exemption has led to the design of small diameter tubing and equipment to other standards without adverse safety issues. CTI, along with multiple other organizations, commented against the proposed rule change. At a meeting this fall, the governing ASME committee effectively deferred any action to a time after the 2019 code is final. ASME did not drop this, and it is already in discussion in the ASME committee for the next cycle. CTI is engaged.

On the Legionella management front, the CTI and ASHRAE guidelines are moving toward completion this year. Another document by NSF International, Standard 444, was in progress for multiple building water hazards, including Legionella. This standard is now ASHRAE SPC514, with a target of completion within 2 years. The membership, which includes some previous NSF members and new members under the ASHRAE process, is in process, and the committee will begin shortly as an ASHRAE standards committee.

The new Pitot tubes using the tip design resulting from the CTI funded research project are now in use on a global basis. Additional research is in progress to refine the application of calibration data using the new design.

As many of you know, quite a few of you in our industry have been sharing old pictures and other information about the early history of cooling towers with me. Please continue to share what you find. I hope to have some things to share in 2019. FYI, some pre-1900 pictures from Europe and the United States are in hand so far, as the oldest.

Respectfully,

Paul Lindahl, CTI Journal Editor

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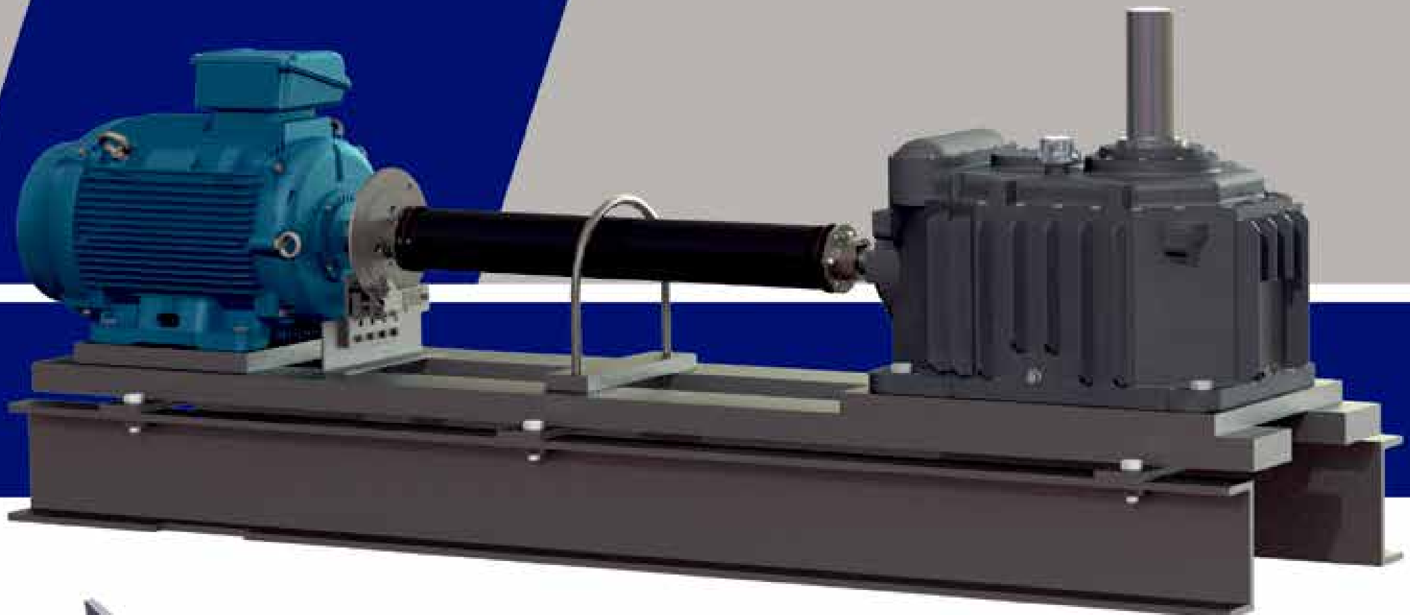

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Adiabatic Fluid Coolers And Condensers: Impact of Pad System Design on Saturation Efficiency and Unit Operation

Trevor Hegg, Gordon Struder, Jennifer Hamilton, Chad Nagle and Pat Strine; Evapco, Inc.

Jennifer Hamilton

Introduction

- What are adiabatic pads and what do they do?
- What variables affect adiabatic pad performance?
- Is saturation efficiency all that matters to adiabatic fluid cooler or adiabatic condenser thermal capability?

Closed circuit coolers and refrigerant condensers which utilize air-cooled heat exchange are growing in popularity for various reasons, but mainly to conserve water. However, in climates with high ambient temperatures, air-cooled heat exchangers require too much capital cost, consume too much energy and/or require too much plan area. In many cases, incorporating adiabatic pads on an air-cooled heat exchanger (a.k.a., an adiabatic fluid cooler or refrigerant condenser) is the best solution to balance costs, energy consumption and the size or number of units required.

Figure 1: Typical Adiabatic Air-cooled Heat Exchanger

Executive Summary

A surprisingly wide range of claimed saturation efficiency was discovered for adiabatic pads during an investigation of various adiabatic pad designs and suppliers. Therefore, an extensive adiabatic pad test program was conducted to help understand actual/verified pad performance and the variables which impact pad performance.

Because adiabatic pad performance has a direct impact on adiabatic unit performance, verified pad performance should be considered a fundamental building block for any thermal ratings methodology expected to yield 100% fully rated dry and adiabatic performance for units utilizing adiabatic pads.

The adiabatic pad test program included testing ten pad designs from four adiabatic pad suppliers (3 pad designs from each of two suppliers and 2 pad designs from each of the other two suppliers). The independent research contained in this report is offered for the benefit of industry, and to de-mystify some of the variables surrounding adiabatic cooling technology which have been misrepresented in the marketplace. It is important for manufacturers, specifiers and owners/end users to remember that an adiabatic fluid cooler or refrigerant condenser is no more than an air-cooled heat exchanger that is sized to operate at a lower-than-ambient air dry-bulb temperature. The adiabatic air pre-cooling system uses water to depress the ambient air dry-bulb to a lower value, reducing the necessary size of the heat exchanger compared to a 100% air-cooled equivalent.

The following are specific recommendations borne from this research and separated into the three broad categories, namely 1) Adiabatic Unit Manufacturers; 2) Adiabatic Unit Specifiers; and 3) Adiabatic Unit Owners/End Users.

1. Adiabatic Unit Manufacturers should be certain that their unit design accounts for the following conclusions which have been proven by this research.
    a. Saturation efficiency changes with air velocity – it is not a constant value!
        i. As shown in Figure 13, the maximum saturation efficiency achieved for the various adiabatic pad depths and designs tested in this program was:

Air Velocity [m/]	Saturation Efficiency
2.5	76%
3.0	74%
3.5	72%

    b. Saturation efficiency and air side pressure drop are equally important in rating the thermal performance of an adiabatic unit.
    c. Water flow rate and water temperature have very little impact on adiabatic pad saturation efficiency when measured on a full-size adiabatic fluid cooler or condenser.
2. Adiabatic Unit Specifiers must be aware of the following when preparing specifications for adiabatic units.
    a. The overstated saturation efficiency claims which are published by adiabatic pad suppliers are likely to cause unknowing adiabatic unit manufacturers to

provide equipment which does not meet its specified performance.

b. There are no independent third-party performance certification programs or field test standards published for adiabatic fluid coolers or refrigerant condensers.

c. It is wise to specify an optional field performance test to provide a specification with sufficient "teeth" that will cause suppliers to provide fully rated equipment.
   i. Recommended Language: See Attachment #1 at the end of this paper.

d. To eliminate uncertainty regarding thermal capability, require adiabatic unit manufacturers to guarantee:
   i. Thermal capacity at the specified design point when operated adiabatically.
   ii. Thermal capacity at the specified dry switchover point with adiabatic pads installed.
   iii. Adiabatic Pad Saturation Efficiency at full fan speed.

NOTE: Actual adiabatic pad saturation efficiency can be determined using Equation 1 by measuring the air dry-bulb temperature and wet-bulb temperature entering the face of the adiabatic pads and the air dry-bulb temperature exiting the coil or unit without load on the adiabatic unit.

3. Adiabatic Unit Owners/End Users

Adiabatic technology has been an accepted means for improving the thermal performance of air-cooled fluid coolers and refrigerant condensers for decades. After reading this paper and recognizing the facts behind the limitations and variables in adiabatic air pre-cooling systems, end-users and specifying engineers may be asking themselves:

Q: Why haven't more HVAC, Industrial Process, and Industrial Refrigeration Systems using adiabatic pad technology had more performance issues in the field?

A: The short answer is that the deficient unit capacity is often hidden by simply operating the unit in adiabatic mode at wet-bulb temperatures lower than promised by the unit manufacturer (i.e., more frequently than would be required for a properly sized unit).

When the presumed adiabatic saturation efficiency is not achieved, it's likely that the HVAC, Industrial Process, or Industrial Refrigeration system can still be satisfied throughout the year due to:

i. Adiabatic pre-cooling system prolonged run-time at a wet-bulb temperature lower than specified (greater annual water use compared to assumed design data);
ii. Increased fan run-time or higher fan RPM requirements (greater annual energy consumption),
iii. Safety factors applied to load calculations;
iv. Conservative "worst case" design temperatures utilized for equipment selection; and
v. Chillers and compressors which can temporarily handle higher fluid and higher condensing temperatures.

However, in all of these circumstances, an adiabatic fluid cooler or refrigerant condenser with fully-rated performance will operate in adiabatic mode fewer hours , annually (saving water), and will unload fans to lower part speed or cycle fans off (saving energy) more frequently for any load profile and geographical location versus an adiabatic unit that incorporates over-stated saturation efficiencies.

Bottom line: fully-rated thermal performance saves end-users water and energy ($$$'s) while reducing long-term maintenance of adiabatic pads and fan motors due to their less frequent operation.

Another common question by the Adiabatic Owners/End Users is:

Q: How do I get a specifying engineer to ensure I receive fully-rated adiabatic fluid coolers and refrigerant condensers in the absence of any third-party certification standards?

A: Request the specifying engineer to specify and require that adiabatic unit manufacturers guarantee thermal performance capacity in both adiabatic mode and dry mode operation (see Thermal Capacity section of Attachment #1).

And

Request the specifying engineer to include language in the specification for an optional field performance test at the desire and expense of the owner if a thermal performance deficiency is suspected (See **Thermal Capacity Test Guarantee** section of **Attachment #1**).

Editorial Note

The test results contained in this report have been shared with the respective manufacturer of each adiabatic pad tested. Manufacturers have either agreed with or not refuted test results. It is recognized that the adiabatic pads tested represent only a portion of the adiabatic pads currently available in the global market. Testing will continue in search of the next generation of best pads.

Adiabatic Cooling Operating Principle

The basic principle for any air pre-cooling system is to reduce the air dry-bulb temperature entering the coil. Figure 2 illustrates a basic arrangement where water is distributed over the entire adiabatic pad plan area to saturate the adiabatic media.

Ambient air passing through the wetted adiabatic pad increases in moisture content (i.e., increased relative humidity), cooling the entering air dry-bulb temperature toward the entering air wet-bulb temperature. The lower dry-bulb temperature exiting the adiabatic pad is referred to as the depressed dry-bulb.

In an adiabatic fluid cooler or refrigerant condenser, the pre-cooled air or **depressed dry-bulb** travels through the tube and fin coil, offering a substantial increase in heat rejection capability.

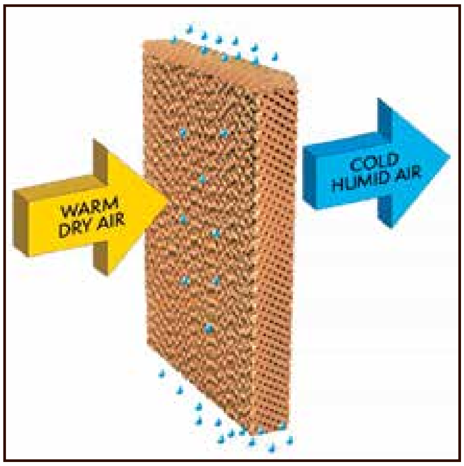

Figure 2: Adiabatic Cooling Operation Principle

Saturation Efficiency

Adiabatic pad manufacturers express the pad's ability to achieve a discharge air dry-bulb temperature (leaving the pad) for a known entering air dry and wet-bulb temperature as **saturation efficiency**. The dry-bulb temperature exiting the adiabatic pad media is calculated using Equation 1 below.

Equation 1: $T_{DB\ exiting} = T_{DB\ entering} - \%_{Saturation\ Efficiency} * (T_{DB\ entering} - T_{DB\ entering})$

The concept of saturation efficiency is further illustrated on the psychrometric chart, shown in Figure 3, and the example below. The air dry-bulb temperature reduces along a constant wet-bulb line [Point 1 to Point 2] when using an adiabatic pre-cooling system.

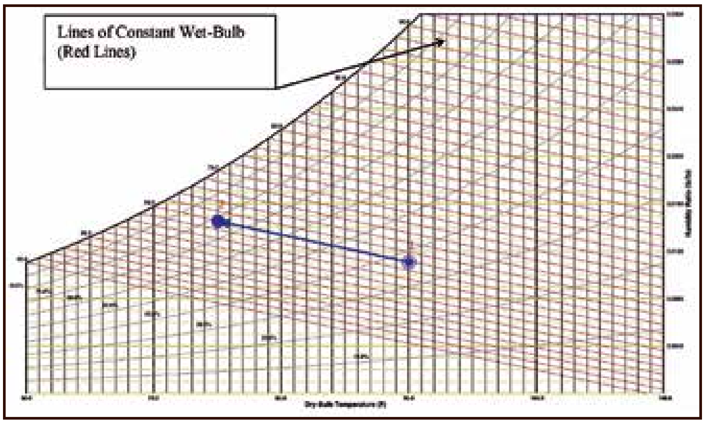

Figure 3: Psychrometric Chart

For the example shown in Figure 3:

$T_{DB\ entering} =$	32.2 °C	Point 1
$T_{WB\ entering} =$	21.1 °C	
$T_{DB\ exiting} =$	23.9 °C	Point 2
$T_{WB\ exiting} =$	21.1 °C	

In this example, adiabatic pad saturation efficiency is calculated by modifying Equation 1 to solve for efficiency:

$$\%_{Saturation\ Efficiency} = \frac{(T_{DB\ entering} - T_{DB\ exiting})}{(T_{DB\ entering} - T_{WD\ entering})}$$

$$\%_{Saturation\ Efficiency} = \frac{(32.2\ °C - 23.9\ °C)}{(32.2\ °C - 21.9\ °C)}$$

$$\%_{Saturation\ Efficiency} = \frac{(8.3\ °C)}{(11.1\ °C)}$$

$$\%_{Saturation\ Efficiency} = 75\%$$

Several manufacturer's published saturation efficiency curves were studied. The wide variation in published saturation efficiency related to adiabatic pad thickness for the different pad manufacturers prompted an extensive test program. As an example, Figure 4 below shows several adiabatic pad manufacturers' published/claimed saturation efficiency curves for 6" adiabatic pads with various flute angles and flute heights. As shown, published saturation efficiency curves are generally limited to entering air velocities from 0.5 – 3.0 m/s and the claimed saturation efficiencies range widely, from 65% to 97%. Please note, only some of these adiabatic pads were included in the ten adiabatic pads tested in the test program.

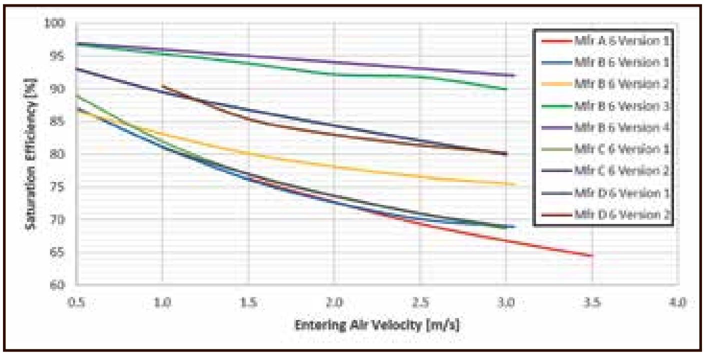

Figure 4: Adiabatic Pad Suppliers' Published/Claimed Saturation Efficiency Curves (6" [150 mm] Pad Thickness)

Why is adiabatic pad saturation efficiency so critical to adiabatic cooler and refrigerant condenser performance?

The thermal capability of an adiabatic unit is strongly influenced by the adiabatic pad saturation efficiency. Overstating adiabatic pad saturation efficiency will overstate unit performance, which will impact system operation. As an example, the resulting leaving fluid temperature using two different saturation efficiencies are compared in Table 1.1 below.

Design Conditions	Design	Actual
Saturation Efficiency	90%	70%
Entering Dry-Bulb Temperature, $T_{DB\ entering\ (before\ pad)}$	35.00 °C	35.00 °C
Entering Wet-Bulb Temperature, $T_{WB\ entering}$	23.89 °C	23.89 °C
Depressed Air Dry-Bulb Temperature, Entering Dry Coil, $T_{DB\ exiting}$ Calculated using Equation 1	= 35 – 90%*(35-23.89) = 25.0°C	= 35 – 70%*(35-23.89) = 27.22°C
Approach Temperature, T_{out} - $T_{DB\ exiting}$	7.22 °C	7.22 °C
Leaving Fluid Temperature, T_{out}	32.22 °C	34.44 °C

Table 1.1: Saturation Efficiency Impact on Leaving Fluid Temperature

Table 1.2 below shows that overstated adiabatic pad saturation efficiency can also have a significant impact when selecting a unit.

Design Conditions	Example 1	Example 2
Saturation Efficiency	90%	70%
Entering Dry-Bulb Temperature, $T_{DB\ entering\ (before\ pad)}$	35.00 °C	35.00 °C
Entering Wet-Bulb Temperature, $T_{WB\ entering}$	23.89 °C	23.89 °C
Depressed Air Dry-Bulb Temperature, Entering Dry Coil, $T_{DB\ exiting}$ Calculated using Equation 1	= 35 – 90%*(35-23.89) = 25.0°C	= 35 – 70%*(35-23.89) = 27.22°C
Design Leaving Fluid Temperature, T_{out}	32.22 °C	32.22 °C
Approach Temperature, T_{out} - $T_{DB\ exiting}$	7.22 °C	5.00 °C

Table 1.2: Saturation Efficiency Impact on Dry-Bulb Depression

Table 1.2 shows a 2.22°C difference in the calculated depressed dry-bulb temperature. The difference in unit size and horsepower required is generally inversely proportional to the calculated approach temperature. Therefore, if the same 32.22°C design leaving fluid temperature is used for both 90% and 70% saturation efficiency, the unit with a 70% saturation efficiency would need to be approximately 44% larger than the unit with a 90% saturation efficiency [7.22°C ÷ 5.00°C]. Table 1.3 below expands on this concept showing the difference in plan area, fan power, operating weight and cost of the units required to satisfy the same design condition by using different saturation efficiencies.

	Example 1	Example 2	
Design Condition	440 kW @ 32.22°C Condensing		
Saturation Efficiency	90%	70%	
Depressed Dry-Bulb Temperature	25.00°C	27.22°C	
Model Number	A	B	
Plan Area	2.4m x 6.1m	2.4m x 8.5m	[+40%]
Fan Power	29 kW	40 kW	[+38%]
Operating Weight	4268 kg	5693 kW	[+33%]
Relative Unit Cost	$1	$1.30	[+30%]

Table 1.3: Saturation Efficiency Impact on Unit Selection

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The Table 1.3 example above clearly illustrates the impact saturation efficiency has on unit selection, first cost and other key decision parameters.

Additionally, if the adiabatic pads do not achieve the saturation efficiency used to thermally rate the unit, the system's operation will be negatively impacted. These negative consequences include:

- Higher leaving fluid temperatures or refrigerant condensing temperatures
- Greater system energy consumption
- Prolonged adiabatic operation time
- Increased water use

To better understand adiabatic pads and their impact on unit ratings, we tested multiple adiabatic pad designs and investigated other parameters that might have an impact on adiabatic pad saturation efficiency.

Parameters that [Potentially] Impact Adiabatic Efficiency

- Several design parameters are commonly believed to influence adiabatic pad saturation efficiency. These include:
- Linear Adiabatic Pad Depth
- Entering Air Velocity
- Pad Configuration and Wetted Surface Area
- Supply Water Flow Rate
- Supply Water Temperature

Adiabatic pad manufacturers acknowledge the first three parameters listed above have a significant impact on saturation efficiency. The last two parameters are also commonly discussed in the industry by equipment suppliers and design engineers, but there is not an overwhelming industry consensus as to their impact.

Testing and Results

To verify the impact that various parameters have on saturation efficiency and resulting adiabatic unit performance, numerous laboratory tests were performed over several months at the Evapco Research Center in Taneytown, MD (USA). These tests and their results are described below.

Adiabatic Pad Test Chamber

Saturation efficiency testing was conducted in the adiabatic pad test chamber shown in Figure 5. The purpose and value of this chamber is to quickly evaluate and compare the accuracy of manufacturer's published data and to determine the impact performance variables, such as supply water flow rate and temperature, have on saturation efficiency. This testing is used to determine which pads were best suited for full-scale testing.

All thermal parameters were measured with precision platinum resistance temperature detectors (RTD) and recorded using an Agilent 34972A data acquisition unit. All RTD's have a resolution of 0.01°F (0.005°C). The chamber was instrumented with the following:

- Five (5) Entering Air Dry-Bulb RTD's
- Four (4) Entering Air Wet-Bulb RTD's
- Five (5) Leaving Air Dry-Bulb RTD's
- Two (2) Leaving Air Wet-Bulb RTD's
- Two (2) Inlet Water RTD's
- Two (2) Outlet Water RTD's

Figure 5: Adiabatic Pad Test Chamber

The test chamber incorporated a calibrated, internal nozzle wall, for accurate airflow measurement. The nozzle wall and airflow measurements meet the criteria outlined in Air Movement and Control Association International, Inc. (AMCA) Standard 210, Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating. Air side pressure drop across the adiabatic pad media was measured with a differential pressure transmitter. Supply water flow rate was measured using an in-line flow meter.

The chamber was used to test a variety of adiabatic pad types and depths from several manufacturers. It was also used to determine the effects of water temperature and water flow rate. Test results proved to be consistent and repeatable, producing an overall test tolerance of ±2%. This tight tolerance provides a high level of confidence in the technical data presented in this report. Additionally, key small-scale test results were compared to full-scale unit testing to confirm the accuracy of both results.

Full-Scale Test Chamber

Testing of selected adiabatic pads on a full-scale unit was conducted in a thermal test chamber (Figure 6). Results from full-scale testing were compared to small scale testing and used to develop performance models to generate fully rated adiabatic fluid cooler and refrigerant condenser thermal capacities.

Figure 6: Full-Scale Test Chamber

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All testing was performed to meet the criteria of industry recognized test methods, such as:

- ASHRAE Standard 20, Method of Testing Remote Mechanical-Draft Air-Cooled Refrigerant Condensers,
- European Standard EN 1048, Air cooled liquid coolers ('dry coolers'). Test procedures for establishing the performance,
- European Standard EN 327, Forced convection air cooled refrigerant condensers. Test procedures for establishing performance,
- CTI ATC-106, Acceptance Test Code for Mechanical Draft Evaporative Vapor Condensers, or
- CTI ATC-105-DS, Acceptance Test Code For Air Cooled Closed Circuit Cooling Towers

Similar to tests conducted in the Adiabatic Pad Test Chamber, all thermal parameters were measured with precision platinum resistance temperature detectors (RTD) temperature probes and recorded using an Agilent 34972A data acquisition unit. All RTD temperature probes have a resolution of 0.01°F (0.005°C). Fluid flow was measured using a magnetic flow meter or venturi tube for water and a Coriolis flow meter for ammonia. Fan motor input power was measured with a calibrated digital kilowatt meter at the motor disconnect. Atmospheric pressure was taken during the test using a mercury barometer.

Linear Adiabatic Pad Depth

According to adiabatic pad manufacturer's published data, the most influential design parameter for adiabatic pad saturation efficiency is the pad's linear depth (Figure 7). Three pad depths from one manufacturer were tested in the adiabatic pad test chamber and on a full scale unit to validate this observation.

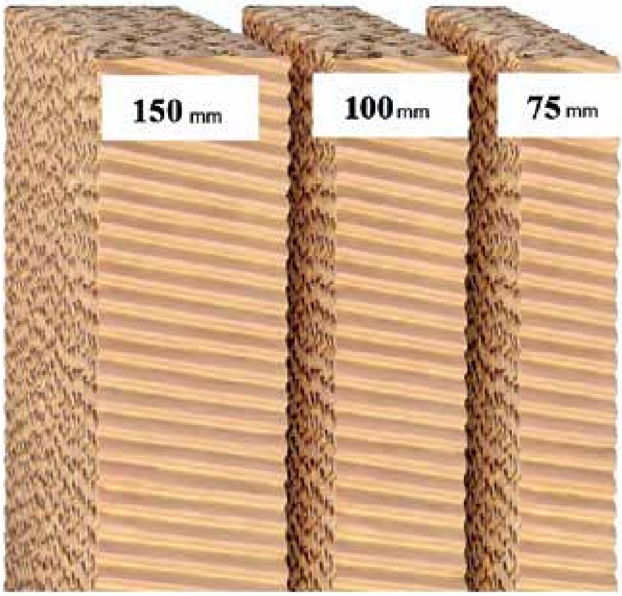

Figure 7: Example Adiabatic Pad

Each point in Figure 8 represents the calculated efficiency from test data gathered in the full-scale lab with the solid line representing the best fit line to the data. The test data from the adiabatic pad test chamber and full scale unit testing confirmed that linear pad depth does indeed have a significant impact on saturation efficiency at a comparative, nominal entering air velocity.

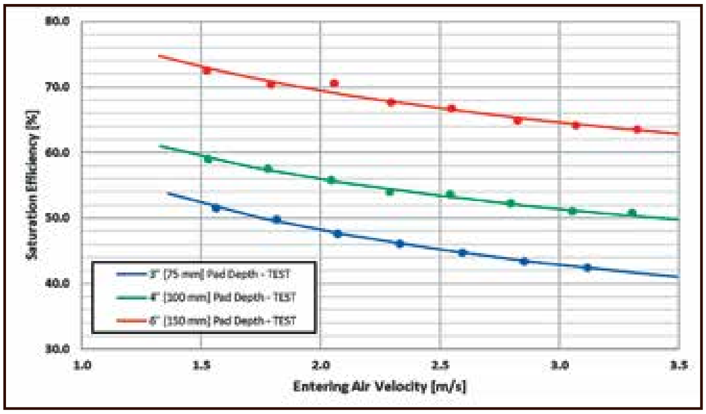

Figure 8: Saturation Efficiency for Multiple Pad Depths

Entering Air Velocity

Saturation efficiency varies significantly with entering air velocity, regardless of adiabatic pad design or pad depth. This effect was confirmed by the test data associated with every test performed (e.g., Figures 8, 9, 12.1-12.8, and 13). Therefore, it is inaccurate to apply a constant adiabatic pad saturation efficiency independent of entering air velocity as part of the unit rating methodology.

Supply Water Flow Rate

Supply water flow rate is a parameter that is often discussed in conjunction with adiabatic system performance. To quantify the impact flow rate has on adiabatic system performance, the supply water flow rate was varied over one of the adiabatic pads and calculated the saturation efficiency from the measured temperatures. Tests were performed at flow rates ranging from 50% below to 50% above the manufacturer's recommended water flow rate with the results presented in Figure 9.

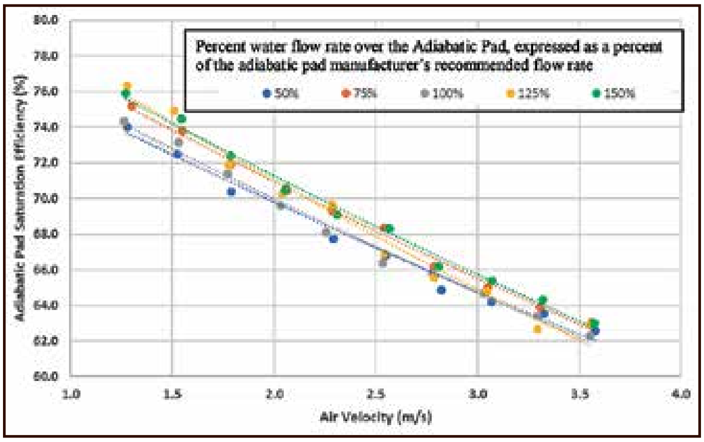

Figure 9: Adiabatic Pad Saturation Efficiency at Multiple Water Flow Rates

The test results provided in Figure 9 suggest that increasing the water flow rate per pad plan area has minimal effect on the resultant depressed air dry-bulb temperature and, therefore, minimal impact on saturation efficiency. However, it should be noted, increasing the water flow rate over the pad increases water use unnecessarily. An optimally designed adiabatic unit uses the minimum threshold supply water flow rate which will keep the adiabatic pad(s) fully wetted, thus maintaining effective air dry-bulb temperature reduction while using the least amount of water possible.

Supply Water Temperature

The supply water temperature distributed onto the adiabatic pad is another parameter marketed as influential to saturation efficiency. Supply water temperatures ranging from approximately 6°C to 36°C were tested on a full scale adiabatic unit. Table 2.1 below exhibits measured adiabatic pad saturation efficiency for the range of water temperatures tested.

Water Supply Temperature to Adiabatic Pad	Difference from Entering Wet-Bulb	Saturation Efficiency	Capacity Effect
35.8 °C	+15.2 °C	66.2%	-3.2%
30.2 °C	+9.6 °C	66.4%	-2.9%
19.4 °C	-4.8 °C	68.4%	Baseline
14.1 °C	-9.7 °C	69.4%	+1.5%
6.8 °C	-17.0 °C	70.8%	+3.6%

Table 2.1: Adiabatic Pad Saturation Efficiency at Multiple Water Supply Temperatures

The testing and data suggest water temperature has a small impact on adiabatic pad saturation efficiency and unit capability.

It was hypothesized the reason water temperature is marginally effective in increasing adiabatic pad saturation efficiency is because it equalizes to the entering air wet-bulb temperature. To confirm this hypothesis, the entering and leaving water temperature were measured and compared to the entering air wet-bulb temperature. Table 2.2 exhibits the entering and leaving water supply temperatures associated with the full scale testing where the adiabatic pad height is about 1.98 meters.

Water Supply Temperature Entering Adiabatic Pad	Entering Wet-Bulb	Water Supply Temperature Leaving Adiabatic Pad v. Entering Wet-Bulb
35.8 °C	20.6 °C	+0.11 °C
30.2 °C	20.6 °C	+0.06 °C
19.4 °C	24.2 °C	-0.06 °C
14.1 °C	23.8 °C	-0.06 °C
6.8 °C	23.8 °C	-0.11 °C

Table 2.2: Entering and Leaving Water Temperatures at Multiple Water Supply Temperatures

The adiabatic pad test chamber using a 0.6 meters tall adiabatic pad was used to evaluate how quickly the supply water temperature equalizes to the entering wet-bulb temperature. In the most extreme example tested (a 20 °C difference between the entering water supply temperature and entering air wet-bulb temperature), the water temperature equalized to within 3.3 °C of the entering wet-bulb temperature after 0.6 meters of travel, pad height direction.

The rapid equalization of supply water temperature to air wet-bulb temperature explains the marginal impact on full scale adiabatic pad saturation efficiency and thermal capability.

Wetted Surface Configuration and Area

The surface configuration and fluting pattern of an adiabatic pad can have a significant impact on saturation efficiency as represented by each manufacturer via published literature.

Most adiabatic pad manufacturers utilize a 15/45 or 45/45 degree opposing flute angle configuration for adjacent corrugated sheets (15/45 example shown in Figure 10). Corrugation (flute) height ranges from 5 mm to 7 mm and the flute is continuous in the air direction, from the entering to leaving edges. These numerical values are typically incorporated into each brand's catalogue description.

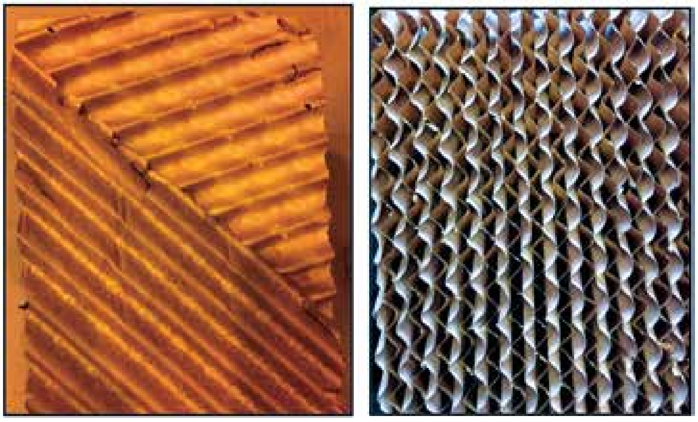

Figure 10: 15/45 Degree Opposing Flute Angle Configuration

One particular adiabatic pad utilizes a 45/45 degree opposing flute angle configuration for adjacent corrugated sheets as shown in Figure 11. The corrugation (flute) height is 7 mm. However, the 45-degree (air direction) flute angle is non-continuous in the air direction, from entering to leaving edges. The 45-degree angle is continuous for the first 50 mm, linear pad depth, followed by a horizontal flute section, also 50 mm in depth, and then continuing at a 45-degree angle (parallel to the first 50 mm) until reaching the pad's leaving edge.

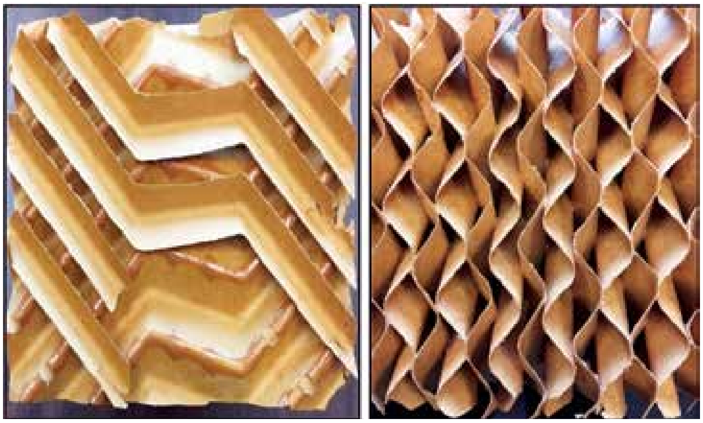

Figure 11: 45/45 Degree Opposing Flute Angle Configuratio

The adiabatic pads tested and reported in this document use essentially the same total surface to achieve entering air dry-bulb cooling due to the flute height and shape being approximately the same. The main difference is that one adiabatic pad exhibits two air directional changes whereas the other adiabatic pad designs do not change air direction once the air stream enters a flute(s).

The variation in published adiabatic pad saturation efficiencies for different wetted surface configurations (refer to Figure 4) again validated the need for the extensive test program. The following figures 12.1 – 12.8 illustrate the adiabatic pad saturation efficiencies as determined in the adiabatic pad test chamber compared to the pad test chamber compared to the manufacturer's published/claimed efficiency curves.

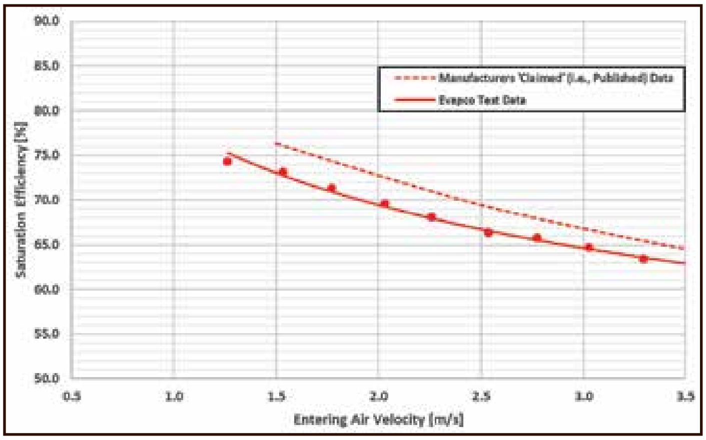

Figure 12.1: Saturation Efficiency for Manufacturer A – 150 mm (Version 1 Flute Configuration)

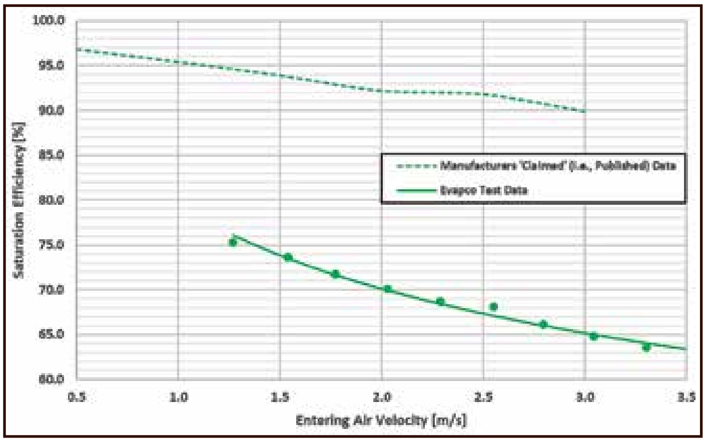

Figure 12.2: Saturation Efficiency for Manufacturer B – 150 mm (Version 3 Flute Configuration)

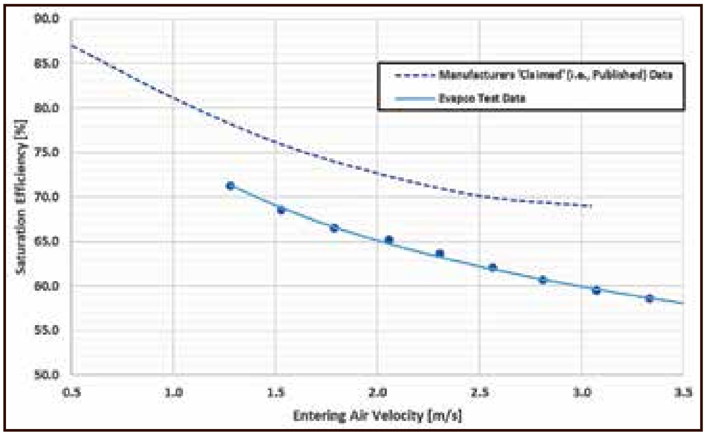

Figure 12.3: Saturation Efficiency for Manufacturer B B – 150 mm (Version 1 Flute Configuration)

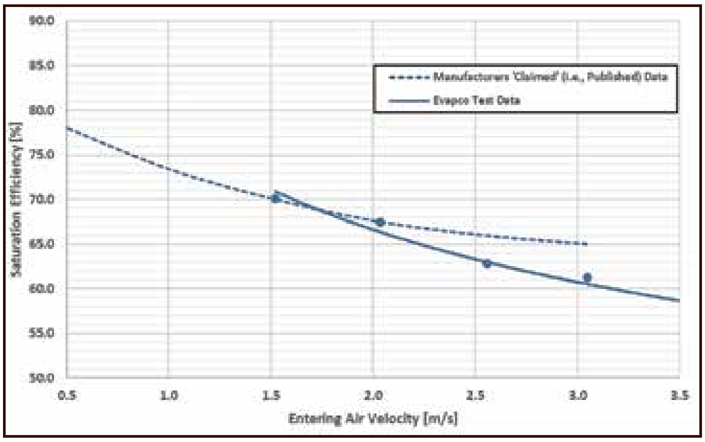

Figure 12.4: Saturation Efficiency for Manufacturer B – 100 mm (Version 2 Flute Configuration)

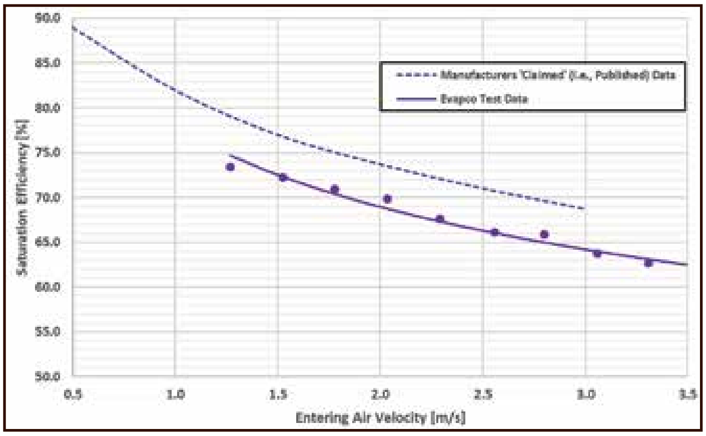

Figure 12.5: Saturation Efficiency for Manufacturer C – 150 mm (Version 1 Flute Configuration)

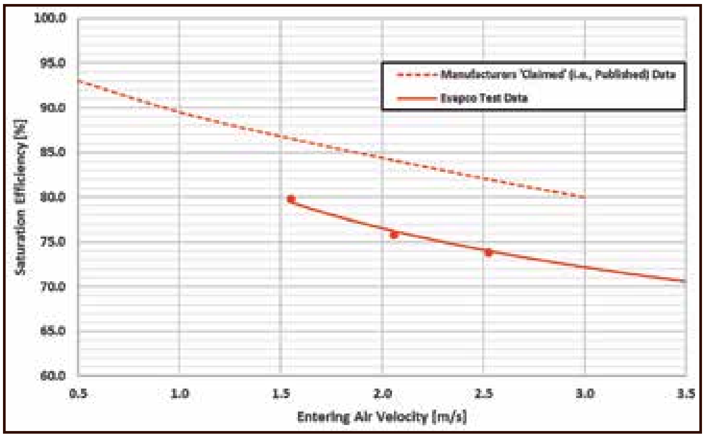

Figure 12.6: Saturation Efficiency for Manufacturer C – 150 mm (Version 2 Flute Configuration)

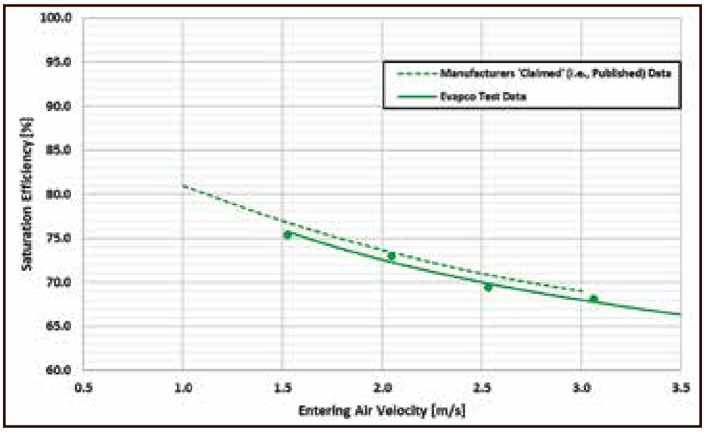

Figure 12.7: Saturation Efficiency for Manufacturer D – 150 mm (Version 1 Flute Configuration)

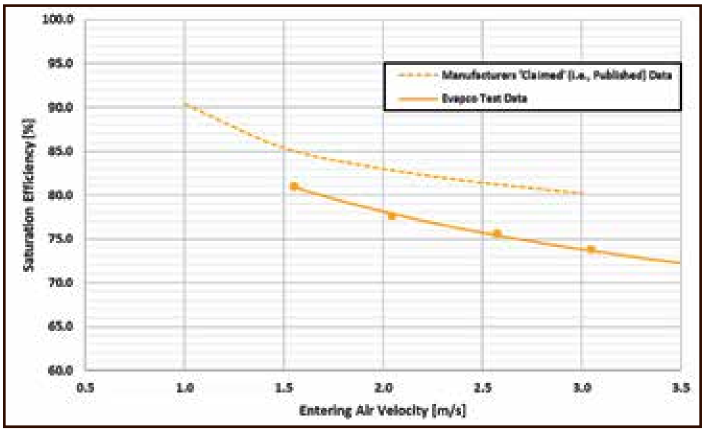

Figure 12.8: Saturation Efficiency for Manufacturer D – 150 mm (Version 2 Flute Configuration)

Figure 13 summarizes graphically the tested saturation efficiencies for the various adiabatic pads tested.

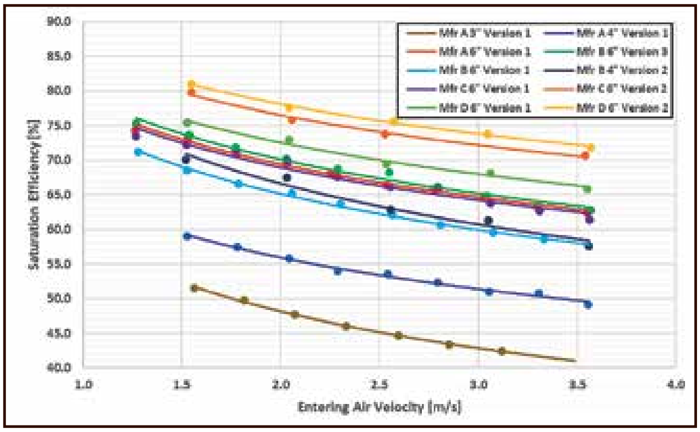

Figure 13: Measured Saturation Efficiency of Tested Adiabatic Pads

Effect of Air-Side Pressure Drop

The difference in wetted surface configurations results in different saturation efficiencies but choosing the highest efficiency adiabatic pad may not result in the highest unit thermal capacity because air side pressure drop is just as important to unit thermal capacity as saturation efficiency. The benefit of installing an adiabatic pad that achieves a high saturation efficiency can be negated or even detrimental if the air side pressure drop across the pad results in less airflow. In addition, air side pressure drop across the pads also affects unit performance when operating in dry mode during periods of low ambient temperature conditions and/or reduced system load.

Figure 14 summarizes the air side pressure drop associated with each of the pads illustrated in Figure 13.

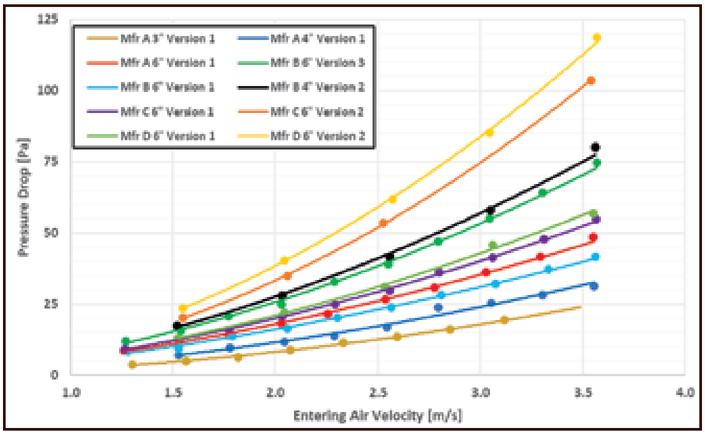

Figure 14: Measured Pressure Drop for Multiple Manufacturer's Adiabatic Pads

Most adiabatic fluid coolers and condensers are selected to satisfy the design operating point with an inlet air velocity around 3 meters per second. Table 3 below presents saturation efficiency and air side pressure drop at 3 meters per second for the adiabatic pads tested in this study.

Manufacturer	Pad Thickness	Flute Configuration	Pressure Drop [Pa]	Saturation Efficiency
D	6" [150 mm]	Version 2	85.2	73.8%
C	6" [150 mm]	Version 2	77.2	72.1%
B	4" [100 mm]	Version 2	57.8	61.3%
B	6" [150 mm]	Version 3	55.0	64.8%
D	6" [150 mm]	Version 1	45.8	68.1%
C	6" [150 mm]	Version 1	41.3	63.8%
A	6" [150 mm]	Version 1	36.1	64.7%
B	6" [150 mm]	Version 1	32.1	59.6%
A	4" [100 mm]	Version 1	25.4	51.0%
A	3" [75 mm]	Version 1	17.4	43.0%

Table 3: Saturation Efficiency and Pressure Drop of Tested Adiabatic Pads at 3 m/s Air Velocity

In general, the adiabatic pads with the higher saturation efficiencies were found to have the higher air side pressure drop values.

Closing Comments

The test results contained in this report were shared with the respective manufacturer of each adiabatic pad tested. Manufacturers have either agreed with or not refuted the test results. It is recognized that the adiabatic pads tested represent only a portion of the adiabatic pads currently available in the global market and will continue to test adiabatic pads in search of the next generation of best pads.

Reiterating points raised in the paper:

- Water flow rate and water temperature have little to no effect on adiabatic pad saturation efficiency when evaluated on a full size adiabatic fluid cooler or condenser.
- Adiabatic pad depth impacts adiabatic pad saturation efficiency.
- Adiabatic pad saturation efficiency changes with air velocity – it is not a constant value!

- Adiabatic pad saturation efficiency and air side pressure drop are equally important in evaluating adiabatic unit thermal performance.
- None of the adiabatic pads tested in this research achieved a 90% saturation efficiency in the normal operating entering air velocity range for this type of equipment.
- Specifying independent field or full scale laboratory testing using industry recognized test methods confirms adiabatic fluid cooler or condenser thermal performance to required operating conditions in the absence of strict certification programs.

As stated in the introduction, engineers and end-users face an unknown stumbling block when trying to apply adiabatic technology. This is due to the widespread variation in "claimed" adiabatic pad saturation efficiency in the global marketplace, which can result in a dramatic impact on the size or performance of the air-cooled closed circuit cooler or refrigerant condenser. Additionally, adiabatic unit manufacturers commonly apply a constant adiabatic pad saturation efficiency when selecting adiabatic units, regardless of actual entering air inlet velocity. "Claimed" adiabatic pad saturation efficiencies of 80-95% have been seen on datasheets from adiabatic fluid cooler and refrigerant condenser manufacturers. Based on the test results of this program, even 80% adiabatic pad saturation efficiency was not achieved at typical entering air velocities for most adiabatic fluid cooler and refrigerant condensers. Full scale laboratory tested saturation efficiency based on the unit's actual air inlet velocity should be used to calculate actual adiabatic unit performance.

Unfortunately, there are no "adiabatic specific" third-party performance verification test standards or certification programs for adiabatic coolers, adiabatic condensers or the adiabatic pads – hence **Attachment #1** is offered as a reasonable means of specifying thermal capability and testing given currently available test standards. Overstating thermal performance is common where third party verification or certification programs do not exist. Additionally, end-users often do not mandate thermal performance guarantees into specifications. Increased (and unnoticed) frequency of adiabatic operation at wet-bulbs lower than promised by the manufacturer masks underperforming adiabatic fluid coolers and refrigerant condensers. Until strict certification programs exist, end-users should insist on field or full scale laboratory acceptance testing and capacity calculation to determine if the adiabatic and dry thermal capacity of the unit meets or exceeds specified design conditions.

Attachment #1

Suggested Specification: Adiabatic Cooler Thermal Capacity and Test GuaranteeUnit(s) shall be selected and guaranteed to satisfy the following two design conditions.

I. Dry Mode:

When operating in dry mode (i.e. adiabatic pre-cooling system OFF), unit(s) shall be guaranteed to cool a design flow rate of ____ lps of water (___% glycol, if applicable) from ___°C entering fluid temperature to ___°C leaving fluid temperature at a ___°C entering dry-bulb temperature. Coil pressure drop shall not exceed ___kPa at the design flow rate.

II. Adiabatic Mode:

When operating in adiabatic mode, the unit(s) shall be guaranteed to cool a design flow rate of ____ lps of water (___% glycol, if applicable) from ___°C entering fluid temperature to ___°C leaving fluid temperature at an entering air condition with an entering air wet-bulb temperature of ___°C and simultaneously occurring entering air dry-bulb temperature of ___ °C.

Thermal Capacity Test Guarantee:

Unit(s) shall be guaranteed to provide the Dry Mode **Thermal Capacity** specified above when field tested in accordance with CTI ATC-105DS, Field Thermal Test Procedure for Dry Coolers.

If the units are suspected to be deficient in thermal capacity, the owner/user has the right to request a Dry Mode field thermal performance test per CTI ATC-105DS, Field Thermal Test Procedure for Dry Coolers, at their own expense. The test shall be conducted by an independent third-party test agency per the ATC-105DS test procedure within one year from date of shipment. In recognition of a +/- 2% field test tolerance, if the CTI Standard ATC-105DS field test results report a capacity of 98% or greater the unit shall be deemed to have satisfied the guaranteed **Thermal Capacity**.

The third-party test agency shall be a CTI licensed thermal test agency (http://cti.org/licensedTestingAgencies.php).

The manufacturer shall be given a minimum thirty (30) day notice prior to the test date and shall be allowed to both pre-inspect the unit and witness the test.

If the field thermal performance test results report the unit capacity to be less than the guaranteed **Thermal Capacity**, the equipment manufacturer shall reimburse the owner for the cost of the field performance test. Additionally, the manufacturer shall absorb all costs to make corrective measures to increase unit capacity to guaranteed **Thermal Capacity** or greater without exceeding the specified total fan motor energy of the unit(s). Corrective measures must be completed by the equipment manufacturer within six (6) months of a test which finds the unit to be less than guaranteed **Thermal Capacity**.

The equipment manufacturer shall then pay to have the modified/corrected units re-tested per ATC-105DS to confirm the corrective actions have improved capacity to the guaranteed **Thermal Capacity** If the retest results report the capacity to still be less than the guaranteed **Thermal Capacity,** the manufacturer shall provide new units which provide the specified thermal capacity free of charge and absorb all costs for removing and replacing the thermally deficient units.

The manufacturer shall pay to have the new/replacement unit's field thermal performance tested per ATC-105DS to confirm they meet the guaranteed **Thermal Capacity**. If the test on the new/replacement units reports capacity to be less than the guaranteed **Thermal Capacity** the manufacturer shall repeat the process (at their own expense) of providing new units and field tests per ATC-105DS until a field test result reports that the installed units meet or exceed the guaranteed **Thermal Capacity** without exceeding the specified total fan motor energy of the unit(s).

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

The Performance & Technology technical committee has developed Standard STD-202 to encourage cooling tower capacity of 100% or better.

Custom cooling towers built by the Participating Manufacturers (PM) are field-tested for thermal performance by CTI-Licensed Thermal Performance Testing Agencies and the results are published in accordance with this Standard.

This program provides big benefits to owners/operators of custom field-erected cooling towers:

- Performance tests demonstrate the actual thermal performance,
- Power generation is increased due to proper thermal performance,
- Heat exchanger efficiency is increased due to lower water temperature and lower energy consumption in the entire system.

This is a voluntary program. For the period of publication of these results, the PM are:

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

CTI STRONGLY RECOMMENDS THAT YOU SPECIFY STD-202 FOR YOUR COOLING TOWER NEEDS:

1. The cooling tower vendor shall be a Participating Manufacturer 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.
2. 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. Testing shall occur within one year of commercial operation of the cooling tower.

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MARLEY®

Participating Manufacturer	Composite Cooling Solutions, L.P.	EvapTech, Inc.	SPX Cooling Technologies	All Multi-Agency Acceptance Tests for the previous year*
Testing during the Period:	08/21/2013 to 10/19/2018	07/18/2016 to 09/06/2018	06/20/2013 to 9/13/2018	2017
Percentage of tests at or above 100% Capability	50	100	90	56
Percentage of tests at or above 95% Capability	100	100	100	79
Average Capability of test results < 95%	0	0	0	87
Average Water Flow Rate	23,600	46,452	133,901	27,083

If N.A. is indicated for Not Available, there are no results available in the category

Underwater Robotic Technology for Online Tower Basin Cleaning

Steven Rydarowski, Joe Leist and Randi Morgan
Scantron Robotics USA, Inc

Introduction

Cooling tower basin cleanings and inspections are expensive. Traditional methods add to the initial costs through the needs for draining, shutdowns, refilling, retreatment, and closed space entries. Safety personal must be kept on hand, which adds fees. A new method of robotic cleaning helps reduce these costs by keeping tanks filled and online, and nearly eliminates closed space entries.


Joe Leist

Traditional Methods

Water tower basin cleaning is not a new concept, nor is it a suddenly-emerging need. Tank cleanings, and inspections, have been a necessary part of maintaining functionality. The traditional methods of cleaning and inspecting industrial water tower basins—permanent structures within industrial facilities designed to contain nonflammable liquids, classified by OSHA as permit-required confined spaces—require some form of entry by personnel into the confined spaces of the water towers. Three methods make up the traditional models: vac trucks, divers, and offline robots.

Vac Trucks

Vac trucks clean water tanks much the same way as a living room is cleaned: people go in with vacuums and suck out as much dirt as is possible. The use of industrial vacuums makes this a fairly efficient method once started, but there is a major issue with starting: getting the people into the basin itself.

First off, the process does not work with a filled tower, so the tank must be drained. Treated water must be safely disposed of by the operator and the tank shut down (often referred to as a turnaround or an outage). Water towers cannot be operational during this process.

Secondly, vac truck cleaners must perform confined-space entries when entering the tank. These come with recognized inherent dangers and require permits, paperwork, and oversight to perform. Having people inside of the water tower as they suction out sediment and other build up keeps people at risk for the duration of the cleaning.

Finally, the water tower basin must be refilled after the cleaning is complete. Water is added, then treated. However, this is all at a cost, which is often overlooked. The drained treated water is essentially a loss for this process. Replacing it is never free.

Divers

Divers clean water basins without draining the water. A team enters the tank and performs the cleaning in the filled tower. Many companies claim to be able to perform cleanings while basins remain online, only requiring the pumps be turned off. This appears to save operators some of the inconveniences associated with cleanings, but it does so at great costs.

First of all, permit required closed space entries must be done in order for this cleaning to be performed. Closed spaces always incur risks and dangers. In 2015, 136 US workers died in closed space entry-related incidents.1 Because of the extreme risks, oversight and permitting are required for these.

Secondly, divers are exposed to constant risk and potential exposure to dangerous materials. Being submerged for lengthy periods of time in treated water or other chemical mixtures could lead to extreme mishaps, such as chemical burns and inhalation or even drowning. Because of these safety risks, support and medical crews must be on-hand at all timed during diving procedures. These are expensive and drive up costs quickly, especially after estimated times grow or are passed.

Finally, unlike other methods, turbidity becomes an issue. The actions of swimming and moving while sediment is broken up and collected moves a great deal into the rest of the water. This may cause something as mundane as slightly cloudy water, but it could cause much worse problems down the line, such as clogs downstream and increases in bacteriological buildup. These greater risks could lead to increased needs for maintenance and cleanings in the future, making this method relatively inefficient and excessively costly.

Offline Robots

Robotic cleaning services have already made a foray into the world of industrial tank cleaning. Large machines enter tanks, break up and pick up material, and later exit the tank. It sounds simple, but it is a more advanced version of the vac truck methods.

First, these robots are not submersible. This means tanks must be drained in order for the robots to enter and clean. Just like the vac truck method, this is costly and comes with a shutdown of the tank, interfering with production.

Second, these robots cannot fully suction and collect everything on their own. After the robots are finished cleaning, vac truck technicians are still required to enter the tank to clean what the robots have left, meaning confined space entries are still a requirement of the process.

Finally, these robots are bulky. They weigh up to 500 lbs. and can damage basin linings and structure. The increase in risk to the tank, as well as the maintained risk to personnel, makes this process a lesser upgrade to the prior methods.

The New Method: Online Robotics

Inspired by industrial pool cleaner robots, the first online industrial water tank cleaning robots were designed for the potable water industry in 2010. These robots demonstrated clear success and promise, despite being bulky and using inefficient methods. They proved capable of removing sediment while also keeping employees from entering confined spaces. Online robotic technology has developed and evolved in the years since, accommodating a much wider array of tank applications and industries, while also improving speed and efficiency.

Online robotic systems improve cleaning and inspection processes by allowing water tower basins to remain online and cutting liabilities. The basic process has robots enter the tower, break up and suction out sediment and other build-up, and leave the tank. People should not have to enter the tank; and the basin does not need to be drained—in fact, this process requires the tower to be full. The suction requires water to be pulled from the tank and filtered outside of the water tower basin, which helps to eliminate turbidity.

Process

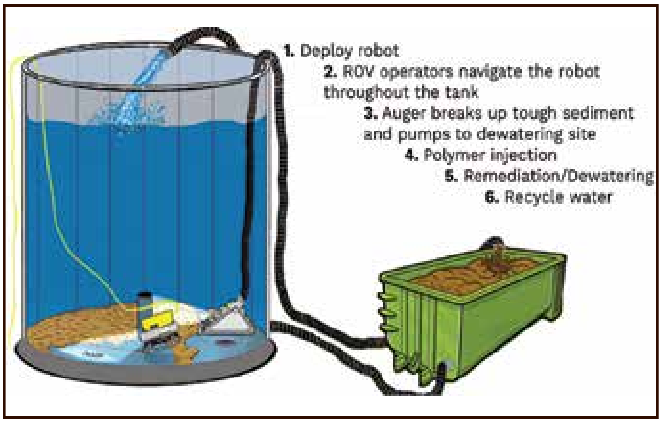

Figure 2 - Illustration of the online robotic industrial water tower basin cleaning process

Step 1: Deploy Robot

The robot is deployed into the tank by the use of an operator-owned, custom crane, or by the use of a crane operated by the client facility. The crane carefully lowers the robot to the tank floor, and the on-board pumps are immediately engaged in order to avoid and eliminate turbidity as it makes contact with sediment.

Figure 3 - Robot being deployed into a basin using custom crane

Step 2: ROV operators navigate the robot throughout the tank

Remote operating vehicle (ROV) operators govern the robot's movements, auger, and pump from a control box. In order to more efficiently navigate a tower, lights and live-feed cameras attached to the frame of the robot are utilized by operators. Blueprints can be used in instances of low visibility due to poor water quality.

Step 3: The Auger Breaks up Tough Sediment as it is Pumped to a Dewatering Site

The type of sediment determines the type of auger installed on the robot. While there are many different types of augers used, the most common is made of stainless steel. A brush auger, however, is used in order to protect liners, such as a rubber liner.

Figure 4 - Online robotic tank cleaning operator

A powerful, on-board pump eliminates the creation of turbidity as the robot moves throughout the water tower basin. The mixture of water and sludge are sucked through hoses to an external dewatering site. The location of the pump was carefully considered to eliminate turbidity, which is a major concern for most tower operators. The robot is capable of a 2-foot suction footprint in every direction from its base, further alleviating any potential turbidity.

Figure 5 – Auger at front of robot

Step 4: Polymer Injection

In order to increase the speed of separating the suspended materials and increasing efficiency of dewatering and remediation, polymers can be injected into the system. This process is always discussed with clients and does not move forward without proper approval.

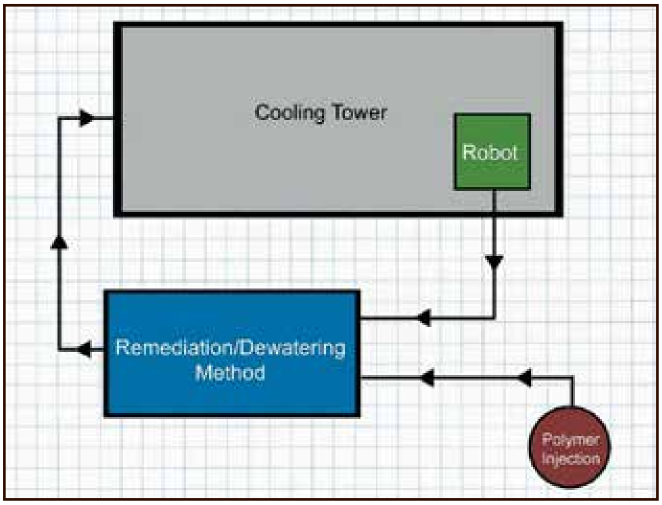

Figure 6 - Flow chart for online robotic tank cleaning method depicting at which stage polymer can be injected

Step 5: Remediation and Dewatering

The mixture of sludge and water is dewatered and remediated, allowing clean water to be returned to the water tower basin. Common means of dewatering include using one or a combination of plate/filter presses, dewater boxes, weir tanks, geo bags, or centrifuges. Other filtering methods may be applied as well.

Industrial water is commonly treated with expensive chemicals, such as chlorine or polymers, to help combat fouling or prevent corrosion. Disposal of such waste when draining a water tower often incurs heavy disposal fees and negatively affects the environment. By separating solids from the liquids, clean water is recycled back into the basin and dry material is left for disposal. Chemical treatments are not removed through this process. Disposal fees for liquid waste can cost up to 7 times those for solid waste; therefore, this step is essential to reducing the costs associated with waste disposal.

Figure 7 - Common dewatering methods used in online robotic tank cleaning

Step 6: Clean Water is Returned to the Water Tower Basin

A continuous pumping process returns clean water to the tank from the dewatering site, recycling the water and often drastically improving the quality.

Figure 8 - Clean water pumped into the basin after remediation process

Sediment Mapping

Traditionally, a "stick test" is used to determine the amount of sludge and sand within a water basin. A length of stick or pole is put into the water until a solid is reached. The height of water on the removed pole is assumed to be the depth of the water. That is then used to make an estimate of the thickness of the buildup on the bottom of the basin. This method can fail for several reasons:

1. The data is fairly incomplete and is too little from which to work.
    a. Sediment is rarely uniform, so testing even a few areas may give way to incorrect predictions.
2. Depth readings may not be as accurate as anticipated.
    a. The stick can easily get caught on a part of the tank, especially if water visibility is low.
    b. The buildup might also be fairly permeable, allowing the pole to pass through without much resistance.
3. Water movement might affect the level on the pole or the pole might be put in at an angle.

These inaccuracies can be costly and create errors. Service estimates are based off of sediment estimates, so service times and equipment rental costs will vary from planned costs. Errors in either direction cost money: over estimates mean workers and rentals must be paid for scheduled time even though a job is finished, while under estimates mean jobs take longer and cost more than expected.

ROVs, however, have a much better, and far more accurate, means of assessing the amount of sediment within a water tower called sediment mapping. A proprietary method of measuring sediment levels, sediment mapping involves taking specific measurements in order to paint a clear image of how much sediment has built up in different areas of a tower. With a clearer picture, estimates become more specific and accurate, especially in regard to the amount of time a cleaning will take.

Sonar imaging is used in order to clearly find where the top of the sediment rests. An underwater ROV scans the tank, collecting upward of 500 data points for an average-sized cooling tower, painting a picture of the bottom of the basin. Sedimentation is then calculated from this data.

At this point, what has actually been measured is how deep the water is at each point. Since water remains level on the surface, depth changes must be caused by either the tank shape or the sediment buildup. Therefore, the data is then compared with the basin construction diagram. The following calculation gives results in an accurate understanding of the buildup within the water tower.

Hsediment = Hdrawing – (Hmeasured + Hsonar)

Hsediment = sediment height

Hdrawing = distance between water surface and the basin floor, as measured from water level and basin diagram

Hmeasured = Distance between sonar and sediment, as measured from sonar

Hsonar = Height of sonar from water surface

The data is then compiled and charted in order to create a sediment heat map. These create visual representations of the unwanted material on the bottom of the basin.

While the heatmaps may be helpful, another step is taken to create a more visual representation of the data. Three dimensional topographic maps show clearly exactly what the buildup depths look like and give an easily accessible view of the peaks and valleys of where sediment settles.


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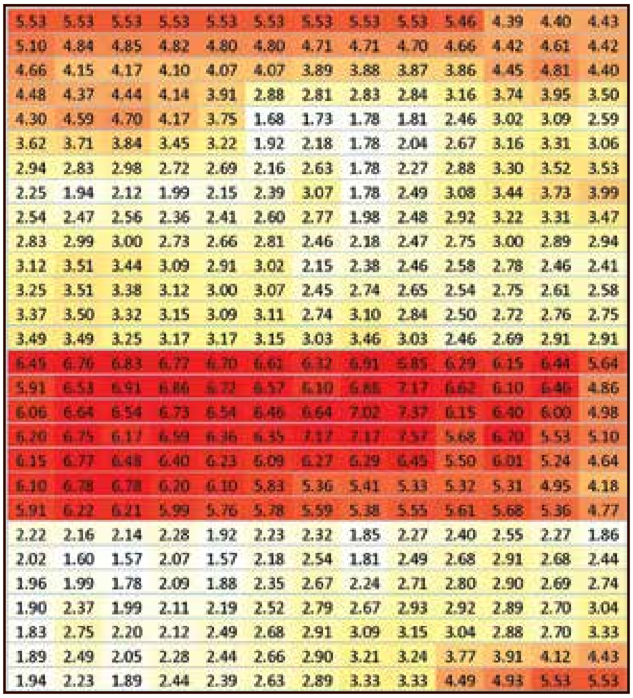

5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.46	4.39	4.40	4.43
5.10	4.84	4.85	4.82	4.80	4.80	4.71	4.71	4.70	4.66	4.42	4.61	4.42
4.66	4.15	4.17	4.10	4.07	4.07	3.89	3.88	3.87	3.86	4.45	4.81	4.40
4.48	4.37	4.44	4.14	3.91	2.88	2.81	2.83	2.84	3.16	3.74	3.95	3.50
4.30	4.59	4.70	4.17	3.75	1.68	1.73	1.78	1.81	2.46	3.02	3.09	2.59
3.62	3.71	3.84	3.45	3.22	1.92	2.18	1.78	2.04	2.67	3.16	3.31	3.06
2.94	2.83	2.98	2.72	2.69	2.16	2.63	1.78	2.27	2.88	3.30	3.52	3.53
2.25	1.94	2.12	1.99	2.15	2.39	3.07	1.78	2.49	3.08	3.44	3.73	3.99
2.54	2.47	2.56	2.36	2.41	2.60	2.77	1.98	2.48	2.92	3.22	3.31	3.47
2.83	2.99	3.00	2.73	2.66	2.81	2.46	2.18	2.47	2.75	3.00	2.89	2.94
3.12	3.51	3.44	3.09	2.91	3.02	2.15	2.38	2.46	2.58	2.78	2.46	2.41
3.25	3.51	3.38	3.12	3.00	3.07	2.45	2.74	2.65	2.54	2.75	2.61	2.58
3.37	3.50	3.32	3.15	3.09	3.11	2.74	3.10	2.84	2.50	2.72	2.76	2.75
3.49	3.49	3.25	3.17	3.17	3.15	3.03	3.46	3.03	2.46	2.69	2.91	2.91
6.45	6.76	6.83	6.77	6.70	6.61	6.32	6.91	6.85	6.29	6.15	6.44	5.64
5.91	6.53	6.91	6.86	6.72	6.57	6.10	6.86	7.17	6.62	6.10	6.46	4.86
6.06	6.64	6.54	6.73	6.54	6.46	6.64	7.02	7.37	6.15	6.40	6.00	4.98
6.20	6.75	6.17	6.59	6.36	6.35	7.17	7.17	7.57	5.68	6.70	5.53	5.10
6.15	6.77	6.48	6.40	6.23	6.09	6.27	6.29	6.45	5.50	6.01	5.24	4.64
6.10	6.78	6.78	6.20	6.10	5.83	5.36	5.41	5.33	5.32	5.31	4.95	4.18
5.91	6.22	6.21	5.99	5.76	5.78	5.59	5.38	5.55	5.61	5.68	5.36	4.77
2.22	2.16	2.14	2.28	1.92	2.23	2.32	1.85	2.27	2.40	2.55	2.27	1.86
2.02	1.60	1.57	2.07	1.57	2.18	2.54	1.81	2.49	2.68	2.91	2.68	2.44
1.96	1.99	1.78	2.09	1.88	2.35	2.67	2.24	2.71	2.80	2.90	2.69	2.74
1.90	2.37	1.99	2.11	2.19	2.52	2.79	2.67	2.93	2.92	2.89	2.70	3.04
1.83	2.75	2.20	2.12	2.49	2.68	2.91	3.09	3.15	3.04	2.88	2.70	3.33
1.89	2.49	2.05	2.28	2.44	2.66	2.90	3.21	3.24	3.77	3.91	4.12	4.43
1.94	2.23	1.89	2.44	2.39	2.63	2.89	3.33	3.33	4.49	4.93	5.53	5.53

Figure 9 – Sediment Heat Map

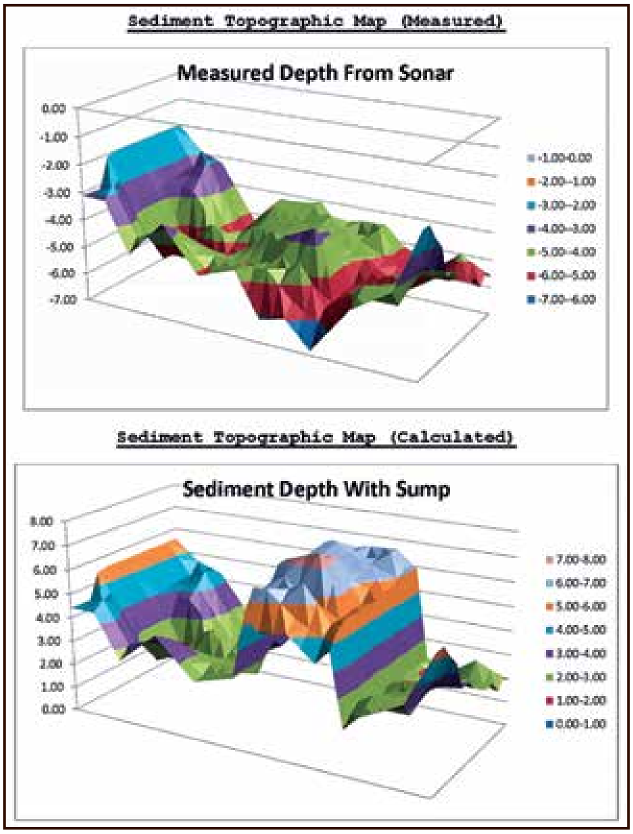

Figure 10 – 3D Topographic Sediment Map

These three-dimensional maps provide an accurate view of the placement and collections of sediment on the bottom of a tank. The hills and valleys allow for cleaning to be performed in a targeted manner, reducing wasted time attempting to clean areas where little cleaning is necessary.

Multiple sediment maps, especially using those created before and after cleanings and after the water tower has been in use for a reasonable length of time, can be used to identify where unwanted material tends to collect. This can allow for plants to schedule for cleanings at a necessary rate and possibly correct movement or feeding issues leading to buildup. Analysis can also be done to create a better understanding of how the water in the tank moves and flows beneath the surface.

Inspections

Traditional tank inspections either utilize divers or require basins to be drained. Both methods require confined space entries, which come with great costs and risks. Online Robotic inspections, on the other hand, do not need to send people into the tank at all.

Inspections are done by putting an ROV with lights and special underwater cameras into the water tower basin. They move through a tank much in the same way a drone moves through the air. Small turbines enable steady, stable control of the ROV's movement while HD pictures and video are generated. These give an accurate understanding of a tower's infrastructure, corrosion, and buildup under the water. Ultrasonic thickness testing can be done to determine the structural integrity of a tower. Also, API-653 certified inspections can be done, all while the basin remains online.

Safety Improvements

One of the most dangerous aspects of industrial tank cleaning is confined space entries. In the past, employees have been sent into enclosures in order to gain the access required to perform cleanings. This meant personnel were exposed to chemicals, which required various PPE—including monitors, masks, gloves, and possibly suits—in order for safety to be maintained. Permits had to be made for each entry, with proper supervision and authorization. Even with these safety practices, confined space entries still carry great hazards and risks. When issues do arise, retrieval of personnel from inside of a tank can often be difficult and slow, which lengthens exposure and reduces the ability of emergency workers to provide aid in a timely manner. In fact, statistics from the Department of Labor show approximately 96 people die each year in confined space entry accidents, 61% of which occur during construction, repair, or cleaning processes. People are injured and do die each year using the traditional method.

The Online Robotics method, on the other hand, strives to avoid and eliminate confined space entries whenever possible. Since robots are sent in through an opening in the tower and retrieved using a winch system, people do not enter the tanks. When issues or damages do occur, they occur with the robot, not a human being. Robots can easily be pulled from the tank and repaired or replaced—people tend not to be so lucky.

Time spent in safety planning and preparation is also significantly reduced. General industrial safety standards are met and adhered to, but there is not need for additional procedures on most sites. Since confined space entries are not required, time is not spent identifying who must go in and addressing the permitting needs. Specific site needs can be focused on without as much worry as to who goes where when. This shift also saves money by reducing costs in planning time and liabilities.

Exposure to extreme climate is also reduced and limited. Prolonged exposure to extreme heat and cold, as well as rain or sleet, can be common dangers for those who clean tanks. Online Robotics, however, allow employees to limit exposure when the need arises. Drivers control robots from inside an air-conditioned trailer. Positions within a team can be easily rotated, and monitoring of dewatering and pump lines can be done from under cover. The only weather

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condition which precludes the use of Online Robotics is prolonged extreme cold. The reason is simply that if the water is frozen, it will not flow through the robot. In such cases, draining a tank is not really an option, either, as frozen water will not flow through an exit line. Below is a picture of a robot after being utilized for an extended period of time in sub-zero temperatures.

Figure 11 –Robot Exposed to Extreme Cold during use

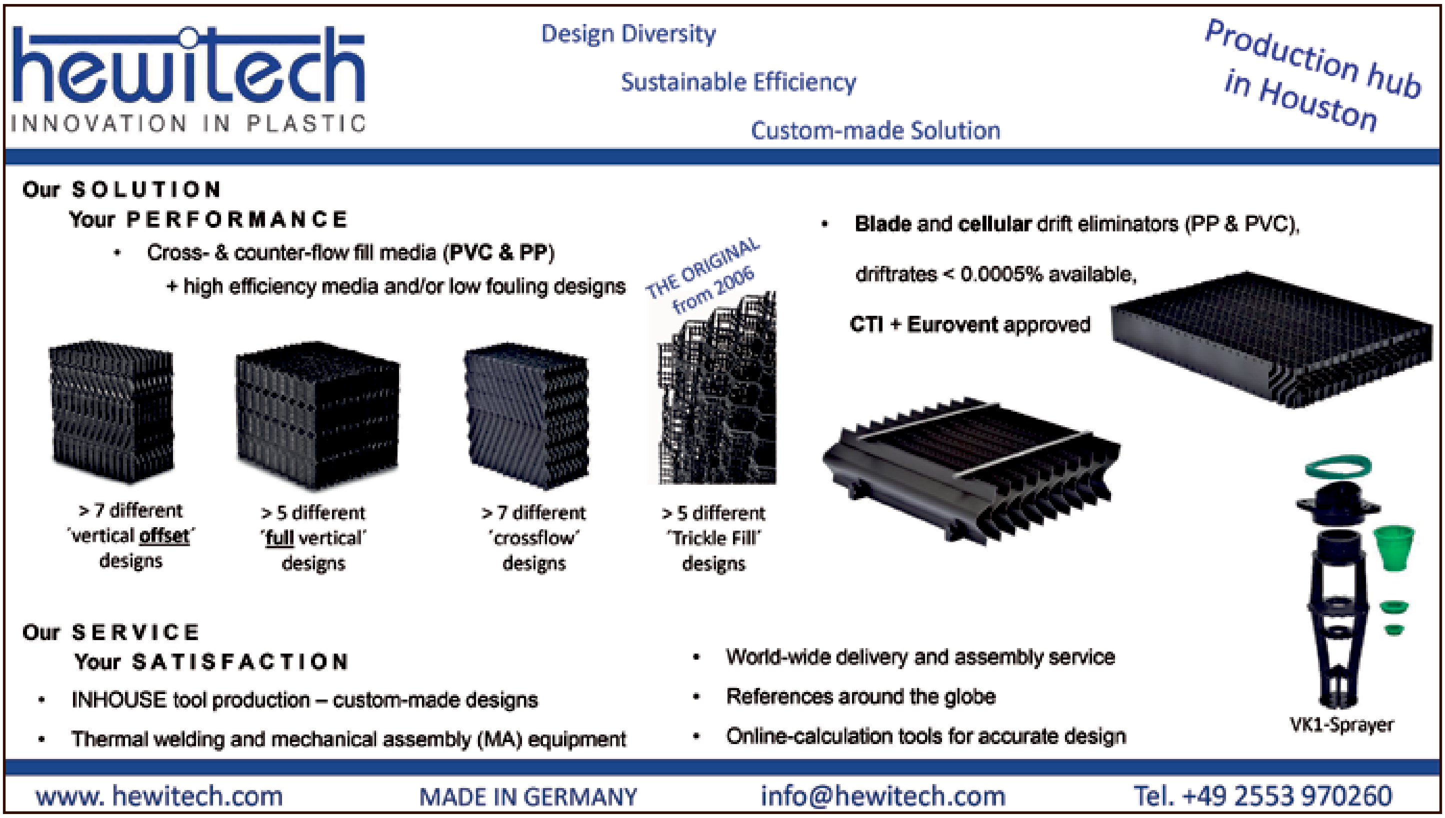
Conclusion—A New Standard For Industrial Tank Cleaning

The savings, especially those in continuing to utilize tanks while services are performed, completely outweigh the competition. Any time spent offline for cleaning is time spent in losses of production. There should be no need to drain for simple cleanings any more. Refilling and treating new water takes time and costs money, which usually goes unnoticed. Wet waste disposal also has significantly higher fees than the dry waste Online Robotics creates.

Environmental savings also abound in Online Robotics. Draining basins needlessly dumps thousands of gallons of treated water out, affecting the other systems into which it flows. Taking out more clean water to fill the tanks also requires unnecessary burdens placed on water and ecosystems. Wet waste has a much higher environmental impact than the dry waste created using Online Robotics.

The safety increases provided by Online Robotics keep employees healthier, saving both lives and money. Reduced liabilities by reducing confined space entries helps keep employees out of harm's way. Keeping people from danger limits risks and liabilities, which prevents injury and saves money. Also, the reduction of permitting required for confined space entries saves both time and money.

Online Robotics, therefore, is the next wave in industrial tank cleaning. It is cost-effective, environmentally friendly, and safer than any previous option. Soon, it will be the standard of the industry.



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Tailoring Scale Prediction Models to a Specific Application: Cooling Water

Robert J Ferguson, French Creek Software, Inc.

Mineral scale formation is a problem across many industries and in diverse applications and equipment. Each application may have specific characteristics that must be considered if a modelling system is to be reasonably accurate. The modelling of cooling water and oil field production chemistry have been studied extensively since the 1970's and state-of-the-art physical chemistry models developed to simulate them with acceptable accuracy, even under extreme conditions.

Robert J Ferguson

Open recirculating cooling water predictive models, for example, must incorporate algorithms to concentrate the water treating the process as an "open" system and address cooling system specific situations including pH control methods and even the impact of chlorination. pH prediction of the concentrated recirculating water is a key requirement.

Oil and gas production chemistry modelling presents another set of unique challenges, including the distribution of gasses such carbon dioxide and hydrogen sulfide between phases as a brine transitions from bottom hole conditions to the well head, and then flashes at the separator. Such a system must incorporate algorithms to treat the process as a "closed" system and partition the critical gasses between phases with pressure and temperature changes, and account for the impact of the sometime dramatic environmental parameter changes upon pH, solubility, and physical constants.

Membrane systems did not begin to receive the same rigorous treatment as oil and gas production, cooling water and applications such as geothermal power production, until the 1990's. Much of the software in use by the industry relies upon simple index calculations on the level of the Langelier Saturation Index, and saturation indices based upon total analytical values. The mainstream reverse osmosis application specific software generally used is not up to the rigors of high ionic strength, high recovery, and water reuse membrane systems. They are definitely not capable of adequately modelling cascade systems. The simple indices used for predicting scale formation, and as driving forces for dosage optimization, do not simulate high ionic strength activity coefficients and near as well as far effects. The simple models fail to account for speciation and the ion association of even such standard (yet critical) pairs such as $CaSO_4°$ aqueous.

Scale inhibitor models in these simple models also do not account for inhibitor dissociation and the active form of the molecules. They also tend to lack the sophistication of models used in other applications which necessitate an induction time extension approach. Without adequate speciation models, inhibitor solubility can not be adequately modelled, or insoluble forms controlled predictably. They also ignore, in many cases, application specific challenges such as membrane specific ion rejection, pH prediction and control in vented (open) or tight (closed) systems, and concentration polarization at the membrane water interface.

This paper discusses the practical application of advanced physical chemistry techniques commonly employed to cooling water systems.

The techniques are discussed and applied to:

- predicting scale formation;
- identifying the upper driving force limit for inhibitors and blends;
- developing inhibitor models for minimum effective dosage;
- developing models for preventing failure due to inhibitor solubility; and
- modeling inhibitor synergy and competitive inhibition.
- The methods discussed have been validated in field applications.

Introduction

In the past, water chemistry and scale control modeling in open recirculating cooling water systems was a straightforward process. Concentration ratio and ionic strength of the recirculating water were relatively low. Systems were operated with acid feed for pH control or at a concentration ratio where inhibitors could prevent or limit scale formation and growth without pH adjustment. The evaluation systems for modeling scale were adequate for low ionic strength systems. Characteristics of these computer models, many of which are still in use today, include:

- scale predictions are based upon simple indices. (1,2,3,4)
- indices are calculated from total analytical values and do not account for the ion associations and common ion effects prevalent in higher dissolved solids waters.
- calculations estimate carbonate from uncorrected "M" alkalinity titrations and do not correct for non-carbonate alkalinity.
- ion activity estimations use methods appropriate for low ionic strength solutions, but that lack accuracy and applicability in high TDS systems.

Models based upon the simple indices and calculations ceased to be applicable in the 1990's and began to be replaced by more sophisticated modeling algorithms. Modeling of systems benefits from the incorporation of sophisticated calculation methods to improve accuracy and optimize treatment. This is of special applicability to those a) operating at higher cycles of concentration and "zero discharge", b) using reuse water such as reverse osmosis concentrates, and industrial discharges for makeup, and c) those operating in high ionic strengths. In this context, treatment optimization includes pH control and anti-scalant dosages.

The use of simple indices and prior art for modeling open recirculating cooling systems can result in:

- pH prediction errors in excess of 0.5 pH units,
- acid requirement predictions off as much as 10X, and
- gross underestimates of sulfate contributed to the makeup and recirculating water from acid feed.

Assumptions on which historic simple index scale evaluations are based can impact system operations by:

- Overestimation of $CaCO_3$ scale potential
- Overestimation of inhibitor requirement for $CaCO_3$
- Establishment of lower concentration ratio controls when $CaCO_3$ limited
- Under estimation of sulfate salt scale potential ($CaSO_4$*$2H_2O$ $BaSO_4$ $SrSO_4$)
- Establishment of out-of-range maximum cycles when sulfate scale limited

A further complication of using simple indices for scale prediction is errors in dosage requirements calculated from their use. Dosage models calculate the minimum effective anti-scalant dosage as a function of parameters such as scale indices, temperature, and time. The errors in indices will be translated directly into the dosage recommendations. The same errors can affect limits for inhibitor performance. These errors can become significant when data from low TDS systems is extrapolated to high TDS waters using the simple indices.

The restrictions and limitations of historic modeling can be minimized or eliminated by their replacement with an ion association model speciation engine. The use of such tools is becoming commonplace on a user level in water chemistry areas such as cooling water, oil field brine chemistry, and reverse osmosis. In the past, sophisticated tools and calculation methods use was limited to university researchers, large end users such as utilities and oil companies, major water treatment service companies, high end consultants, and smaller water treatment service companies willing to invest in technology to differentiate themselves from their peers.

A computer program for modeling an open recirculating cooling water system might have the specific objectives of:

- Predicting and quantifying potential problems as a tower concentrates the make-up water.
- Determining the maximum cycles of concentration (aka concentration ratio) untreated, with pH control, and with scale and corrosion inhibitor feed.
- Optimizing treatment rates.

Other potential objectives might include the evaluation alternative make-up water sources and blends.

In achieving these objectives, the following must be included to reflect the operating system:

- The Physical System
- Make-up water ion concentration and chemistry as the water cycles
- pH prediction and Control
- Speciation and Scale Prediction
- Corrosion rates and control requirements
- Residence Time
- Minimum Effective Dosage

Scale Prediction and the Concept of Saturation

A majority of the indices used routinely by water treatment chemists are derived from the basic concept of saturation. A water is said to be saturated with a compound (e.g. calcium carbonate) if it will not precipitate the compound and it will not dissolve any of the solid phase of the compound when left undisturbed, under the same conditions, for an infinite period of time. A water which will not precipitate or dissolve a compound is at equilibrium for the particular compound.

By definition, the amount of a chemical compound which can be dissolved in a water and remain in solution for this infinite period of time is described by the solubility product (Ksp). In the case of calcium carbonate, solubility is defined by the relationship:

Equation 1 $(Ca)(CO_3) = Ksp$

where

- **(Ca)** is the activity of calcium
- **(CO_3)** is the carbonate activity
- **Ksp** is the solubility product for calcium carbonate at the temperature under study.

In a more generalized sense, the term $(Ca)(CO_3)$ can be called the Ion Activity Product (IAP) and the equilibrium condition described by the relationship:

Equation 2 $IAP = Ksp$

It can be shown that the Langelier Saturation Index is the base ten logarithm of calcite saturation level based upon total calcium in the water, an estimate of carbonate calculated from total alkalinity, and the solubility product for the calcite polymorph of calcium carbonate.2,5

The degree of saturation of a water is described by the relationship of the ion activity product (IAP) to the solubility product (Ksp) for the compound as follows:

- If a water is undersaturated with a compound: **$IAP < Ksp$** (It will tend to dissolve the compound).
- If a water is at equilibrium with a compound: **$IAP = Ksp$** (It will not tend to dissolve or precipitate the compound).
- If a water is supersaturated with a compound: **$IAP > Ksp$** (It will tend to precipitate the compound).

The ratio called Saturation Ratio, Degree of Supersaturation, or Saturation Level, describes the relative degree of saturation as a ratio of the ion activity product (IAP) to the solubility product (Ksp):

Equation 3:

$$\text{Saturation Ratio} = \frac{IAP}{Ksp}$$

Equation 4:

$$\text{Saturation Index} = \log10\,(\text{Saturation Ratio})$$

In actual practice, the saturation levels calculated by the various computer programs available differ in the method they use for estimating the activity coefficients used in the IAP; they differ in the choice of solubility products and their variation with temperature; and they differ in the dissociation constants used to estimate the concentration of reactants (e.g. CO_3 from analytical values for alkalinity, PO_4 from analytical orthophosphate). (5,6,7,8,9)

Table 1 defines the saturation ratio for common scale forming species and provides the basis for their discussion in this paper. Simple indices use analytical values for the ions, e.g. Ca. For example, by definition, the Langelier Saturation Index is the base ten logarithm of saturation level if calculated a) using analytical values rather than free ion concentrations, b) using an alkalinity which is not corrected for non-carbonate alkalinity, and c) using simple activity coefficients.

Some programs will output a Sauturation Index rather than a Saturation Ratio. The Saturation Index is be definition, the log10 of Saturation Ratio.

Ion Association in Cooling Water and Higher TDS Brines

Ions in solution are not all present as the free species. For example, calcium in water is not all present as free Ca.$^{+2}$ Other species form which are not available as driving forces for scale formation. Examples include the soluble calcium sulfate species, hydroxide species, and bicarbonate - carbonates. Table 2 outlines example species that can be present in a typical water.

Speciation of a water is time prohibitive without the use of a computer for the iterative calculations required. The process is iterative and involves:

1. Checking the water for a electroneutrality via a cation-anion balance, and balancing with an appropriate ion (e.g sodium or potassium for cation deficient waters, sulfate, chloride, or nitrate for anion deficient waters).
2. Estimating ionic strength, calculating and correcting activity coefficients and dissociation constants for temperature, correcting alkalinity for non-carbonate alkalinity.
3. teratively calculating the distribution of species in the water from dissociation constants
4. (a partial listing is outlined in Table 1).
5. Checking the water for balance and adjusting ion concentrations to agree with analytical values.
6. Repeating the process until corrections are insignificant.
7. Calculating saturation levels based upon the free concentrations of ions estimated using the ion association model (ion pairing).

The use of ion pairing to estimate the free concentrations of reactants overcomes several of the major shortcomings of traditional indices. Indices such as the LSI correct activity coefficients for ionic strength based upon the total dissolved solids. They do not account for "common ion" effects.(5) Common ion effects increase the apparent solubility of a compound by reducing the concentration of reactants available. A common example is sulfate reducing the available calcium in a water and increasing the apparent solubility of calcium carbonate. The use of indices which do not account for ion pairing can be misleading when comparing waters where the TDS is composed of ions which pair with the reactants versus ions which have less interaction with them.

When indices are used to establish operating limits such as maximum recovery or maximum pH, the differences between the use of indices calculated using ion pairing can be of extreme economic significance. In the best case, a system is not operated at as high a recovery as possible, because the use of indices based upon total analytical values resulted in high estimates of the driving force for a scalant. In the worst case, the use of indices based upon total ions present can result in the establishment of operating limits too high. This can occur when experience on a system with high TDS water is translated to a system operating with a lower TDS water. The high indices which were found acceptable in the high TDS water may be unrealistic when translated to a water where ion pairing is less significant in reducing the apparent driving force for scale formation.

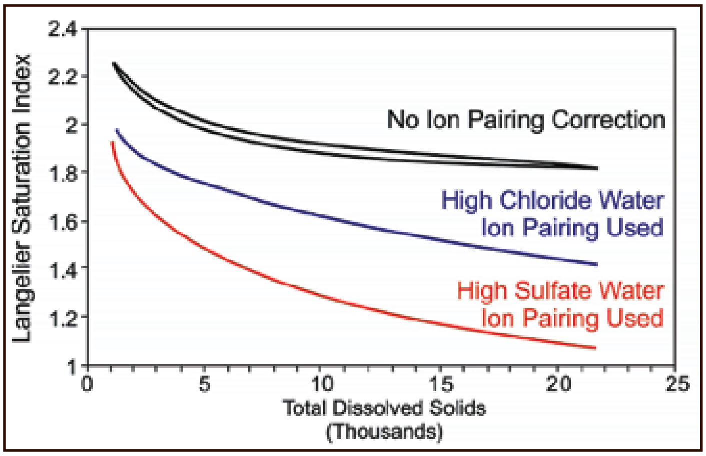
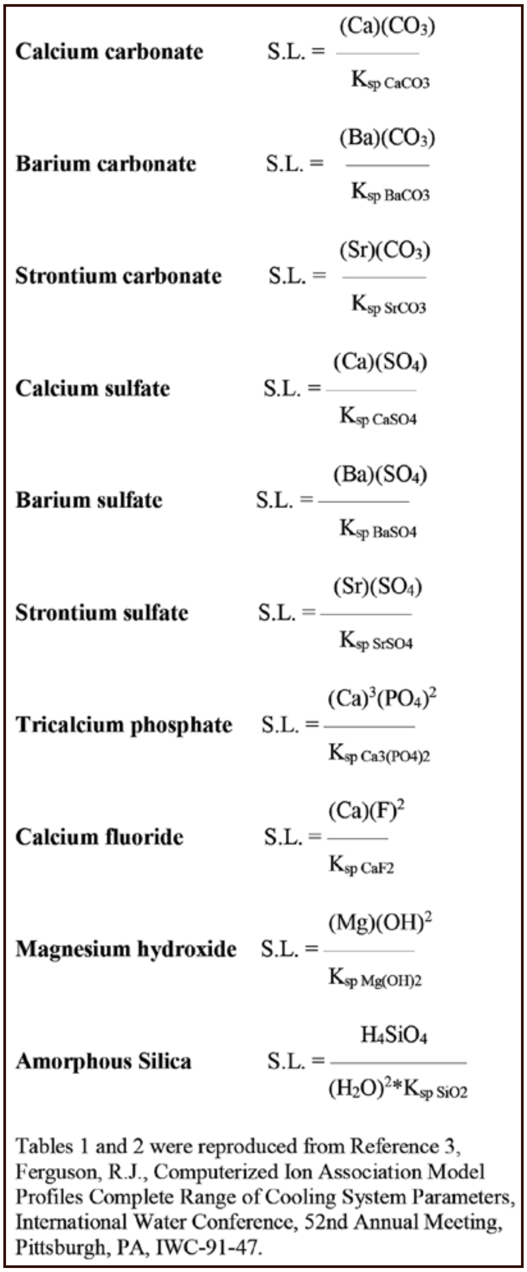


Figure 1 Ion Pairing Reduces LSI (Sulfate Effect Greater Than Chlorine)

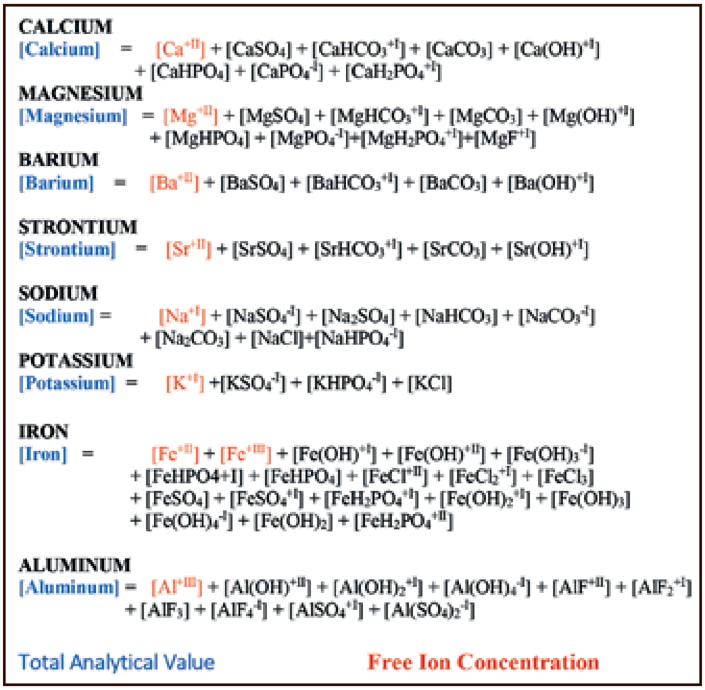


Calcium carbonate	$S.L. = \dfrac{(Ca)(CO_3)}{K_{sp\ CaCO3}}$
Barium carbonate	$S.L. = \dfrac{(Ba)(CO_3)}{K_{sp\ BaCO3}}$
Strontium carbonate	$S.L. = \dfrac{(Sr)(CO_3)}{K_{sp\ SrCO3}}$
Calcium sulfate	$S.L. = \dfrac{(Ca)(SO_4)}{K_{sp\ CaSO4}}$
Barium sulfate	$S.L. = \dfrac{(Ba)(SO_4)}{K_{sp\ BaSO4}}$
Strontium sulfate	$S.L. = \dfrac{(Sr)(SO_4)}{K_{sp\ SrSO4}}$
Tricalcium phosphate	$S.L. = \dfrac{(Ca)^3(PO_4)^2}{K_{sp\ Ca3(PO4)2}}$
Calcium fluoride	$S.L. = \dfrac{(Ca)(F)^2}{K_{sp\ CaF2}}$
Magnesium hydroxide	$S.L. = \dfrac{(Mg)(OH)^2}{K_{sp\ Mg(OH)2}}$
Amorphous Silica	$S.L. = \dfrac{H_4SiO_4}{(H_2O)^2 * K_{sp\ SiO2}}$

Tables 1 and 2 were reproduced from Reference 3, Ferguson, R.J., Computerized Ion Association Model Profiles Complete Range of Cooling System Parameters, International Water Conference, 52nd Annual Meeting, Pittsburgh, PA, IWC-91-47.

Table 1 - Saturation Level Formulas

Figure 1 compares the impact of sulfate and chloride on scale potential. The curves profile the calculation of the Langelier Saturation Index in the presence of high TDS. In one case the TDS is predominantly from a high chloride water. In the other case, a high sulfate water is profiled. Profiles for the index calculated based upon total analytical values are compared with those calculated with ion association model free ion activities.



CALCIUM

[Calcium] = $[Ca^{+II}] + [CaSO_4] + [CaHCO_3^{+I}] + [CaCO_3] + [Ca(OH)^{+I}] + [CaHPO_4] + [CaPO_4^{-I}] + [CaH_2PO_4^{+I}]$

MAGNESIUM

[Magnesium] = $[Mg^{+II}] + [MgSO_4] + [MgHCO_3^{+I}] + [MgCO_3] + [Mg(OH)^{+I}] + [MgHPO_4] + [MgPO_4^{-I}]+[MgH_2PO_4^{+I}]+[MgF^{+I}]$

BARIUM

[Barium] = $[Ba^{+II}] + [BaSO_4] + [BaHCO_3^{+I}] + [BaCO_3] + [Ba(OH)^{+I}]$

STRONTIUM

[Strontium] = $[Sr^{+II}] + [SrSO_4] + [SrHCO_3^{+I}] + [SrCO_3] + [Sr(OH)^{+I}]$

SODIUM

[Sodium] = $[Na^{+I}] + [NaSO_4^{-I}] + [Na_2SO_4] + [NaHCO_3] + [NaCO_3^{-I}] + [Na_2CO_3] + [NaCl]+[NaHPO_4^{-I}]$

POTASSIUM

[Potassium] = $[K^{+I}] +[KSO_4^{-I}] + [KHPO_4^{-I}] + [KCl]$

IRON

[Iron] = $[Fe^{+II}] + [Fe^{+III}] + [Fe(OH)^{+I}] + [Fe(OH)^{+II}] + [Fe(OH)_3^{-I}] + [FeHPO4+I] + [FeHPO_4] + [FeCl^{+II}] + [FeCl_2^{+I}] + [FeCl_3] + [FeSO_4] + [FeSO_4^{+I}] + [FeH_2PO_4^{+I}] + [Fe(OH)_2^{+I}] + [Fe(OH)_3] + [Fe(OH)_4^{-I}] + [Fe(OH)_2] + [FeH_2PO_4^{+II}]$

ALUMINUM

[Aluminum] = $[Al^{+III}] + [Al(OH)^{+II}] + [Al(OH)_2^{+I}] + [Al(OH)_4^{-I}] + [AlF^{+II}] + [AlF_2^{+I}] + [AlF_3] + [AlF_4^{-I}] + [AlSO_4^{+I}] + [Al(SO_4)_2^{-I}]$

Total Analytical Value

Free Ion Concentration

Table 2: Example Ion Pairs Used To Estimate Free Ion Concentrations

Alkalinity Correction for Non-carbonate Alkalinity

The use of simple indices can result in a much lower than required pH control point for the following reasons. The scale potential for calcium carbonate is over estimated in ammonia contaminated systems when simple indices are used to estimate scale potential and the alkalinity is not corrected for non carbonate alkalinity (e.g. ammonia). It is important to remember that a total "M" alkalinity titration measures the acid neutralizing capacity of the water, not just the carbonate and bicarbonate contributions.[10]

In neutral waters where carbonic acid equilibria is in complete control, simple indices such as the Langelier saturation index have their minimum error. In this case:

Equation 5:

$$ANC = 2.0 * [CO_3^{=}] + [HCO_3^{-}] + [OH^{-}] - [H^{+}]$$

The contribution of hydroxide to the Acid Neutralizing Capacity (ANC) is negligible near pH 7. Carbonate and bicarbonate concentrations can be estimated with reasonable accuracy.

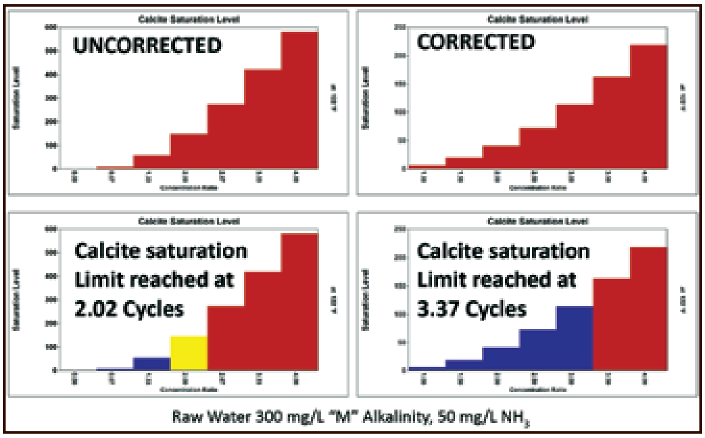
At higher pH, or when other alkalis such as ammonia are present:

Equation 6:

$$ANC = 2.0 * [CO_3^{=}] + [HCO_3^{-}] + [NH_3] + [PO_4] + [B(OH)_4] + [OH^{-}] - [H^{+}]$$

Hydroxide becomes an increasing contributor to Acid Neutralization Capacity as water pH increases above 7.0 . Ammonia and other alkali contributions can lead to very high estimates of carbonate and bicarbonate if the alkalinity (ANC) is not corrected for them prior to use in simple index calculation. Langelier noted the necessity of correcting for non-carbonate alkalinity in his original paper.(1) He also pointed out the desirability of including the impact of ion association and common ion effects in all but low TDS waters. The graphs in Figure 2 compare models with and without correction for non-carbonate in an ammonia contaminated system.

Failure to correct for non-carbonate alkalinity when using simple indices can result in the establishment of a much lower pH control point than is really necessary to minimize calcium carbonate scale potential. The lower control point can increase the difficulty in maintaining control in poorly buffered waters, and increase the sulfate based scale potential of the water due to the higher sulfates in the feedwater and brine. Ion association model saturation levels corrects for the errors introduced by non-carbonate alkalinity and high TDS and should be employed when available.(5)



Raw Water 300 mg/L "M" Alkalinity, 50 mg/L NH_3

Figure 2: The Impact of Non-carbonate Alkalinity Correction Upon Maximum Cycles

Acid Requirements in "Closed" versus "Open" Systems

Most modeling programs limit themselves to open recirculating cooling systems and assume free gas (CO_2) exchange with the atmosphere. This approach may be inappropriate for "once through" systems which are unvented and totally closed with respect to carbon dioxide exchange with the atmosphere. Calculations performed for "closed" systems assume that CO_2 produced by acid addition builds up in the system. Calculations performed for "open" systems assume that CO_2 produced by acid addition is removed from the system. Figure 3 compares acid requirements, and the resultant sulfate contributions, for pH control in a "closed" versus "open" system.

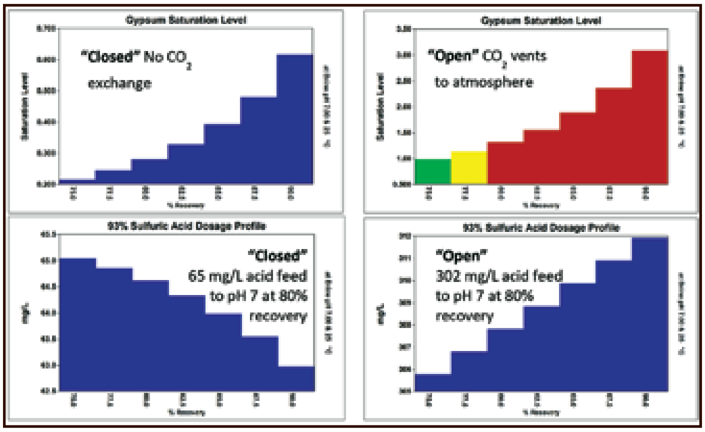


Figure 3: pH Control in Closed versus Open Systems (R.O. example)

In this case it can be seen that approximately five times is much acid is required for an "open" system rather than for a "closed" system. The difference is sufficient to create a calcium sulfate scale problem. Modeling software should be capable of treating a system as "closed" or "open" to assure that sulfate scale potential is evaluated accurately.

Kinetic Aspects

Thermodynamics tells you if a scale is likely to form. Thermodyamics can also indicate how much scale is likely to form through indicators such as "free ion" momentary excess, which describes the instantaneous precipitation (or dissolution) required to bring a water to equilibrium. Kinetics can tell you when the scale is likely to form, and the rate at which it will form. As outlined in this section, the thermodynamic and kinetic models are intimately related.

Saturation level calculations, and even simple indices, indicate whether or not scale is likely to form, or dissolve, if left undisturbed for an infinite period of time. Residence times in industrial systems such as reverse osmosis and cooling systems are significantly less than infinity. The thermodynamic based indices, such as ion association model saturation ratios, tell you whether or not scale is likely to form. Kinetics tell you when it is likely to form, and if it will form before the water passes through the cooling system and is safely discharged. A criticism of thermodynamic based indices is that they only tell you what will happen at time equals infinity. This section discusses induction time, its relationship to thermodynamic based saturation levels, and the relevance of thermodynamic indices under actual cooling water chemistry, temperature, and residence times.

Induction Time: When reactants are mixed, a solution is heated, cooled, undergoes a pressure change or is otherwise perturbed, the impact of the environmental changes is not immediate. A finite time passes before the perturbation affects any susceptible reaction. In the case of scale formation, induction time can be defined as the time before a measurable phase change (precipitation or growth) occurs after perturbation. In a pure system, with only the reactants present such as calcium and carbonate, or barium and sulfate, scale formation might proceed as follows:

1. Aqueous calcium carbonate molecules congregate and form larger and larger clusters.
2. The clusters grow to a critical size and overcome the "activation energy" needed for the change from the "aqueous" to "solid" phase to occur.
3. The phase change is then observed. In the case of $CaCO_3$, pH drops as the salt changes phase, and the induction time can be defined.
4. Crystals will then grow.

Induction time has been studied extensively for industrial processes. In the case of sucrose crystallization, the objective is to minimize induction time and maximize crystallization. In the case of scale control, the objective is to extend the induction time until a water has safely passed through the cooling system, or other process adversely affected by scale. The induction time, in the absence of scale inhibitors, has been modeled for common scales, including barite ($BaSO_4$) and calcite ($CaCO_3$).(15) Figures 4 and 5 are derived from this, and related works by Mason Tomson and his graduate students at Rice University.

Figure 4 profiles the untreated induction time for calcite in the practical operational range for calcite of 0 to 150x saturation. This range was chosen because it is the effective range for most scale inhibitors. The 150x saturation level limit is a commonly accepted upper limit for operation with common inhibitors such as phosphonates and polymers. Figure 5 profiles the saturation level range for barite, 0 to 80x saturation.

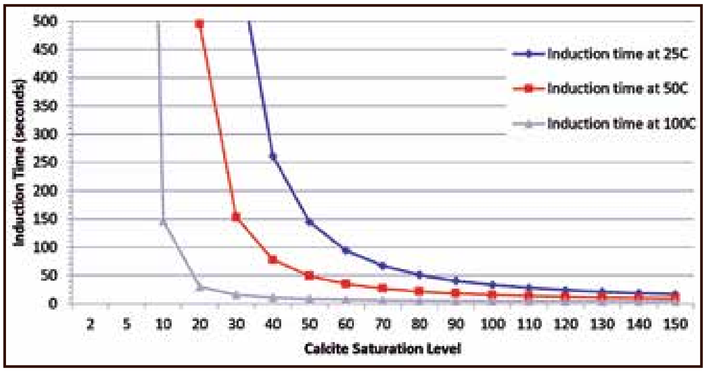


Figure 4: Induction Time vs Calcite Saturation Level

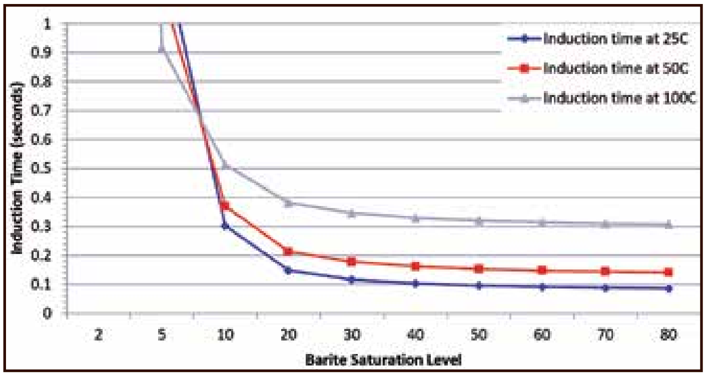


Figure 5: Induction Time vs Barite Saturation Level

It should be noted that the induction times for both calcite and barite are several orders of magnitude below the typical residence time in open recirculating and many once through systems. As a result, the use of the thermodynamic saturation ratios for predicting scale is accurate and an acceptable practice in typical operating ranges.

Actual induction times in industrial systems will typically be lower than those of a pure system. Existing "seed" crystals and deposits provide a substrate for crystal growth without the necessity for achieving the "activation energy" for the initial phase change. In other words, it is easier to keep a clean system clean than to keep a dirty system from getting dirtier. Other factors can also decrease induction time.

Although beyond the scope of this paper, it should be noted that scale formation in membrane systems is typically "second order" for bulk water precipitation. Once through systems, such as potable water and utility condenser cooling systems, tend to be closer to "first order" for growth on an existing substrate.(16, 17)

Dosage Optimization

Induction Time: The Key To The Models

Reactions do not occur instantaneously. A time delay occurs once all of the reactants have been added together. They must come together in the reaction media to allow the reaction to happen. The time required before a reaction begins is termed the induction time.

Thermodynamic evaluations of a water scale potential predict what will happen if a water is allowed to sit undisturbed under the same conditions for an infinite period of time. Even simplified indices of scale potential such as the ion association model saturation index can be interpreted in terms of the kinetics of scale formation. For example, calcium carbonate scale formation would not be expected in an operating system when the saturation index for the system only slightly above 1.0 x saturation. The driving force for scale formation is too low for scale formation to occur in finite, practical system residence times. Scale would be expected if the same system operated with a saturation index of 50. The driving force for scale formation in this case is high enough, and induction time short enough, to allow scale formation in even the longest residence time systems. (12) Scale inhibitors don't prevent precipitation, they delay the inevitable by extending induction time.(10,11,12)

Equation 7:

$$\text{Induction Time} = \frac{1}{k\,[\text{Saturation Ratio} - 1]^{P-1}}$$

Where:

Induction Time is the time before crystal formation and growth occurs;

k is a temperature dependent constant;

Saturation Ratio is the degree of super-saturation;

P is the critical number of molecules in a cluster prior to phase change

Temperature is a second parameter affecting dosage and is represented by the temperature dependent constant k in formula 3. A common concept in basic chemistry is that reaction rates increase with temperature. The rule-of-thumb frequently referenced is that rates approximately double for every ten degrees centigrade increase in temperature. The temperature constant above was found to correlate well with the Arrhenius relationship, as outlined in equation 8.

Equation 8: $K = A\,e^{Ea/RT}$

Where:

k is a temperature dependent constant;

Ea is activation energy;

R is the Gas Constant;

T is absolute temperature.

Models for optimizing dosage demonstrate the impact of dosage on increasing induction time. An example is profiled in Figure 6. Saturation level and temperature impacts upon the dosage requirement to extend induction time are depicted in figures 6 and 7. Factors impacting the anti-scalant dosage required to prevent precipitation are summarized as follows:

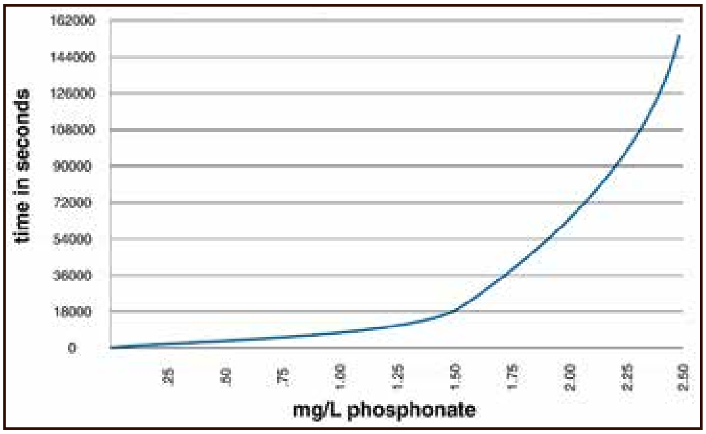


Figure 6: Induction Time vs Phosphonate Dosage
(at constant temperature and calcite saturation ratio)

Time ¬ The time selected is the residence time the inhibited water will be in the cooling system. The inhibitor must prevent scale formation or growth until the water has passed through the system and been discharged. Figure 6 profiles the impact of induction time upon dosage with all other parameters held constant.

Degree of Supersaturation ¬ An ion association model saturation level is the driving force for the model outlined in this paper, although other, similar driving forces have been used. Calculation of driving force requires a complete water analysis, and the temperature at which the driving force should be calculated. Figure 7 profiles the impact of saturation level upon dosage, all other parameters being constant.

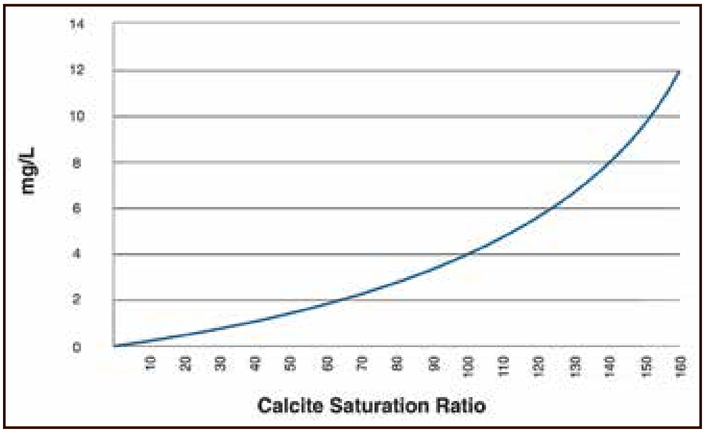


Figure 7: Phosphonate Dosage vs Calcite Saturation Ratio
(at constant temperature and induction time)

Temperature ¬ Temperature affects the rate constant for the induction time relationship. As in any kinetic formula, the temperature has a great impact upon the collision frequency of the reactants. This temperature effect is independent of the effect of temperature upon saturation level calculations. Figure 8 profiles the impact of temperature upon dosage with other critical parameters held constant.

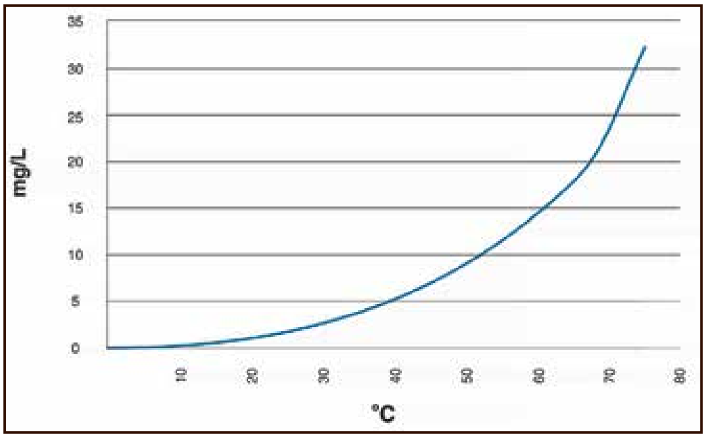


Figure 8: Phosphonate Dosage vs Temperature
(at constant temperature and induction time)

pH ¬ pH affects the saturation level calculations, but it also may affect the dissociation state and stereochemistry of the inhibitors(18). Inhibitor effectiveness can be a function of pH due to its impact upon the charge and shape of an inhibitor molecule. This effect may not always be significant in the pH range of interest (e.g. 6.5 to 9.5 for cooling water).

Active sites It is easier to keep a clean system clean than it is to keep a dirty system from getting dirtier. This rule of thumb may well be related to the number of active sites for growth in a system. When active sites are available, scale forming species can skip the crystal formation stage and proceed directly to crystal growth.

Equation 9 adds the impact of inhibitor dosage on extending induction time to equation 7. The goal of the inhibitor dosage is to extend the time before precipitation until the treated water has passed through the system and precipitation will no longer be a threat to membrane life.

Equation 9:

$$\text{Induction Time} = \frac{[\text{inhibitor}]^{M}}{k\,[\text{Saturation Ratio} - 1]^{P-1}}$$

Other factors can impact dosage such as suspended solids in the water. Suspended solids can act as sources of active sites and can reduce the effective inhibitor concentration in a water by adsorption of the inhibitor.

State-of-the-art RO modeling software should incorporate the ability to optimize dosages for all of the scales expected.

Inihibitor Upper Limits

Scale inhibitors have upper limits and are not effective above saturation level driving force, regardless of the inhibitor dosage. Table 3 outlines generally accepted limits for inhibition of scales by standard commercially available inhibitors. Limits are provided for both standard inhibitors and for those formulated for extreme, "stressed" conditions.

SCALE FORMING SPECIE	FORMULA	MINERAL NAME	TYPICAL SATURATION RATIO LIMIT	STRESSED TREATMENT LIMIT
Calcium carbonate	$CaCO_3$	Calcite	135 - 150	200 - 225
Calcium sulfate	$CaSO_4*2H_2O$	Gypsum	2.5 - 4.0	4.0 +
Barium sulfate	$BaSO_4$	Barite	80	80+
Strontium sulfate	$SrSO_4$	Celestite	12	12
Silica	SiO_2	Amorphous silica	1.2	2.5
Tricalcium phosphate	$Ca_3(PO_4)_2$		1500 - 2500	125,000

Table 3: Treated Limits Comparison

Inhibitors have an upper driving force that they can handle. Once this upper limit is reached, even increasing inhibitor dosage drastically will not provide scale control.

Upper limits can be determined by a series of induction time test at various saturations and dosages. The limit is the last saturation ratio where scale could be controlled. Ohers may use a pilot system and recovery increased until scale control cannot be achieved regardless of inhibitor dosage.

A "Progressive Carbonate Test" can be used to estimate upper limits in a reasonable period of time for calcium carbonate.(18) Two solutions were prepared for the test:

- An anion solution of bicarbonate and carbonate.
- A cation solution of calcium.

The scale inhibitor, or blend being tested is included in the anion solution. No inhibitor is added for the blank, untreated, tests.

The test is initiated by mixing the cation and anion solutions. pH is monitored as anion solution is added to the mixture. The additional anion solution increases carbonate, pH, and the calcium carbonate saturation ratio. The upper limit for the inhibitor is indicated by loss of control, and a drop in pH as calcium carbonate precipitates. The solution is also observed for turbidity. Figure 9 profiles a typical plot of pH as the solution is "titrated" to the upper saturation limit for the inhibitor.

Care must be taken in the experimental design so that the solubility of inhibitor salts does not interfere, such as through the formation of Ca-HEDP. The time for the test must also be less than the treated induction time to prevent precipitation other than that from exceeding the upper limit. Similar procedures can be used to estimate and compare upper limits for other scales, e.g. a Progressive Sulfate test.

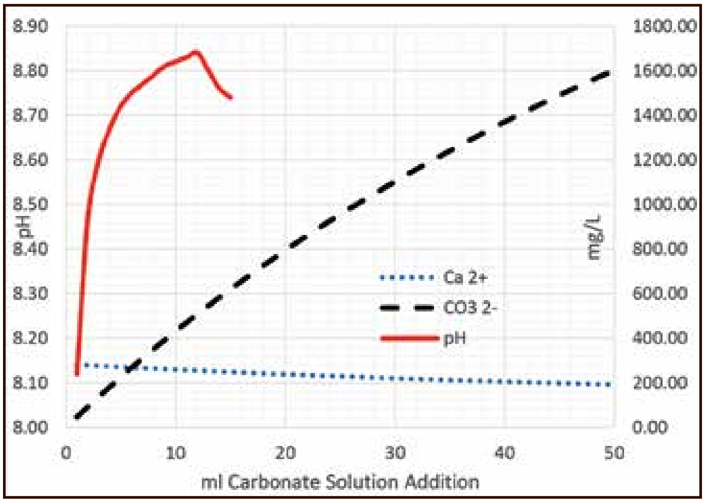


Figure 9: Example Progressive Carbonate Test Plot

Inihibitor Dissociation

The dissociation state of a scale inhibitor has a significant effect upon inhibitor efficacy. The dissociated form of the inhibitor has been demonstrated to be the active species responsible for scale control in industrial water treatment. Basing treatment dosages upon the active specie, rather than total inhibitor concentration, allows for improved accuracy of dosage models, and an increased effectiveness of treatment optimization. A knowledge of the dissociation constant for scale inhibitors is necessary to calculate the active specie fraction of the total inhibitor dosage. The pK_a for inhibitors decreases, and active fraction present increases with increase in temperature, increase in ionic strength (TDS), and as pH increases. The relationships can be quantified using standard chemistry calculations for weak acids and the properties profiles for various inhibitors measured using standard analytical techniques.(19)

Equations 10, 11 and 12 plot α, the dissociation fraction, versus pH, and provide the basis for calculating the dissociated and protonated inhibitor specie concentrations. A rigorous calculated procedure can be found in Ferguson, 2015.

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.

Equation 11 can be used to calculate the dissociated and protonated inhibitor form concentrations, so that inhibitor models can be developed using correlations to the active (dissociated) form rather than the total inhibitor concentration.

Equation 10: H-Inhibitor <--> H^+ + Inhibitor^-

Equation 11: $K_a = \{H^+\}\{\text{Inhibitor-}\}/\{\text{H-Inhibitor}\}$

Equation 12: $pK_a = -\log10(K_a)$

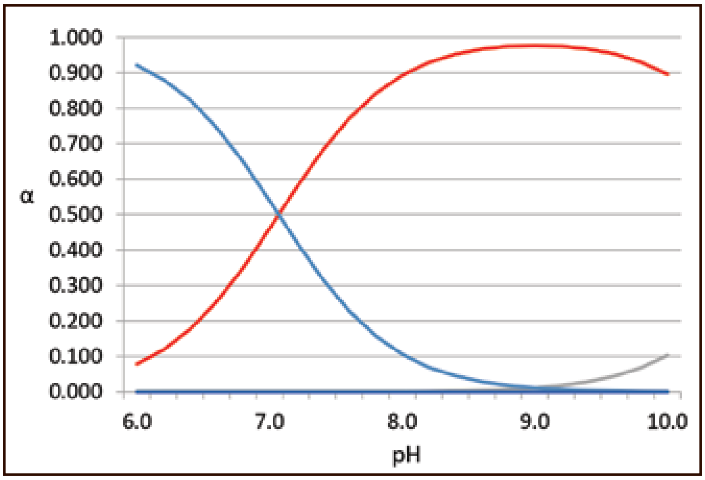


Figure 10: HEDP Distribution of Species

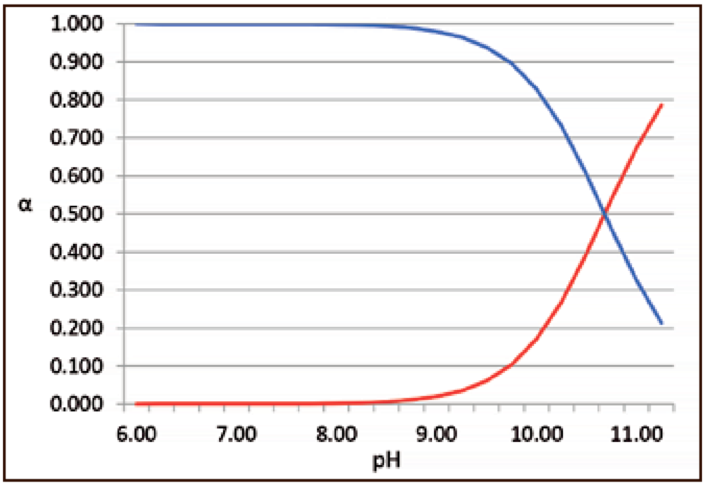


Figure 11: AA-AMPS Distribution of Species

Figures 10 and 11 profile the dissociated and protonated form concentrations for two common inhibitors HEDP, and AA-AMPS. It should be noted that the phosphonate HEDP is over 90% dissociated in the pH range of interest for membrane systems, while the copolymer AA-AMPS is predominantly in the inactive protonated form in the pH range of interest.

Figures 12, 13 and 14 demonstrate the importance of developing models to the active inhibitor form, rather than the total inhibitor concentration.

Figure 12 compares the predicted and observed minimum effective dosages calculated using a model developed using a form of Equation 9, and the total inhibitor concentrations. Note the three distinct scatter curves.

The data was developed in jar tests at pH 7, 8 and 9. Adding pH to the model increased the correlation significantly as depicted in Figure 13.

Correlating to the dissociated active state dramatically increased to goodness of fit as can be seen in Figure 14.

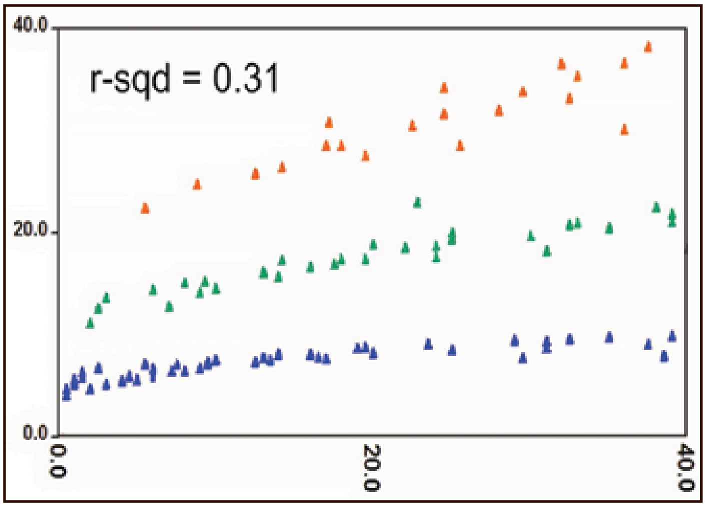


Figure 12: Basic Model

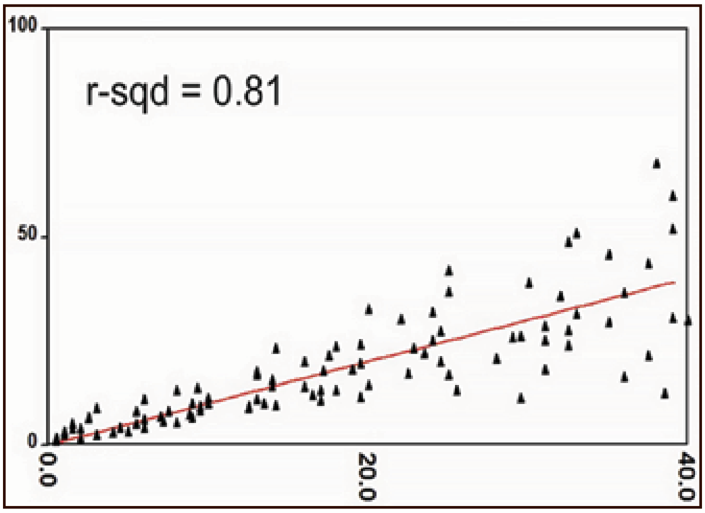


Figure 13: pH Added to Model

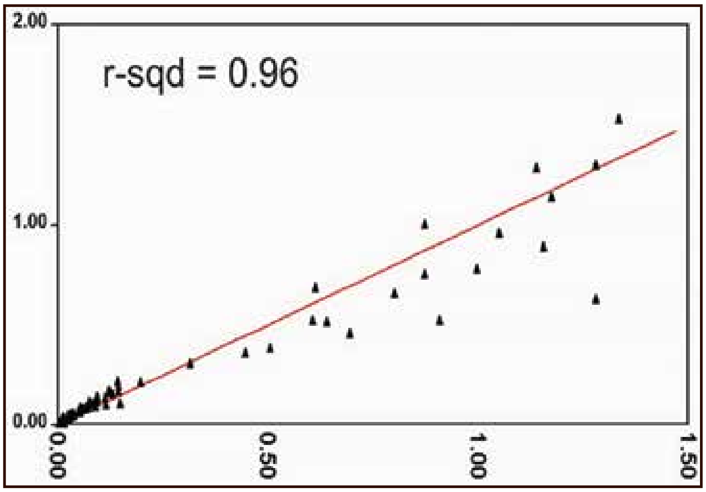


Figure 14: Correlated to Dissociated Form

Inihibitor Synergy

It has been known that blending inhibitors can increase the upper limit. The combination of a phosphonate and polymaleic anhydride (PMA), for example, has been observed to raise the upper limit well above that of the phosphonate alone. Not all combinations or ratios show this positive effect. Possibilities for the impact of inhibitor blends on the upper limit include:


aggreko
aggreko
aggreko
aggreko
aggreko

Aggreko Cooling Tower Services

Supplemental cooling

Emergency cooling tower replacement

Thermal discharge cooling

Planned cooling tower repair

Exchanger isolation

- The limit for the blend would be the lower of the limits for the inhibitors in the blend
- The limit would be a weighted average of the limit for each inhibitor when applied alone.
- The limit would be the higher of the limits for the individual inhibitors in the blend.
- The new limit would be higher than the limit for any of the inhibitors in the blend.

A laboratory study reproduced the impact of polymaleates observed in field applications when blended with PBTC, and for the phosphonate blend of HEDP and ATMP . The study measured the upper saturation ratio limit for calcium carbonate for the individual inhibitors, and when blended in various ratios.(20) Two solutions were prepared:

- An anion solution of bicarbonate and carbonate.
- A cation solution of calcium.

The scale inhibitor, or blend being tested is included in the anion solution. No inhibitor is added for the blank, untreated, tests.

The test is initiated by mixing the cation and anion solutions. pH is monitored as anion solution is added to the mixture. The additional anion solution increases carbonate, pH, and the calcium carbonate saturation ratio. The upper limit for the inhibitor is indicated by loss of control, and a drop in pH as calcium carbonate precipitates. The solution is also observed for turbidity. Figure 10 profiles a typical plot of pH as the solution is "titrated" to the upper saturation limit for the inhibitor.

Care must be taken in the experimental design so that the solubility of inhibitor salts does not interfere, such as through the formation of Ca-HEDP. The time for the test must also be less than the treated induction time to prevent precipitation other than that from exceeding the upper limit.

In Search Of Upper Limit Synergy: Results

PBTC:PMA Combination:

The combination of PBTC and PMA demonstrated the most dramatic impact of blending upon the upper saturation limit, as depicted in Figure 16. As the blend ratio in the test goes from polymer only to phosphonate only, there appears to be a drop in the upper limit at high polymer to PBTC ratios, possibly indicating an antagonistic effect when the polymer is the primary inhibitor. The upper limit failure point increases to a maximum at a ratio of 3 to 1 PBTC to polymer, with the upper limit of the higher ratios indicating a synergy between the PBTC and lower levels of PMA. This trend has been observed in field applications.

Antagonism might occur as a result of polymer adsorbing near newly formed active sites and blocking the PBTC from nearby active sites, or by changing the surface charge to decrease attraction. In this case, the upper limit for the blend would be expected to have a lower limit than either inhibitor alone.

Synergy might occur as a result of polymer attaching near newly formed active sites and by changing the surface charge to increase the attraction of PBTC to nearby active sites. In this case, the upper limit for the blend would be expected to have a higher limit than either inhibitor alone.

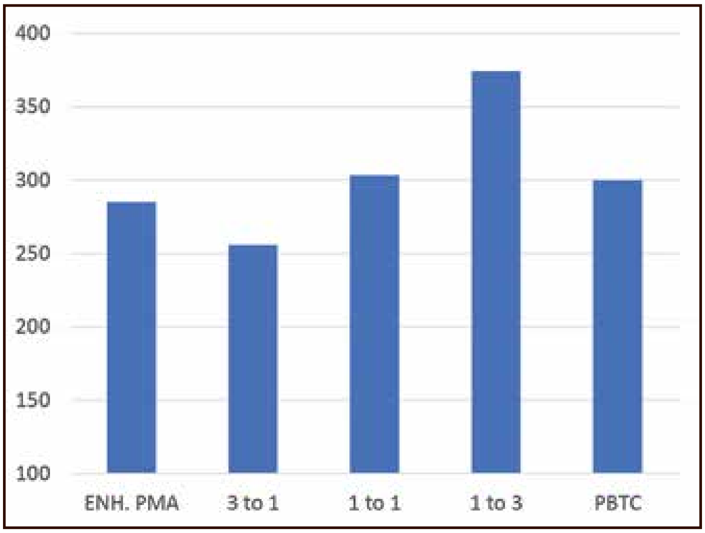


Figure 15: Impact of Polymer to Phophate Ratio Upon Maximum Saturation for Enhanced PMA and PBTC

Concentration Cells

Concentration cells are a phenomena whereby ion concentrations in the boundary layer at water tube-wall interfaces, for example, are projected to be higher than those of the bulk water. This effect is similar to concentration polarization in reverse osmosis systems.(14)

Concentration cells can, in theory, affect all concentration dependent calculations including:

- pH;
- ion concentrations;
- concentration ratio limits for treated and untreated conditions;
- maximum cycles based upon antiscalant saturation ratio upper limit;
- dosage.

In practice, the residence time of water in the boundary layer is insignificant with respect to its impact on dosage calculations. The much longer residence time at the lower bulk water saturation level provides a dosage higher than is required for the higher saturation level, much, much shorter residence time in the boundary layer. The exception to this observation is the case where the saturation level in the boundary layer will exceed the antiscalant maximum saturation level limit. For example, if a calcite inhibitor has a saturation level upper limit of 150x saturation, and the projected boundary layer saturation level is 175x, cycles should be decreased, and/or pH decreased so that the projected boundary layer saturation level is under 150x saturation.

Application Of The Models

Figures 16 and 17 profile calcite scale potential and dosage requirements for a common commercial inhibitor, 30% active polyacrylic acid. The model incorporates cut-off limits beyond where the inhibitor is unable to prevent scale. Limit summaries assist in assuring that a treatment scheme will handle all potential scales at the target operating pH and recovery. Table 4 summarizes the status for the treatment at four (4) cycles and a pH of 8.4


CCond (S11) 3040 µS/cm
Temp (S12) 77.1 °F
Flowmeter (D2) 2900 gal
WALCHEM

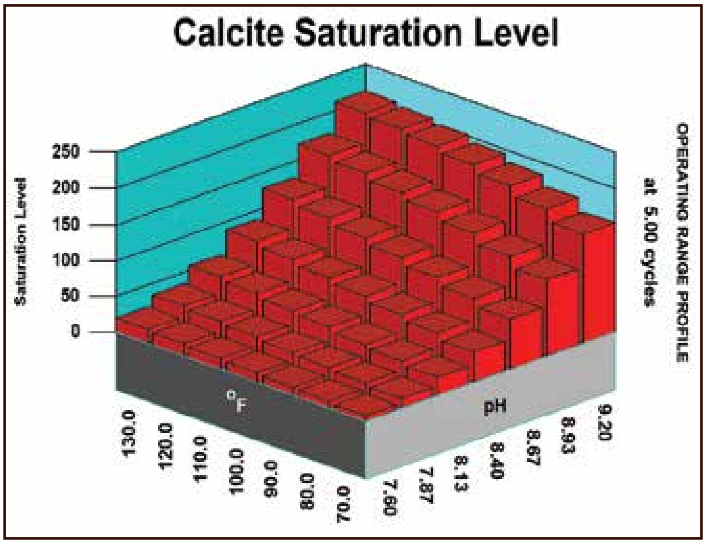


Figure 16: CaCO^3 Scale Potential

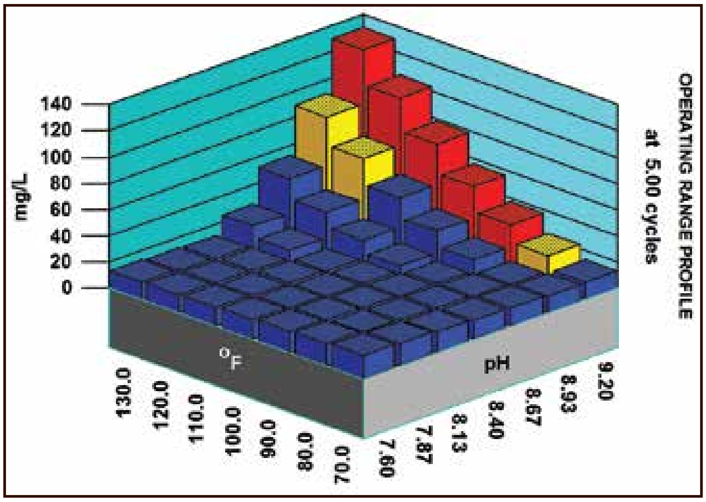


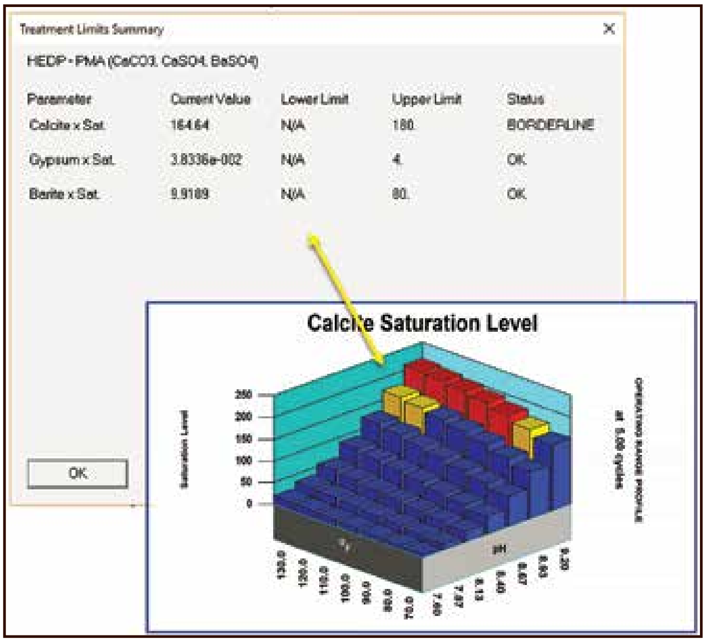
Figure 17: Inhibitor Dosage Profile

A program should also include the capability of checking current saturation ratio versus the upper limit for the current treatment. This allows a user to determining why a graph is turning a warning color, and to check how close a system is operating near the treatment limits.

Comparing "Actual" to "Theoretical" Recirculating Water Chemistry

Summary printouts provide useful tools for evaluating scale precipitation and accuracy of projections for pH, and recirculating water chemistry. A comparison of the "Actual" measured water chemistry to the calculated "Theoretical" recirculating water chemistry provides insight into accuracy of pH predictions and acid feed, and precipitation.

The "Theoretical" value is what would be expected at the target concentration ratio. For example, if the makeup calcium concentration in 36.4 mg/L as Ca, 182 mg/L would be expected at a concentration ratio of 5.0 If a significantly lower concentration is observed, and other values are in line, calcium precipitation might be expected, Check "theoretical" versus "actual" alkalinity to check on $CaCO_3$ precipitation, or check "theoretical" versus "actual" SO_4 to check on $CaSO_4$ precipitation.

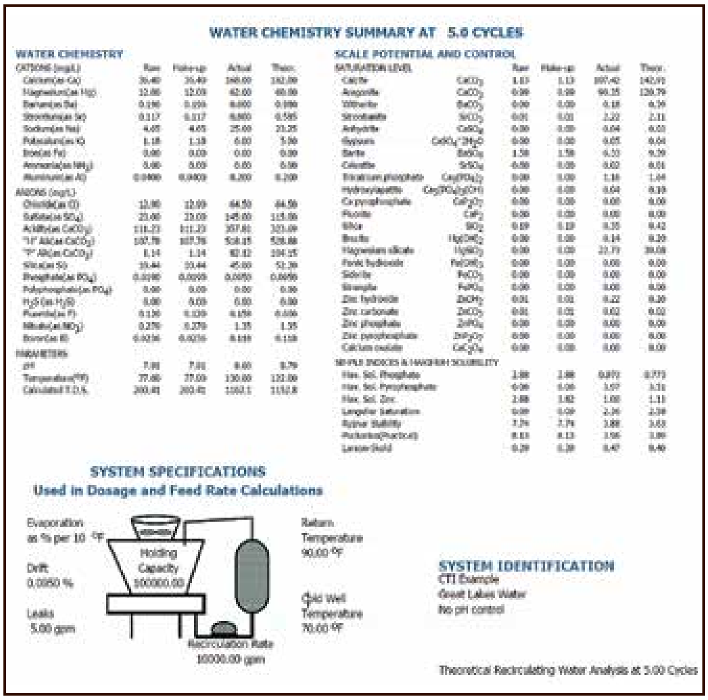


Treatment Limits Summary

HEDP - PMA (CaCO3, CaSO4, BaSO4)

Parameter	Current Value	Lower Limit	Upper Limit	Status
Calcite x Sat.	164.64	N/A	180.	BORDERLINE
Gypsum x Sat.	3.8336e-002	N/A	4.	OK
Barite x Sat.	9.9189	N/A	80.	OK

Table 4: Treatment Status at ph 8.9 and 130 °F



WATER CHEMISTRY SUMMARY AT 5.0 CYCLES

WATER CHEMISTRY

SCALE POTENTIAL AND CONTROL

SYSTEM SPECIFICATIONS
Used in Dosage and Feed Rate Calculations

Evaporation as % per 10 °F

Drift 0.0050 %

Leaks 5.00 gpm

Holding Capacity 100000.00

Recirculation Rate 10000.00 gpm

Return Temperature 90.00 °F

Cold Well Temperature 70.00 °F

SYSTEM IDENTIFICATION
CTI Example
Great Lakes Water
No pH control

Theoretical Recirculating Water Analysis at 5.00 Cycles

Table 5: Water Chemistry Summary at 5.0 Cycles0

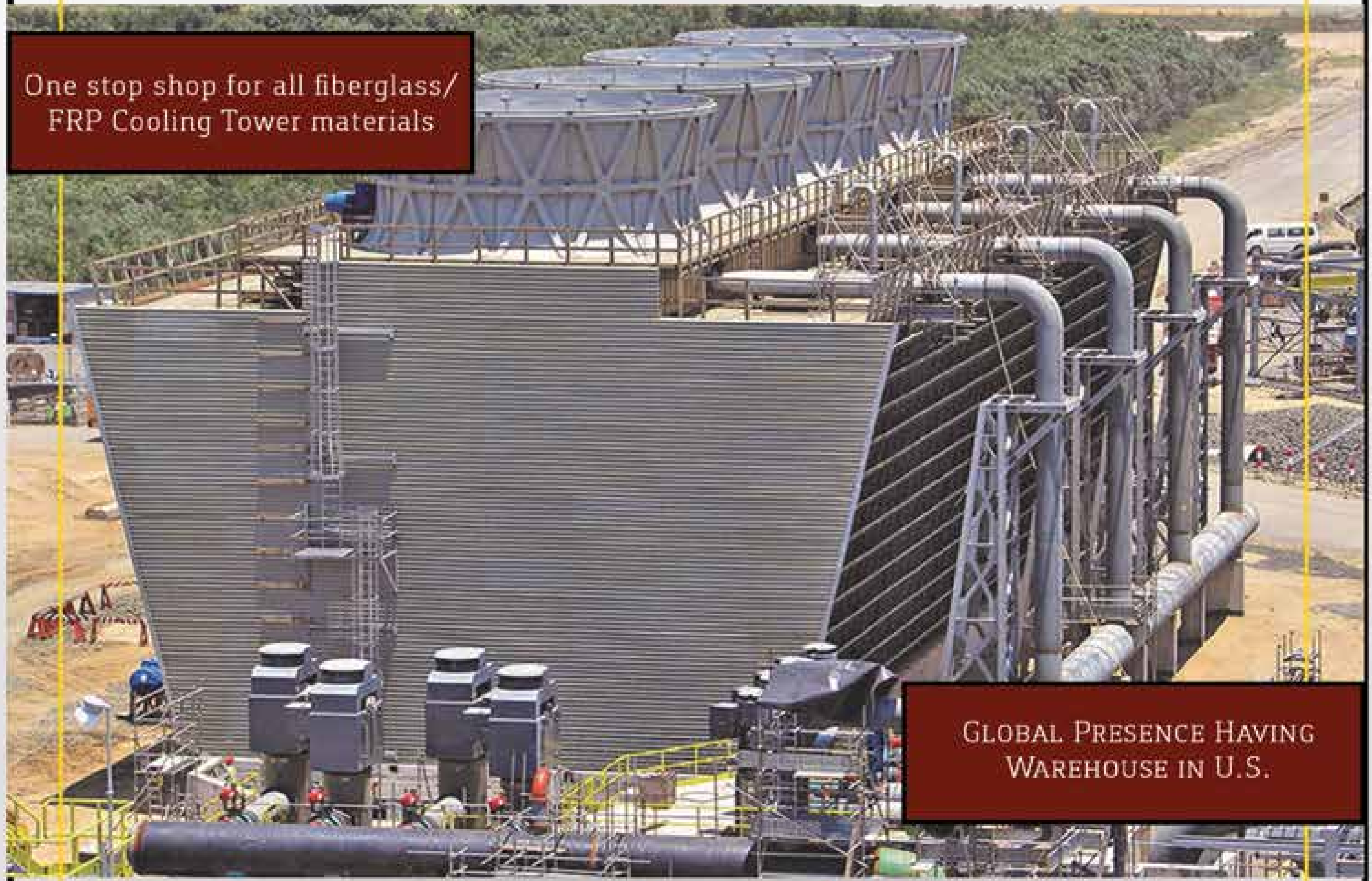
Table 5 summarizes the chemistry for a Great Lakes water at a concentration ratio of 5.0 (five).

Summary

Classic cooling water models lack accuracy as TDS, pH, and alkalinity increase due to the use of simple indices that are accurate only at low TDS and near neutral pH. They suffer from the same shortcomings pointed out by Langelier in 1936.

State-of-the-art calculations include calculation methods which overcome the limitations of prior art and allow accurate modeling in high TDS systems including those for water reuse and zero liquid discharge. Refinements provided include corrections for non-

ARVIND
COMPOSITES



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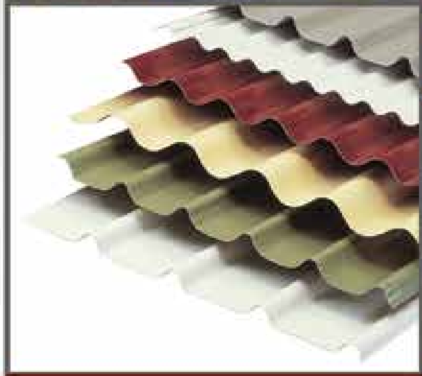

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carbonate alkalinity, the use of free ion concentrations and activities for driving force calculations. They also provide options for treating systems "Closed" or "Open" with respect to carbon dioxide equilibrium with the atmosphere to improve the accuracy of carbonate equilibria and pH adjustment calculations.

Dosage models are available or can be developed for new inhibitors, that allow accurate prediction of dosage requirements and treatment failure points. State-of-the-art inhibitor models for minimum effective dosages should be correlated to the dissociated (active) form of the inhibitor molecule(s) rather than to the total inhibitor concentrations. Tests such as the Progressive Carbonate Test can be used to determine the upper saturation ratio limit for individual inhibitors as well as blends. Inhibitor ratios can be optimized in blends to achieve a synergy and highest saturation ratio limit.

The same methods used to model the scale potential for mineral scale forming species can also be applied to inhibitor solubility. Dosage models can also be developed for controlling inhibitor precipitation in the presence of high cation concentrations.

Application of technologies from high TDS related water treatment applications such as oil field chemistry, can be successfully adapted and applied to upgrading the modelling of scale formation and control in cooling water systems as long as application specific characteristics and algorithms are employed in the models.

References

1. Langelier, W.F., The Analytical Control Of Anti-Corrosion Water Treatment, JAWWA, Vol. 28, No. 10, p. 1500-1521, 1936.
2. Ryznar, J.W., A New Index For Determining The Amount Of Calcium Carbonate Scale Formed By Water, JAWWA, Vol. 36, p. 472, 1944.
3. Stiff, Jr., H.A., Davis, L.E., A Method For Predicting The Tendency of Oil Field Water to Deposit Calcium Carbonate, Pet. Trans. AIME 195;213 (1952).
4. Oddo, J.E., Tomson, M.B.,Scale Control, Prediction and Treatment Or How Companies Evaluate A Scaling Problem and What They Do Wrong, CORROSION/92, Paper No. 34, (Houston, TX:NACE INTERNATIONAL 1992).
5. Ferguson, R.J., Computerized Ion Association Model Profiles Complete Range of Cooling System Parameters, International Water Conference, 52nd Annual Meeting, Pittsburgh, PA, IWC-91-47.
6. W. Chow, J.T. Aronson, W.C. Micheletti, Calculations Of Cooling Water Systems: Computer Modeling Of Recirculating Cooling Water Chemistry, International Water Conference, 41rst Annual Meeting, Pittsburgh, PA, IWC-80-41.
7. Johnson, D.A., Fulks, K.E.,Computerized Water Modeling In The Design And Operation of Industrial Cooling Systems, International Water Conference, 41rst Annual Meeting, Pittsburgh, PA, IWC-80-42.
8. Truesdell, A.H., Jones, B.F., WATEQ - A Computer Program For Calculating Chemical Equilibria Of Natural Waters, J. Research, U.S. Geological Survey, Volume 2, No. 2, p. 233-248, 1974.
9. Musil, R.R., Nielsen, H.J., Computer Modeling Of Cooling Water Chemistry, International Water Conference, 45th Annual Meeting, Pittsburgh, PA, IWC-84-104.
10. Werner Stumm and James J. Morgan, Aquatic Chemistry, John Wiley & Sons, Inc,, New York, 1996, pp 138 - 140.
11. Gill, J.S., Anderson, C.D., Varsanik, R.G., Mechanism Of Scale Inhibition By Phosphonates, International Water Conference, 44th Annual Meeting, Pittsburgh, PA, IWC-83-4.
12. Amjad, Z., Masler,III, W.F., The Inhibition Of Calcium Sulfate Dihydrate Crystal Growth By Polyacrylates And The Influence Of Molecular Weight, CORROSION/85, Paper No. 357, Houston, TX: NACE INTERNATIONAL, 1985).
13. Ferguson, R.J., Developing Scale Inhibitor Models, WATERTECH, Houston, TX, 1992.
14. Byrne, Wes, Reverse Osmosis A Practical Guide For Industrial Users, Tall Oaks Publishing, Inc., Littleton, CO, 2002, pp 158, 457 - 458.
15. Tomson, M.B., Fu, G., Watson, M.A. and A.T. Kan, "Mechanisms of Mineral Scale Inhibition, Society of Petroleum Engineers, Oilfield Scale Symposium, Aberdeen, UK, 2002.
16. Ferguson, R.J., A Kinetic Model for Calcium Carbonate Scale, CORROSION/84,Paper No. 46, (Houston, TX:NACE INTERNATIONAL 1984).
17. Ferguson, R.J., Thirty Years of Ultra Low Dosage Scale Control , CORROSION/2003,Paper No. 063, (Houston, TX:NACE INTERNATIONAL 2003).
18. Ferguson, R.J., Standish, C., "Developing Realistic Laboratory Test Methods and Models: CaCO3," Association of Water Technologies, 2017.
19. Ferguson, R.J., Standish, M., "The Impact of Inhibitor Speciation on Efficacy: pH, Ionic Strength and Temperature Impact," Association of Water Technologies, 2015.
20. Ferguson, R.J., Standish, C., "In Search of Synergy," Association of Water Technologies, 2016

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Utilizing New Technology to Provide Comprehensive Asset Management for Cooling Tower Maintenance

Glenn Schaefer and Eric Koehler
Structural Technologies

Introduction

For illustrative purposes, the bulk of this paper will consider the exterior concrete shell of a cooling tower in our examples. Cooling tower assessments / inspections are recognized as a practical and necessary aspect of regular monitoring of the structure's condition. Historically, these inspections and assessments have produced "snap-shots" in time that document the current condition with a focus on safety (i.e. falling concrete hazard) and conditions that are related to long term performance (i.e. spalling and corrosion of embedded reinforcement). Since these inspections traditionally required considerable time on site and complex rigging of swing stages and work platforms, they were often expensive and typically have to coincide with shut-downs. As a result, regular periodic assessments / inspections were not always the norm. Finally, there was little thought given to what could be done with the data / information gathered other than to produce an archival report and execute repairs on the highest priority issues.

Glenn Schaefer

Background

Cooling towers are massive vertical structures that impose challenges when a condition assessment or inspection is performed. Traditionally, highly specialized skills, specialized equipment, and significant time are required to inspect these structures. But, new technologies are emerging which address these challenges, while improving safety, saving time, and reducing cost.

Reinforced concrete elements have a limited service life and must be inspected periodically. These inspections evaluate the condition of structures and provide the basis for the development of a maintenance and repair plan. Often, these assessments are primarily performed by visual inspection techniques, a Non-Destructive Testing (NDT) method which provides useful information related to the condition of the structure (existing cracks and other damage).

Using traditional approaches for visual inspections, investigators / engineers must be in close physical proximity to the concrete surface of the cooling tower to perform a detailed examination. This typically entails rigging the cooling tower with swing stages or other work platforms from which the inspection can be performed. As the surface area that is to be directly inspected increases, swing stages need to be moved, adding cost and time to the overall effort. Ultimately, using this method, the inspection is limited to the selected areas of the structure that are accessed, many man-hours have been spent traveling, rigging, and inspecting, and specialized access equipment have been utilized.

Inspections Using Drone Photography

Recent advancements in technology, such as high-resolution imagery captured using drones, can provide more comprehensive inspection coverage in less time at a lower cost, while improving safety. In fact, the approach we use takes drone photographic capture a step further by integrating photogrammetric imaging and 3D modeling technologies into our inspection process workflow. We believe this integrated technology approach improves the efficiency and cost effectiveness of cooling tower inspections.

Photography-based aerial drone inspections capture the entire structure. In addition to providing supporting data for the inspection report, photographs and models can be stored and retrieved for historical asset management, repair assessment, and other time-condition reporting. An additional benefit is that the 3D point cloud produced from the drone photographs can be used to generate CAD drawings, BIM Models, and other measurement analytics.

Advancements are taking the outputs from these assessments and moving past standard static reporting and into 3-D graphic modeling which can also be used in repair design and integrated quality assurance during repairs to create an asset management approach for cooling tower infrastructure maintenance.

Drone Photo of Cracks and Corrosion at 400'

Drone Inspection Work Flow

The typical process workflow applied to photographic drone inspections is designed to optimize results, minimize time and reduce risk. The objective of the drone photography mission is to capture high resolution, high quality photos that can be used for the following:

1. Photographic inspection of the entire structure
2. Produce photo-realistic 3D models
3. Generate accurate point cloud data

These outputs enable efficient analysis by Subject Matter Experts (SMEs) and the production of a comprehensive and accurate inspection report.

1. Evaluate Airspace and Regulation Compliance
    a. The FAA controls all airspace in the US
    b. Unmanned Aircraft Systems (like manned aircraft) must comply with FAA regulations, which specify how and where aircraft can operate.
    c. Special rules exist in some cities, federal properties, public gatherings, and national security facilities.
    d. Employees at the facility where the drone inspection will occur should be notified, since flight over people is prohibited.
2. Analyze Subject Structure
    a. Dimension of subject structure
    b. Adjacent structures
3. Select Appropriate Equipment
    a. Drone
    b. Camera
    c. Lens
    d. Storage and Review Equipment
    e. GPS/Ground Control points
4. Plan Mission
    a. Review objectives
        i. Inspection and/or modeling
        ii. Specific elements of interest
    b. Review site assessment
    c. Review structural drawings
    d. Confirm mission objectives
        i. Mapping
        ii. Modeling
        iii. Measuring
        iv. Inspecting
    e. Determine flight paths
    f. Calculate minimum and maximum altitudes
    g. Set optimal camera angles
    h. Set optimal overlaps
        i. Determine if flight will be automated or manual
5. Conduct Preliminary Reconnaissance Flight
    a. Establish actual location
    b. Establish/confirm precise height
    c. Scan for obstacles (locations and heights)
6. Review Mission
    a. Confirm min/max altitudes are appropriate
    b. Confirm all flight parameters
    c. Verify flight and photo parameters are correct
7. Fly Mission and Capture Images
    a. Automated
    b. Manual
    c. Both
8. Review Images
    a. Review photos before leaving site
    b. Back up images
    c. SME acceptance
9. Upload Images for Modeling and Storage

It can be noted that while photography provides a visual record for analysis and modeling which is explained below, the drone is basically a flying platform. Other remote sensing technologies such as LIDAR or Thermal Imaging can be mounted to the drone and similar data capture processes apply.

3D model of cooling tower

Application

The use of drones to capture high resolution imagery of difficult to access structures is not new, but the sophistication of drones themselves and image capture technology is rapidly advancing. When the use of drones in this type of application was first implemented, the output consisted of hundreds, if not thousands, of individual photographs. While these early attempts at capturing 100% visual coverage of a structure accomplished the basic objective, the individual photographs were not usefully geolocated, so the position of any observed defect/distress feature was difficult to determine. In addition, the relationship of individual photographs to each other was not always well understood. Hence, while providing documentation, as an analysis tool, the approach was somewhat lacking.

Capturing data, in this case the photographic imagery, is just one aspect of the assessment process. The more complicated and critical question is what does one do with that data / imagery to create a useful tool for further analysis. Individual images capture small discrete areas of a large structure. The challenge is how to combine these individual pieces into a complete and accurate representation of a structure. This can be accomplished using advanced photogrammetric technology that combines all the individual photographs to create a photo-realistic 3D model. (see Figure 1)

Note the small frustums around the model. They represent the locations of the camera while taking each individual photograph. This allows for the determination of the location of any image or specific defect feature within the image. The model can be rotated and tilted to provide detailed views from all angles and the model can be zoomed into for close-up views of particular features. The image clarity of the 3D model itself allows for identification of many damage features. And, the model is interactive - any area of interest can be clicked upon and its closeup inspection-grade photo will automatically appear for detailed review and interpretation (see Figure 2 for an example of the resolution associated with an inspection grade photo). In addition, the 3D modeling software incorporates features that enable tagging and measurement of defects / areas of distress, facilitating reporting and repair cost estimates.

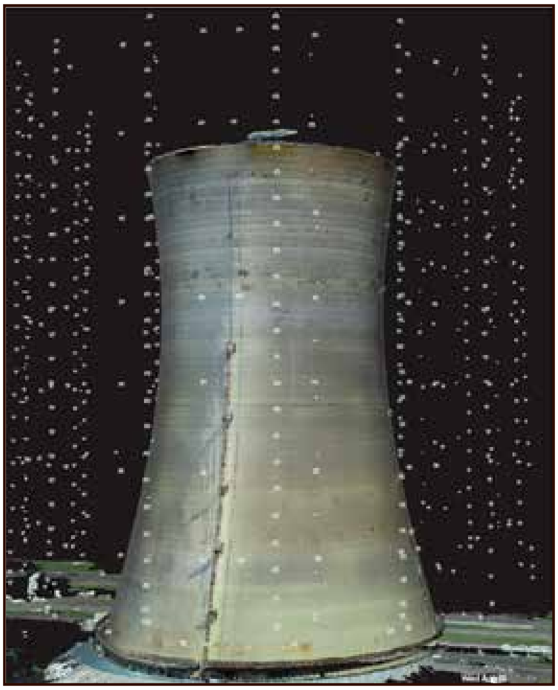


Figure 1 - 3D model showing camera position

Figure 2 – Inspection-grade photo from 3D model

Tagging of defects is an important component of an asset management approach for large civil structures. Since an inspection / assessment is a snapshot in time, a traditional written assessment report is not a living document. Its photographs and report are often filed away for archival purposes and there is not an easy way to update the document with changes in condition or repairs that have been executed. As a result, at some future time, when it is appropriate to repeat an assessment / inspection of the structure, it is difficult to compare that previously created static document to new information gathered.

However, our 3D model approach is dynamic. It provides a tool for tagging, defining, and quantifying defects, while enabling "real-time" tracking of repairs and changes in condition over time.

When concrete repairs are executed, additional "layers" of the model can be activated to capture the details associated with the repairs. This information may include, but is not limited to: date, time, repair details, materials used, documentation (photos) of process steps such as surface preparation and the completed repair area itself. All of this information is located within tags stored directly on the model so repair history is well understood. The tagging also permits an evaluation of the progression of repairs over time, ensuring the model is always current. Former defects that have been repaired can be placed in the background of the model for reference purposes leaving only current (or to be executed) defects active.

The 3D model also allows for unbiased monitoring of changes in condition (ongoing / continued degradation) over time. When a new assessment is conducted, investigators can use the existing 3D model to update the condition and integrate new drone captured imagery. Since their locations and sizes are stored on the model, previously executed repairs and defects can be referenced and compared to updated sizes or severity to determine if (or how much) they have worsened. New defects or areas of concrete distress are also easily identified.

Clearly, the use of drone captured imagery is purely visual in nature. It does not replace the need to occasionally perform direct tactile investigations or physical testing to assess conditions. However, in our experience, we have found that the use of drone imagery and 3D modeling provides insights as to when these more detailed inspections should be scheduled (rather than an arbitrary approach of every number of years). Drone imagery and 3D modeling also help optimize the detailed inspection by directing investigative teams to those locations that are of highest importance, rather than simply performing several evenly spaced swing stage drops. In short, the use of drone captured imagery and 3D modeling provides a cost effective, efficient, and innovative approach to understanding and monitoring the overall condition of large structures.

Understanding and documenting the overall condition of large structures is one component of asset management. Intervening at strategic points in an asset's normal life cycle to extend the expected service life is also an aspect of asset management. To accomplish this, an understanding of the future condition is also required so the timing of these interventions can be planned for and budgeted. For concrete structures, advances in service life analysis allow for a more sophisticated and accurate prediction of future performance.

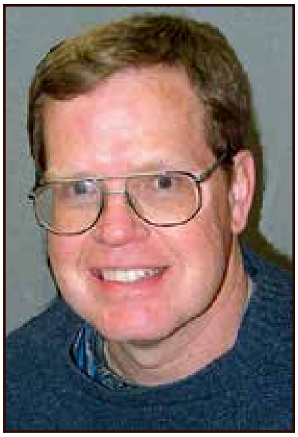
Corrosion of embedded steel is one of the primary causes of reinforced concrete distress. Many instances of concrete distress (i.e. spalling and cracking) are often the result of corrosion activity. Since the corrosion product (rust) occupies more volume than the original steel, tensile forces are generated which are greater than the tensile strength of the concrete. Prediction of when corrosion will initiate and propagate can provide valuable guidance on the timing of intervention. Second generation models represent the most recent developments in ionic transport modeling and numerical solutions. Finite-element calculations can model the ingress of chloride and other ion species, that contribute to corrosion, under different types of environmental conditions. The model also considers the complex interactions between contaminants penetrating the porous network of concrete and the hydrated phases of the cement paste. Specialized testing of concrete core samples generates data that can be used to characterize the ion and moisture ingress properties. With this information engineers can provide a better evaluation of the extent of chloride ingress and other contaminants in a structure during its service life. Hence, the appropriate timing to perform inspections, apply protective or mitigating treatments, or other maintenance activities can be scheduled and budgeted as part as an asset management program.

Conclusion

Advances in technology, such as drone based image capture and 3D modeling, permit the streamlining of inspection / assessment services to provide insights into the current condition of large concrete structures. This technology also provides reporting, history, and data that is more useful, interactive, and aligned with the tenets of a longer-term asset management program. Advances in service life prediction techniques using sophisticated modeling help frame the future performance of structures. When used in combination, a change from the reactive approach to the predictive approach for asset management can occur. This systematic approach for organizing and implementing activities related to planning, maintaining, repairing, rehabilitating and ultimately replacing structures results in an improved sustainable structure.

Reclaim Water for Cooling Tower Makeup; Not as Simple as Perceived

Ray Post, P.E., and Brad Buecker
ChemTreat



Brad Buecker

Abstract

Growing emphasis, and rightly so, is being placed on water recovery and reuse to help sustain our planet's water supplies. By choice or mandate, design engineers for many new industrial plants are selecting alternatives to fresh water for plant makeup, with an increasingly common choice being effluent from a publicly owned treatment works (POTW). These waters go by various names including reclaim water, grey water, purple-pipe water, and so forth. Regardless, virtually all reclaim waters contain elevated concentrations of ammonia, nitrate, organics, phosphate, and suspended solids, all of which, if left untreated, can lead to a nightmare scenario of microbiological fouling in cooling towers and cooling systems; a point that is sometimes not emphasized enough to those designing new facilities or switching supplies at existing plants. But with proper pre-treatment and cooling water chemical treatment, these waters can successfully be utilized for cooling water makeup. Methods to prepare this water for use in cooling systems include biological treatment of the makeup, consistent and reliable biocide feed to the recirculating water, and use of non-phosphorus treatment for scale/corrosion control in place of the phosphate/phosphonate programs of the past. The latter has also been gaining impetus due to concerns about the environmental impacts of phosphorus discharge to lakes and rivers.

The Complexity of Keeping Cooling Systems Clean

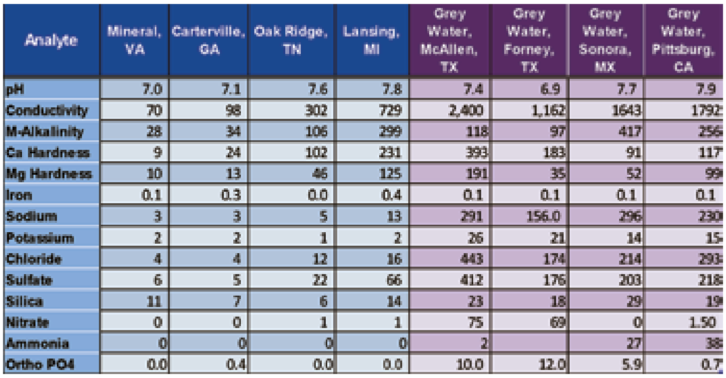
Experienced personnel know that cooling systems provide an ideal environment, warm and wet, for microbiological fouling, even with clean fresh water as the makeup. But the mindset that "water is water" continues to persist among many design engineers and plant operators. An example from author Buecker's recent history is a case in point. It involved a project in which secondary-treated POTW effluent was chosen for makeup to a combined-cycle power plant, most of it to supply the plant cooling tower. The design engineers originally selected just standard clarification (for suspended solids removal) as pre-treatment for the plant makeup. Their thought was that a more sophisticated pre-treatment scheme would make the overall project bid non-competitive. When the anticipated cooling tower makeup water quality was given to a major tower manufacturer, the firm's personnel quickly replied that film fill could not be utilized in the tower due to the fouling potential, and that the tower would have to be designed with splash fill. The increase in tower size would have raised the cost by nearly eight figures. This was a real eye-opener for the engineers, who then realized that their water group co-workers had been correct in insisting on more robust pre-treatment.

The key point, which the remainder of this paper examines, is that the concept of water reuse, while being environmentally beneficial, cannot be taken lightly when it comes to design and operation of industrial water systems.

Figure 1. Fouled cooling tower film fill.

Reclaim Water Chemistry

As can be imagined, wastewater, even after having been processed in a treatment plant, contains a number of impurities in higher concentrations than exist in the fresh water supplies from which the water originally came. The table below outlines the primary constituents from several different water sources, both fresh and reclaim, around the United States.



Analyte	Mineral, VA	Carterville, GA	Oak Ridge, TN	Lansing, MI	Grey Water, McAllen, TX	Grey Water, Forney, TX	Grey Water, Sonora, MX	Grey Water, Pittsburg, CA
pH	7.0	7.1	7.6	7.8	7.4	6.9	7.7	7.9
Conductivity	70	98	302	729	2,400	1,162	1643	1792
M-Alkalinity	28	34	106	299	118	97	417	256
Ca Hardness	9	24	102	231	393	183	91	117
Mg Hardness	10	13	46	125	191	35	52	99
Iron	0.1	0.3	0.0	0.4	0.1	0.1	0.1	0.1
Sodium	3	3	5	13	291	156.0	296	230
Potassium	2	2	1	2	26	21	14	15
Chloride	4	4	12	16	443	174	214	293
Sulfate	6	5	22	66	412	176	203	218
Silica	11	7	6	14	23	18	29	19
Nitrate	0	0	1	1	75	69	0	1.50
Ammonia	0	0	0	0	2		27	38
Ortho PO4	0.0	0.4	0.0	0.0	10.0	12.0	5.9	0.7

Table 1. Comparison of Several U.S. Waters
(Values apart from pH and Conductivity are in units of mg/l)


Real experts, real results

For purposes of this discussion, compare the surface water supplies from Mineral, Virginia; Cartersville, GA; Oak Ridge, TN; and Lansing, MI with the grey water supplies from McAllen, TX; Forney, TX; Sonora, MX; and Pittsburg, CA. Easily distinguishable in the grey water are the much higher concentrations of the major cations (calcium, magnesium, potassium, sodium), anions (chloride, nitrate, phosphate, sulfate), and, of course, conductivity. Ammonia in surface waters is typically inconsequential, but for grey water is often in the double digits as mg/l, as illustrated by the Sonora and Pittsburg waters, unless the POTW employs a nitrification facility to convert the ammonia to nitrate. Not shown is Total Organic Carbon (TOC), which is also typically much higher than in fresh water, even in POTWs that have effective tertiary treatment.

So, with untreated POTW effluent as makeup, the cooling system would receive plenty of organic food, and the nutrients nitrogen and phosphorus. With regard to phosphorus, many cooling towers still operate on phosphate/phosphonate chemistry, and thus the argument could be made that POTW influent does not introduce phosphorus nutrients where none previously existed. But, introduction of extra and variable concentrations of phosphate via the makeup water can play havoc with control of the cooling tower treatment program. (As will be examined later in this paper, a trend is growing towards non-phosphorus cooling water treatment chemistry due to phosphorus discharge issues and associated environmental concerns.)

Reclaim Water Pretreatment Methods

Basic clarification, as mentioned in the case history above, for the most part only removes suspended solids, although some large organics may precipitate as well. Also, use of an aluminum or iron-based coagulant will precipitate phosphate, and thus basic clarification can often serve a valuable purpose in this regard. If the makeup water is high in hardness, lime softening clarification may be justified, although lime softening generates large quantities of sludge that must be disposed. Lime softening also removes bicarbonate alkalinity, which reduces acid requirements for pH control and efficiently removes phosphate.

Like other technologies, clarifier design has been significantly enhanced over the large, circular types that were ubiquitous during the last century. A common rise rate (effluent flow divided by the surface area at the top of the clarifier) of 1 gpm/ft^2 or slightly less is a common standard for these older designs, as the gentle flow allows particles to settle. But now, in systems such as the ballast type (typically micro-sand or magnetite), the influent, after coagulant injection, encounters a ballasted recirculating flow in the flocculation zone.

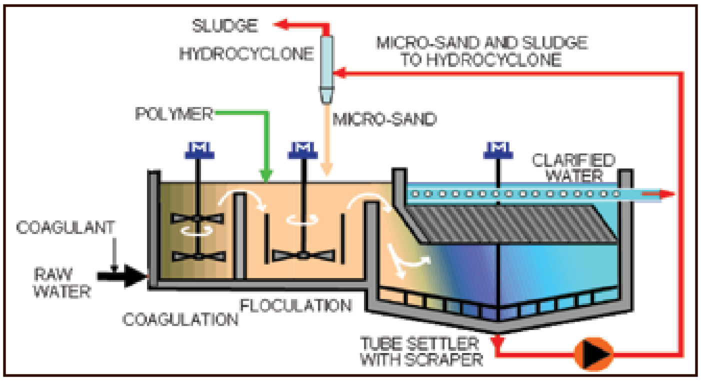


Figure 2. Schematic of a ballasted clarification process. This figure and Figure 4 courtesy of Veolia Water Technologies.

The microsand or magnetite is much heavier than the coagulated solids, which attach to the ballasted material, and thus settling is much faster in the clarifier. Rise rates as high as 25 gpm/ft^2 or even higher have been reported for some of these technologies. The ballast material is recovered in hydrocyclones for reuse, while the sludge exits from the hydrocyclone overflow to disposal.

However, clarification does nothing for nitrogen-based impurities, particularly ammonia and nitrite/nitrate. Also, most organics carry through a clarifier. Thus, even with clarification for suspended solids and phosphate removal, much food/nutrients will still enter the cooling system. These aspects are driving selection of biological treatment methods for pre-treatment.

Biological methods to treat both municipal and industrial wastewater have been in place for many years. Very common is the activated sludge process, in which, following large solids and grit removal, the waste stream flows into a large basin or basins filled with beneficial microorganisms that consume the organics and nitrogen/phosphorus nutrients. The term activated comes from the fact that air is injected into pond volume, often at numerous locations, to provide an aerobic environment for the microbes. A common variation on this technology was that of the trickling filter, in which the wastewater flowed over fixed media to which the organisms are attached. Thus, the microbes had a stable base to carry out waste removal.

A difficulty with either of these technologies is that the treatment processes are slow, and require large pond volumes or media surface area. In today's world of fast start plants, and, especially in the case of the power industry, high cycling facilities, more robust biological treatment methods are necessary. Biological aerated filtration (BAF) has proven to be a mature technology for some applications, and two other technologies have emerged as leading candidates. These are membrane bioreactors (MBR) and moving-bed bioreactors (MBBR). A basic schematic of the former is outlined below.

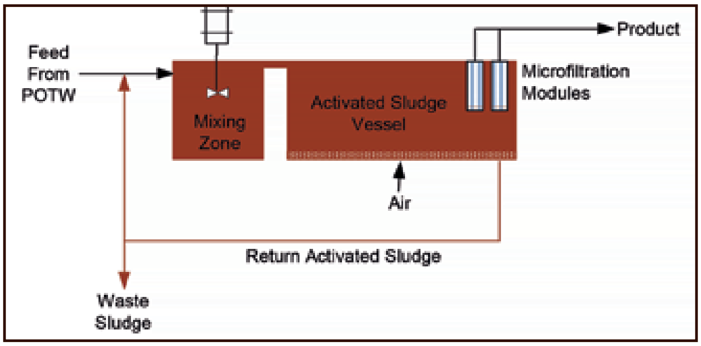


Figure 3. Basic MBR design.

The fundamental process is that of return activated sludge, wherein beneficial microorganisms consume the food and nutrients that enter the main vessel via the mixing zone. A recycle stream helps to bring active, well-established organisms to the inlet of the mixing zone. A major difference of MBR from conventional activated sludge is the use of microfilter membranes rather than a traditional clarifier to separate solids from the effluent. The microfiltration process produces a very clear stream, essentially free of suspended solids. One deficiency of this most basic MBR process is that ammonia in the stream is converted to nitrite/nitrate, but the nitrogen remains. Thus, the nitrogen can still serve as a nutrient in the plant cooling water system. This problem can be solved, if necessary, by expanding the MBR system to include anoxic or anaerobic reaction chambers, with microorganisms that convert nitrite/nitrate to elemental nitrogen. However, this adds complexity to the process that plant personnel may not desire. Of note is that MBR has also become accepted technology for raw wastewater treatment in smaller applications. (Buecker, 2013)

Regarding MBBR, the main reaction vessel includes mobile plastic media that serves as sites for the beneficial microorganisms to attach and then consume the nutrients and food from the influent.

Figure 4. MBBR reaction vessel diagram showing mobile media.

MBBR can in some respects be thought of as a very advanced version of the trickling bed wastewater treatment process, where the beneficial microbes were attached to fixed media and then consumed nutrients and food as water flowed over and along the media. Due to the use of solid media in the reaction vessel, filtration membranes cannot be placed in this compartment. Rather, filtration must be performed separately.

One concern often raised at industrial plants is providing staff, both from a quality and quantity standpoint, to operate these seemingly complex systems. Two ideas immediately come to mind. First, if the plant is located close to the POTW, it may be possible to place the MBR or MBBR at the POTW, and have that staff operate it. Secondly, many of the reputable manufacturers offer "build-own-operate-maintain (BOOM)" programs, where, for an annual fee, they will take care of all equipment details.

Even with good pretreatment of these or other makeup water streams, additional issues continue to gain momentum. One is increasing concern with phosphorus discharge to the environment, and how to reduce such discharge in cooling tower blowdown while still protecting the cooling systems from corrosion and scale formation.

Cutting-Edge Cooling Water Treatment

An evolution is underway regarding scale and corrosion control in industrial cooling-tower based systems. For four decades, the most common treatment programs have been based on a core chemistry of inorganic and organic phosphates (the latter typically go by the name of phosphonates or phosphinates) that combine with potential scale-forming elements, most notably calcium, and whose reaction products precipitate at anodes and cathodes of metal surfaces to inhibit corrosion. However, of growing concern is the discharge of phosphorus to natural bodies of water, and the effects such discharge has on proliferation of toxic algae blooms. Phosphate also drives algae growth in cooling towers, increasing chlorination costs and the production of undesirable chlorinated organics.

Figure 5 (Left). Algae completely covering a pond surface. and Figure 6 (Right). Algae hanging from plastic tower fill.

At many locations now, phosphorus discharge is limited if not entirely banned. Also being restricted is discharge of metals, including zinc; a common key ingredient in phosphate/phosphonate formulations for additional corrosion inhibition. These restrictions have led to development of alternative, polymer-based programs that offer a more sustainable alternative to algae control in cooling systems.

Polymer formulations containing the carboxylate group have been successfully utilized for decades to control calcium carbonate ($CaCO_3$) scale in cooling water.

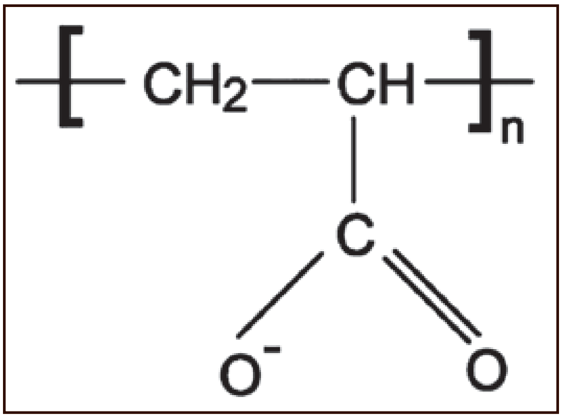


Figure 7. Carboxylate functional group.

However, many other scaling compounds are possible, including calcium and magnesium silicates, calcium sulfate, calcium fluoride, and manganese dioxide, to name some of the most common. The need to combat these and other scale-formers has generated development of co- and ter-polymers, containing more than one functional group.

The polymers inhibit scale formation by two mechanisms, crystal modification and ion sequestration. A low part-per-million residual is often sufficient to inhibit scale formation, but the choice of polymer or polymer blend is in large part dependent upon the chemistry of the cooling water. That is why, especially for new plants, comprehensive, and ideally historical, makeup water analyses are necessary. Too often, project designers only receive partial water quality data, which makes it very difficult to select proper treatment chemistry and makeup water treatment equipment. The pretreatment facilities should be flexible and robust, since POTW makeup water quality tends to worsen over the long term, and can experience short term upsets due to "combined sewer overflow" during periods of heavy rainfall.

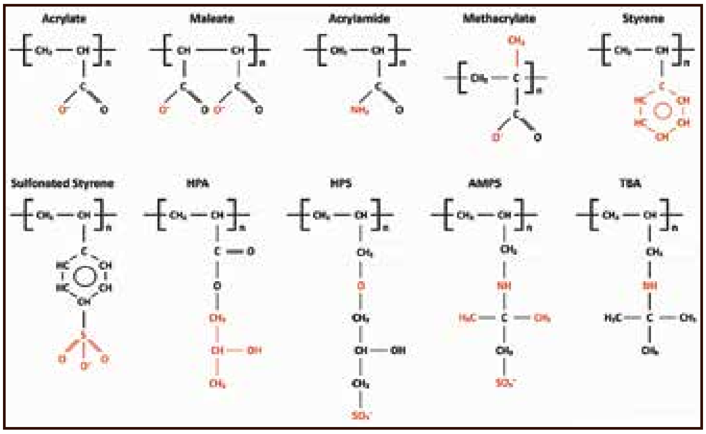


Figure 8. Basic structures of important co- and ter-polymers.

Enhancements to environmentally friendly non-phosphorous and non-zinc chemistry have also improved corrosion protection in cooling systems. Particularly effective is a chemical formulation best described generically as a reactive polyhydroxy starch inhibitor (Post, 2017). The chemistry is capable of providing a number of critical benefits in cooling systems, most notably:

- General corrosion protection of carbon steel
- Passivation of rusted steel surfaces
- Improved protection of stainless steels from chloride-induced crevice and pitting corrosion (Figure 9)

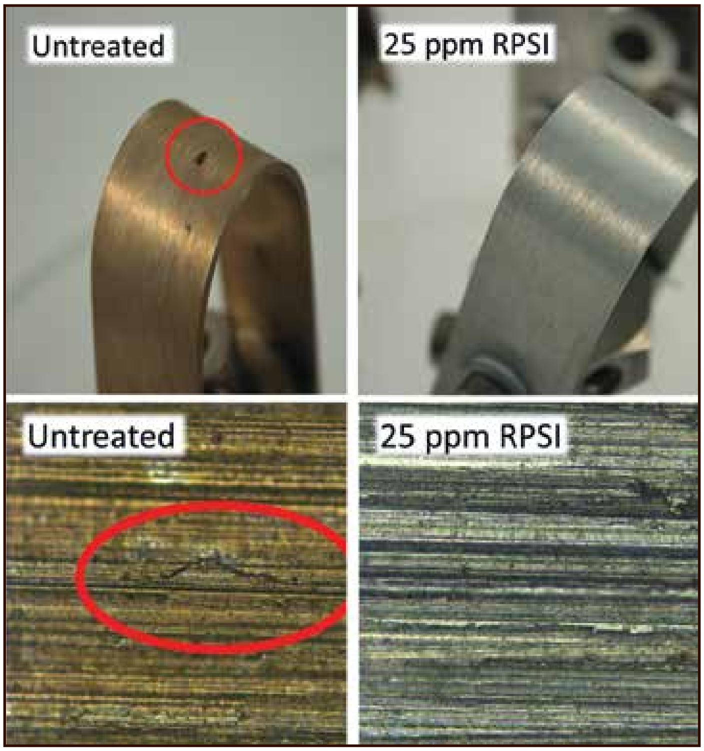


Figure 9. Type 304 Stainless Steel Stress Cracking Coupons subjected to 1,000 mg/l chloride at 105 °C for 15 days under air. Note the absence of staining, pitting, and cracking in the specimen treated with the Reactive Polyhydroxy Starch Inhibitor as compared to the untreated control.

Corrosion inhibitors such as the reactive polyhydroxy starch inhibitor contain functional groups that attach directly to the base metal, upon which the components form a passive film. This is much different than corrosion protection in the phosphate-based programs, where the reaction products with calcium and other species formed a barrier. Such "protective" deposits have limitations, including porosity and a propensity to be washed away by the cooling water flow. Beyond that issue, mistakes in chemical dosage and/or a change in water chemistry have the potential to induce severe deposition, most notably of calcium phosphate. By contrast, the reactive polyhydroxy starch inhibitor does not rely on precipitation reactions and is non-fouling. This non-fouling property allows the inhibitor to be applied at sufficient dosage to provide excellent protection even in highly corrosive waters.

Reviewing the Importance of Cooling Water Fouling Control

Although many papers have been given at various conferences over the years regarding biological control in cooling water systems, both micro- and macro-fouling continue to affect many cooling systems. Given the retirement of many experienced industrial personnel and an influx of new employees, it is worth reviewing some of the most important chemistry, with an emphasis on current technology.

The core of any microbiological treatment program is feed of an oxidizing biocide to kill organisms before they can settle on heat exchanger tubes, cooling tower fill, and other locations. Chlorine was the workhorse for many years, where when gaseous chlorine is added to water the following reaction occurs:

$$Cl_2 + H_2O \Leftrightarrow HOCl + HCl \qquad \textbf{EQ(1)}$$

HOCl, hypochlorous acid, is the killing agent, and functions by penetrating cell walls and then oxidizing internal cell components. The efficacy and killing power of this compound are greatly affected by pH due to the equilibrium nature of HOCl in water, as shown in Eq. 2.

$$HOCl \Leftrightarrow H^+ + OCl^- \qquad \textbf{EQ(2)}$$

OCl- is a much weaker biocide than HOCl, probably due to the fact that the charge on the OCl- ion does not allow it to effectively penetrate cell walls. The killing efficiency of chlorine dramatically declines as the pH goes above 7.5. Because most cooling tower scale/corrosion treatment programs operate at an alkaline pH, chlorine chemistry may not be the best choice in some applications. Chlorine efficiency is further influenced by ammonia and organics in the water, which react irreversibly with the chemical and increase chlorine demand. This is yet another reason why ammonia removal from grey water is very important.

Due to safety concerns, liquid bleach (NaOCl) feed has replaced gaseous chlorine at many facilities, although bleach is more expensive. Bleach contains a small amount of sodium hydroxide, so when it is injected into the cooling water stream it raises the pH, perhaps only slightly, but if the water is alkaline to begin with, most of the reactant will exist as the OCl^- ion. A popular answer has been bromine chemistry, where a chlorine oxidizer (bleach is the common choice) and sodium bromide (NaBr) are blended in a makeup water stream and injected into the cooling water. The chemistry produces hypobromous acid (HOBr), which has similar killing powers

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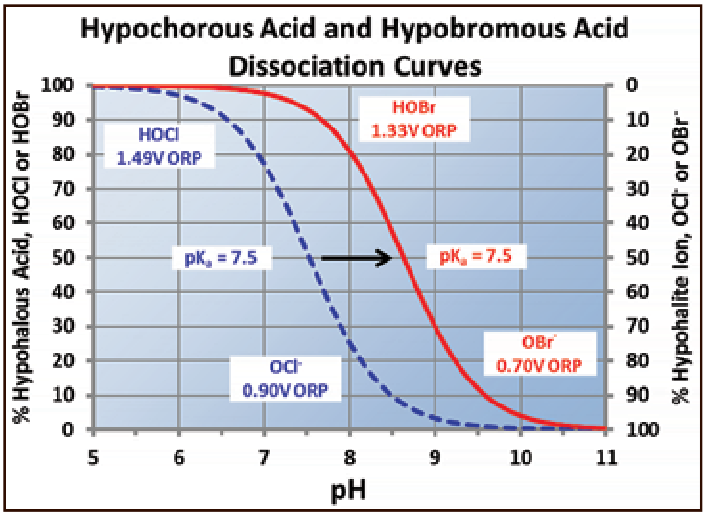

to HOCl, but functions more effectively at alkaline pH. Figure 10 compares the dissociation of HOCl and HOBr as a function of pH.

Figure 10. Dissociation of HOCl and HOBr vs. pH

Other alternatives include chlorine dioxide (ClO_2), monochloramine (NH_2Cl), and monobromamine (NH_4Br). The latter two are weaker oxidizers than the others, but appear to be more effective at penetrating the protective slime layer that bacteria produce, to then directly attack the organisms. Also to be considered are on-site hypochlorite generating systems, as exemplified by the MIOX® technology, where no oxidizer needs to be stored.

A factor that influences the efficacy of many oxidizers, and most notably the strong oxidizers such as chlorine and bromine is the ability, or lack thereof, to penetrate the polysaccharide (slime) layer, that bacteria form for protection. Sessile microbiological colonies may be almost impossible to destroy with standard treatment. Recently developed is a new halogen stabilizer/biodetergent, which is applicable for bleach-only oxidizing treatment. The product itself has no biocidal properties, and thus does not fall under regulatory guidelines, but it helps to stabilize chlorine and reduce losses from irreversible reactions. Also, the biodetergent portion of the formulation, as its name implies, disperses the biofilm formed by the organisms, and allows the biocide to contact the organisms directly.

In many cases, oxidizer feed is limited to two hours per day, which gives microbes time to settle and form colonies during off times. A supplemental feed of a non-oxidizing biocide on perhaps a once-per-week basis can be quite effective in controlling biological growth. These non-oxidizers in conjunction with biodetergents reduce overall chlorine usage and do not produce halogenated by-products such as THMs. Table 2 below lists properties of some of the most common non-oxidizers.

Chemical	Advantages	Disadvantages
2,2-dibromo-3-nitrilo-propionamide (DBNPA)	Fast acting, effective against bacteria, degrades quickly to non-hazardous byproducts.	Degrades quickly above pH 9, not very effective against fungi and algae. Degraded by reducing conditions
Glutaraldehyde	Effective against sulfate-reducing bacteria (SRB).	Incompatible with ammonia and some amines. Weak on algae.
Isothiazoline	Effective against bacteria, particularly nitrifiers, and fungi. Works well with oxidizing biocides. Active over a wide pH range.	Skin sensitizer. Degraded by sulfide, sulfite, and reducing conditions.
Quaternary amines	Effective against most microorganisms, particularly algae. Active over a wide pH range.	Can cause foaming. Efficacy reduced by hardness. Interacts with anionic dispersants and fluorescent tracers

Table 2 - Non-Oxidizing Biocides

Careful evaluation of the microbial species in the cooling water is necessary to determine the most effective biocides. Antimicrobial compounds should not be used or even tested without approval from the appropriate regulating agency. They must be incorporated into the plant's National Pollutant Discharge Elimination System (NPDES) permit. Also, as with all chemicals, safety is an absolutely critical issue when handling biocides.

Conclusion

Alternatives to fresh water are becoming increasingly common for industrial plant makeup. Rigorous pretreatment of these waters, and in particular POTW effluent is necessary to protect the plant, and in particular the cooling water system. And even with good pretreatment, cooling water process chemistry must not be neglected. The cooling system offers the ideal environment, warm and wet, for microbes, and if they are allowed to settle and establish colonies, severe fouling is typically the result. Also, new methods of scale/corrosion control offer great promise in improving cooling system efficiency and reliability.

References

B. Buecker, Trip report from visit to the De Soto, Kansas wastewater treatment plant, March 2013, courtesy of Smith & Loveless.

R.M. Post, P.E. and R.P. Kalokodimi, Ph.D., "The Development and Application of Non-Phosphorus Corrosion Inhibitors for Cooling Water Systems"; presented at the World Energy and Environmental Congress, Atlanta, Georgia, October 26, 2017.

High Efficiency Heat Exchanger For Ice Energy Storage and Beyond

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Active Energy Systems

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Abstract

Freezing ice on coils is a slow and transient process that hinders the deployment of ice thermal energy storage systems for large commercial buildings. Here, we share observations of a novel interfacial phenomenon that was used to engineer an ice-phobic heat exchanger. Water drops that were frozen on the ice-phobic surface demonstrated extremely low interfacial adhesion, allowing the frozen drops to be shed off by body forces alone. Heat transfer coefficient measurements of this steady-state freezing process indicates improved performance over the traditional ice-on-coil process. Increasing the heat transfer coefficient reduces the necessary heat exchanger size, which decreases an ice thermal storage system's footprint, important for high-density urban environments. These factors combine to substantially lower costs and increase applicability of ice thermal energy storage systems.

Introduction

Ice thermal energy storage is a process in which ice is produced using off-peak, low-cost electricity as a means of storing energy in the form of latent heat. The ice is used to provide cooling for buildings during the warmer, on-peak hours of the day (avoiding chiller operation during these hours). Ice thermal energy storage is used by commercial buildings and campuses to lower energy costs all over the country [4,6]. Current shortcomings of ice thermal energy storage technology can be attributed to poor heat transfer during the ice making process [4,6]. Ice-on-coil heat exchangers (HEX) grow ice radially outward from the cooling surface. As ice grows on the surface, the thermal resistance between the water and the HEX surface increases, and thus the heat transfer coefficient (HTC) decreases. Eliminating the ice layer would increase overall efficiency and lower costs.

The major challenge in developing an ice-phobic heat exchanger is the adhesion of ice onto other surfaces. It is a notoriously strong force to overcome, even on superhydrophobic surfaces [2,3,7]. The current state of the art in ice-phobicity is either removing condensate before freezing with either a superhydrophobic surface or SLIPS (slippery lubricant impregnated porous surface) or removing the ice after it has formed by using some thermal or mechanical energy [1,8,9]. Our approach to the problem of ice-phobicity was inspired by SLIPS which uses a combination of hydrophobic surfaces and lubricating oils. Whereas a traditional SLIPS uses a thin film of lubricant to enhance the superhydrophobic characteristics of the surface, our approach was to totally submerge water drops in oil so that frost and ice build-up cannot suppress with the freezing process.

Active Energy Systems has developed a new method of making ice that passively sheds ice as it is produced, eliminating the inefficiency of thermal resistance from ice-on-coil systems. The key innovation is a new HEX design that can produce up to 6 times more ice per cycle than existing HEXs with the same surface area. The new HEX design is ice-phobic: the adhesion stress of freezing water is negligible.

Here we present our observations of this new phenomenon and the associated freezing HTC.

Experimental Setup

Heat Exchanger setup

The ice adhesion experiments were initially done on a much smaller scale than the HTC experiments. A small piece of aluminum was placed at the bottom of a glass container on a cold plate cooled by a chiller. The aluminum stage had a small hole drilled into it for a thermocouple probe. Adhesive PTFE (polytetrafluoroethylene) tape was applied to the aluminum surface. The glass container was then filled with 5 cSt silicone lubricating oil. The density of the silicone oil was nominally reported to be $\sim 930\ kg/m^3$ @ 0 °C, which would place it at an intermediate density between ice and liquid water. The camera was then setup so the PTFE surface was in focus at approximately 40x zoom and recording at 10 fps.

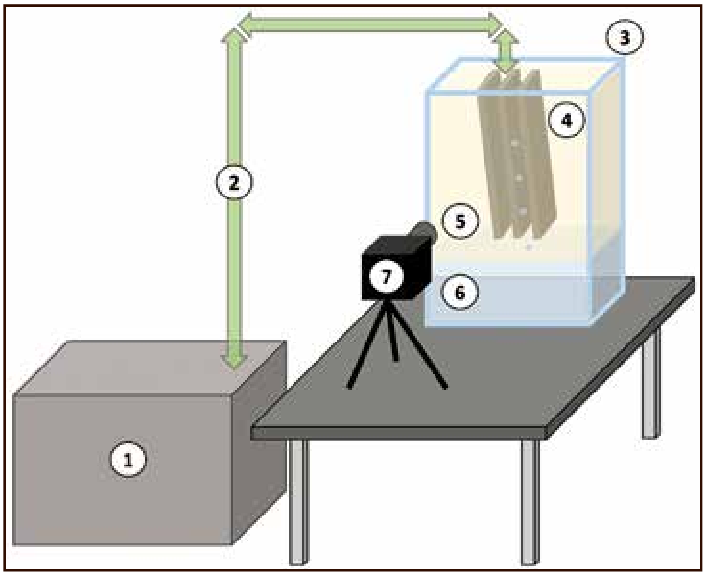

Figure 1. Heat exchanger experimental setup.

We designed a benchtop-scale test bed for proof-of-concept testing of our heat exchanger prototype. A basic diagram of this setup is illustrated in Figure 1. A chiller was used as the source of cooling for these experiments (1). The heat exchanger we used is made of three aluminum plates with imbedded copper tubes (4). The plates are fastened together using a bolt and the spacing between the plates is 0.5 *in*. The plates were spray coated with a 5 μm layer of PTFE. The inlets and outlets of each plate is connected to a header that leads back to the chiller inlet and outlet (2). The refrigerant in the system is a glycol mix. This heat exchanger is submerged in oil (5) inside of an acrylic tank (3). A smaller layer of water is at the bottom of the tank (6). The phase change material (PCM) we are using is a mixture of water and an ice nucleating protein like that found in *Pseudomonas syringae*. The oil is a PAO (poly-alpha-olefin) without any additives or surfactants. It is important to the function of the system that the oil be less dense than the PCM, which allows the negative buoyancy of the water drops in the oil to drive them down the plates.

Instruments and Methods

The camera we used for these experiments is the Dino-Lite Digital Microscope (7). The associated software is DinoCapture 2.0. The camera has a variable zoom lens from 0x-80x. The temperature data was recorded with National Instruments thermocouples and a LABVIEW DAQ. The software used to measure velocity was Tracker by Open Source Physics.

A metric ruler was taped to the side of the acrylic tank in frame so that a fixed distance could be determined in the video. In the Tracker software, it is possible to measure something of a known length in frame so that a ratio of pixels to millimeters can be established.

Ice Adhesion Experiments

The objective of these tests was to determine the effectiveness of the icephobic properties of the heat exchanger surface. The chiller was initially set to -8 °C, and the surface temperature of the aluminum was -5.25 °C. The PCM drops were then deposited onto the PTFE surface and allowed to cool. The PCM exhibits freezing with less supercooling ($\Delta T \approx -2$ °C) than pure water due to the ice nucleating protein. The camera would begin recording at deposition and continue until the drops were sufficiently frozen to detach from the surface. Detachment occurs once the density of the drop becomes less than the oil around it. This makes the drop buoyant, and once the buoyant force overwhelms the adhesive force holding the drop to the PTFE surface, the drop detaches and begins to float. From the video, we can determine the time until nucleation and time until liftoff.

HTC Measurement

The HTC of drops deposited on chilled PTFE coated plates was measured. The chiller was set to -9 °C and the drops were nominally 50 *μL*. The system was left to cool for an hour before beginning the first test, so it could equilibrate. The camera was setup so that the moment of nucleation would be captured in frame as closely as possible. The metric ruler taped along the side of the tank was used as a reference for how far the drop had traveled down the plate. From the video we can measure the velocity of the drop as it travels down the plate. It is assumed that the drop reaches terminal velocity in the oil immediately, so the average velocity it is traveling down the plate is assumed to be constant. By knowing the distance traveled down the plate and the average velocity, we can calculate the time between deposition and nucleation.

Results and Discussion

Passive removal of ice from a sub-freezing surface has not yet been demonstrated to the best of our knowledge. In this case, we show that buoyancy alone can remove frozen drops from a surface, which demonstrates extremely low adhesion to the substrate. An example of this liftoff event happening can be seen in Figure 2. Two tests were conducted to confirm this finding and describe the phenomenon. The first was testing the surface temperature versus the time until liftoff. Second was testing the volume of the drop versus the adhesion stress.

Figure 2. Frozen drop demonstrating low adhesion with a PTFE coated surface in a silicone oil bath. The drop passively detaches itself from the surface once the buoyancy force has exceeded the adhesive force. The ice layer grows upwards from the chilled substrate.

The next experiment was meant to illuminate some of the underlying mechanics of the liftoff events. Drop size was varied from 30 *μL* to 400 *μL* to see if the volume of the drop influenced whether the drops would liftoff. Satellite drops as small as 5 *nL* were also observed detaching from the surface, which represents a range of sizes over five orders of magnitude in volume. The average value of the adhesion stress was calculated to be 5.21 *Pa*. Compared to previously measured ice adhesion stresses of 500 *kPa* for aluminum and 100 *kPa* for PTFE, this is a tremendous improvement [3,5]. The stress was calculated by assuming the only forces in play are the body force of the drops (buoyancy) and the adhesive stress at the interface:

$$\tau\pi R_c^2 \le (\rho_d - \rho_o) g V_d$$

Where τ is the adhesive stress, R_c is the contact diameter, ρ_d is the density of the drop, ρ_o is the density of the oil, g is the acceleration due to gravity, and V_d is the volume of the drop. The contact diameter between the drop and the surface was measured in the Tracker software. This would give a reasonable approximation for the contact radius to estimate the contact area. The body force was calculated by measuring the average diameter of the droplet in Tracker and finding the volume of the drop that way. The density of the oil was determined by measuring the temperature of the oil and the surface and using that data to adjust the nominal density of the silicone oil. The density of the oil is the factor with the highest degree of uncertainty, although we know for certain it must be between 0.916 g/cm^3 (ice) and 0.998 g/cm^3 (water). For this calculation, the density was assumed to be 0.940 g/cm^3.

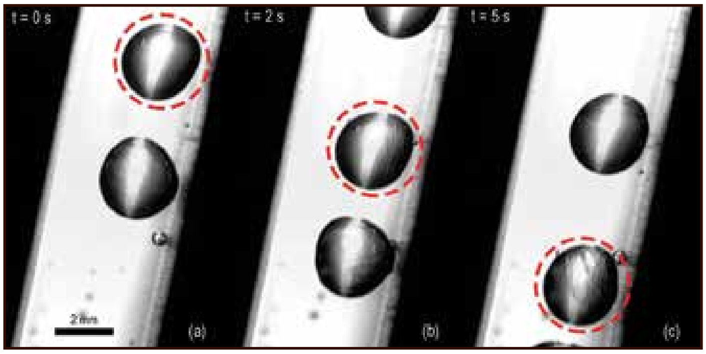

Figure 3. A drop of PCM sliding down a PTFE coated aluminum plate during the nucleation process. The highlighted drop in the image shows how freezing happens when the drop is in motion.

After demonstrating low ice adhesion, we designed our heat exchanger using our findings. This required testing and measuring the HTC of the freezing process. The following formula was used to calculate the HTC of the freezing process:

$$h = \frac{m\,c_p}{A\,\Delta t}\ln\frac{\Delta T_i}{\Delta T_f}$$

Where m is the mass, c_p is the specific heat capacity of water, A is the cross-sectional diameter of the drop, Δt is the time between deposition and nucleation, ΔT_i is the initial temperature difference between the drop and the plate, and ΔT_f is the final temperature difference between the nucleation temperature and the plate. The nucleation temperature was separately measured to be –2.2 °C ± 0.5 °C.

From the data we gathered from experiments, the freezing HTC was measured to be:

There is relatively high uncertainty in this measurement because it

$$520 \pm 60 \frac{W}{m^2K}.$$

is based on the nucleation time. By nature, nucleation, whether homogeneous or heterogeneous, is a stochastic phenomenon so there is not a time at which nucleation will always occur.

A constant HTC throughout the freezing process is a critical part of improving ice thermal energy storage. Whereas a traditional ice-on-coil HEX has a transient HTC, in which the HTC value decreases over time due to increasing thermal resistance, our new HEX operates under steady state conditions. Over the course of the entire freezing cycle, this results in up to more ice made for the same amount of area.

Conclusions

Observations of a new icephobic phenomenon have been reported. Water drops frozen in a silicone oil bath on a PTFE coated cold plate have demonstrated very low adhesion with the substrate. The maximum ice adhesion stress for a small drop was calculated to be 5.21 Pa. Frozen water drops that passively liftoff from the heat exchanger surface allow for elimination of the thermal resistance of ice growing on the heat exchanger surface. The freezing heat transfer coefficient of drops sliding down the heat exchanger surface was measured and recorded. The average freezing HTC for a 50 μL

$$520 \pm 60 \frac{W}{m^2K}.$$

drop using the HEX was measured to be:

Because this HTC is a constant value over the duration of the freezing process, it drastically reduces the required surface area to make ice, and thus reduces overall costs.

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References

1. Kim, P., et al. (2012). "Liquid-Infused Nanostructured Surfaces with Extreme Anti-Ice and Anti-Frost Performance." ACS Nano **6**(8): 6569-6577.
2. Kulinich, S. A. and M. Farzaneh (2009). "How Wetting Hysteresis Influences Ice Adhesion Strength on Superhydrophobic Surfaces." Langmuir **25**(16): 8854-8856.
3. Kulinich, S. A. and M. Farzaneh (2009). "Ice adhesion on super-hydrophobic surfaces." Applied Surface Science **255**(18): 8153-8157.
4. Lin, Y., et al. (2018). "Review on thermal conductivity enhancement, thermal properties and applications of phase change materials in thermal energy storage." Renewable and Sustainable Energy Reviews **82**: 2730-2742.
5. Meuler, A. J., et al. (2010). "Relationships between Water Wettability and Ice Adhesion." ACS Applied Materials & Interfaces **2**(11): 3100-3110.
6. Safari, A., et al. (2017). "A review on supercooling of Phase Change Materials in thermal energy storage systems." Renewable and Sustainable Energy Reviews **70**: 905-919.
7. Varanasi, K. K., et al. (2010). "Frost formation and ice adhesion on superhydrophobic surfaces." Applied Physics Letters **97**(23): 234102.
8. Wilson, P. W., et al. (2013). "Inhibition of ice nucleation by slippery liquid-infused porous surfaces (SLIPS)." Physical Chemistry Chemical Physics **15**(2): 581-585.
9. Wong, T.-S., et al. (2011). "Bioinspired self-repairing slippery surfaces with pressure-stable omniphobicity." Nature **477**: 443.

The Rest Of The Story: You Have Treated Your Cooling Tower - What Can Go Wrong?

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Abstract

Open and closed cooling systems are subject to the very real constant threat of corrosion, scale, and microbiological fouling. While water treatment is the science of minimizing these conditions, water treatment alone may not avail a system. What is the universe of factors that affect a cooling system and how do they affect successful long- term maximization of system performance and minimization of deterioration and premature failure? It is helpful to group these factors into the following non-exclusive list of general considerations: (1) Mechanical Factors; (2) Operational Factors; (3) Environmental Factors; (4) Microbiological Factors; and (5) Chemical Factors. This publication will address these factors with case studies in an effort to minimize risk of loss.

Introduction

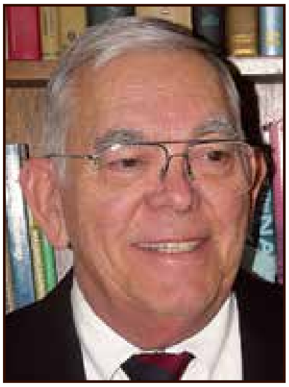
Despite the fact that a cooling tower is being properly treated, there are a variety of mechanical, operating, chemical, and microbiological factors that may defeat a sound treatment program. Detective work including a comprehensive monitoring program with routine checks for certain conditions may be the only thing that can avail a system from imminent perils. These undertakings extend beyond the reasonable scope (and pay) for ordinary and normal water treatment and routine services. It is a reasonable expectation that the owner who has continuous access to the system should routinely investigate its system for symptoms and material issues; however, reality dictates that this is not often the case and those with primary access and responsibility frequently shirk the same in favor of blaming the periodic service visits of the water treating company.

Frequently, the water treater is the most technically sophisticated and comprehensively insured party with any role or responsibility relating to the building water system. Accordingly, the water treating company, providing these routine services can become a primary target of misdirected litigation regardless of the merits of the claim.

While a good defense attorney may be able to successfully defend you in court, it is much less expensive to operate with simple contracts which clearly define the scope of the water treater's roles and responsibilities. Thus, water treating companies are increasingly documenting not only the extent of their work but also expressly disclaiming those duties not undertaken to provide protection from baseless litigation. With routinely small profit margins for water treatment service, even a successful defense can disproportionately impact a risk reward analysis.

A myopic focus on water treatment alone fails to recognize that even the best chemical treatment and control efforts are just one of the many efforts that have to be routinely monitored and actively managed in order to have a truly successful outcome. Those who assume that chemicals alone will avail the system may do so at the peril and the possibility of serious financial expense.


Adam Green


Robert J. Cunningham

What defines the universe of factors that affect a cooling system and how do they affect successful long-term maximization of system performance and minimization of deterioration and possibility of premature failure? It is helpful to group these factors into the following non-exclusive list of general considerations: (1) Mechanical Factors; (2) Operational Factors; (3) Environmental Factors; (4) Microbiological Factors; and (5) Chemical Factors.

Mechanical Factors

Mechanical factors include over-all system design and construction, as well as the design and construction of each component in the system. Too often, attention is focused on the cooling tower, evaporative condenser, or closed-circuit cooler, while the overall system, that employs various types of heat exchangers, pumps, piping, valves, fittings, sensors, and controllers is overlooked. Each of these components have been supposedly designed, fabricated, selected, and deployed in the cooling system with specific and limiting parameters. These include material selection, design process and coolant fluid flow characteristics as well as routine optimum operating ranges and operating range limits for factors such as temperature, mechanical stress, and chemical tolerance specifications. Compatibility considerations such as coupling requirements when coupled with dissimilar metals can also be critical.

Redundancy is also an important design consideration for specific system components. For example, if the system incorporates redundant cooling towers, pumps, and exchangers, which is often a necessary indispensable system reliability consideration, then it is necessary to consider how this additional redundant equipment is to be operated, as well as protected from deterioration during idle or lay-up periods. Finally, consideration needs to be given to proper insulation of some components to prevent undesirable coolant temperature changes in the system due to environmental changes.

Case Study (Mechanical Factors):

A large university cooling system was renovated. Specifically, all of the comfort heating and cooling equipment was removed, the building was upgraded structurally to incorporate the latest seismic design refinements, and all of the piping, pumps, and equipment were replaced. The plans and specifications were provided by a very experienced team including an architectural firm, a large general contractor, and well known sub-contractors and suppliers.

Three years after the renovation, recirculating piping in the basement began to leak, and severe corrosion and tuberculation of steel pipe was found. All parties were sued in the university's zeal to recover substantial direct and indirect repair and replacement costs. The defendants included two water treatment suppliers, each of whom had successively enjoyed the business briefly after start-up.

During the litigation, it was discovered that some remote sections of pipe had not been replaced, and that the old piping had been isolated from the start-up hydro-testing, cleaning, and passivation. It was also eventually discovered that the property had been shut down for an extended time after piping, hydro-testing, cleaning, and passivation, and neither treater was informed that old pipe was re-connected into the system after the start- up process was completed. The new system was found to have experienced severe MIC (Microbially Induced Corrosion) during this process, and the old, unremediated piping was also found to be severely corroded and full of MIC. The lawsuit started as a misdirected case of treater negligence and was later resolved in a settlement with the mechanical parties.

Operational Factors

The breadth of factors to be considered in the operation of a water cooling system and its components can vary widely. Operators need to be aware of the previously discussed mechanical factors that are involved in the system and component design to allow long- term trouble-free use of the physical plant components. Generally, operation involves all maintenance functions required to result in the expected system reliability and service life.

For day-to-day operations, the engineers who prepare the operating specifications and operating manuals for the facility must consider all of the above mechanical factors to ensure the system is operated in a manner consistent with the system and component design considerations. It is the responsibility, however, of the operators to follow these operating manuals and to perform all of the required performance and control sampling and testing required to ensure that the operation is compatible with both design and service life expectations. Frequently, the periodic water treater is accused of having operational responsibilities despite their limited access and correspondingly limited pay. Water treaters are typically on-site for a defined service period (either monthly or weekly in most cases) and limited scope /purpose, other than performing routine wet chemistry checks. They do not own the system, nor do they have the final say in operational decisions that can easily defeat sound water treatment.

Case Study (Operational Factors):

A 20-story commercial building in a seasonal climate was equipped with a hydronic system that could be used for heating or cooling. The configuration included an open cooling tower system with a closed condenser loop and a hot water loop. These separate loops would mix at all times between valve exercise and mode operation. Accordingly, at any given time the water chemistry would be shared among all of the systems.

During the warmer summer months, the hot water loop would be "laid up" for at least 120 days. As opposed to draining, drying and cleaning the surface before start-up in the fall, the building maintenance crew would leave the hot water loop partially filled and isolated. Ultimately, the system and its attendant equipment failed. The Owner and property manager blamed the monthly water treater citing elevated bacterial levels in the water as the purported root cause of failure. It was discovered in litigation that because the hot water system was not completely drained, and dried, or otherwise properly laid up, microbial colonies flourished during the stagnant period. This water contaminated the rest of the system.

Despite the fact that the property manager had full access to the premises 365 days a year, the infrequently visiting water treater was promptly blamed for the failure to drain and repassivate. This was the case although the equipment manufacturer's written standards advised that "Proper cleaning and surface preparation must be completed prior to system start-up." Notably, the Owner's contract with the water treater specifically provided that the "Owner will not be liable for any charges other than those described and expressly authorized." The authorized acts were limited to a single monthly service visit for the stated purpose of treatment of the systems and water analysis. For that task, the treater was paid a gross sum of $300 per month. The agreement contained no provisions regarding any shutdowns, cleaning, flushing, or passivation.

Nonetheless, the owner opted not to turn to its property manager that was charging in excess of $20,000 per year. Instead, it opted to target the $300 per month water treater whose contract limited it to a single monthly visit that lasted no more than an hour each month with the chief task of water analysis. When asked where these duties appeared within its contract, the Owner stated, "We hired you guys to take care of the system. You're the experts."

It was successfully argued that the task of re-passivation was beyond the scope of the limited duties to be completed during the once per month visit of the water treater. Further evidence revealed that the hot water loop could not be independently shut down, cleaned and drained, and the chemical treater did not have the autonomy or discretion to do so.

Although a successful legal defense was secured, there were no contingent fee defendants and the cost of defense overwhelmed the relatively small profits for the water treater. While the contractual language providing that the "owner will not be liable for any charges other than those described and expressly authorized" was helpful in the defense, the water treater would have been well served to include a specific scope of work with a one-line disclaimer providing that all duties not expressly listed were otherwise disavowed.

Environmental Factors

Environmental factors include indoor and outdoor environmental temperatures, humidity, air quality, the physical location of equipment, and any expected or possible plant process contamination. Additional environmental factors include quality, quantity, and availability of the make-up water and the availability of proper disposal facilities for tower blowdown and larger volumes of system cooling water if the system requires draining, flushing, and refilling.

The regulatory environment must also be considered, as well as any client-imposed limits including limits on the water treatment chemistry, water consumption, or any other aspect in the use of the water cooling equipment. Some questions to ask include:

(1) Is the cooling tower sited so that the exit air stream is in close proximity to facility inlet air ducts, open building windows, or entrances? (2) Is the tower sited in close proximity to utility stack discharges, fly ash handling facilities, coke plant discharges, paint booths? (3) Will exchanger leaks result in contamination of the cooling water with process gasses/fluids, or solids? (4) Will exchanger or piping leaks be likely to contaminate product with cooling water?

Case Study (Environmental Factors):

A very prominent technology firm was looking for a technical breakthrough to reduce the cost of their cooling tower water treatment programs in an effort to appease their stockholders that they were reducing their "chemical footprint". With these client- imposed restrictions, a water treater recommended the use of a water softener on the cooling tower make-up at the new campus headquarters. The treatment vendor advised that the client shut-off the tower blowdown and depend on drift to limit cycles of concentration.

The water softener removed calcium and magnesium and was regenerated with sodium chloride. As a result of softening the make-up water, the treater recommended shutting off the blowdown. As a result, the chloride in the make-up water cycled up causing excessive chloride concentration in the recirculating water. Within 18 months, the client experienced highly aggravated pitting in the 304 stainless steel cooling towers. In addition, they experienced a rash of complaints concerning water spotting of automobile paint, etching of window glass, and discoloration of building siding. The client incurred substantial damages relating to these self-imposed environmental restrictions.

Micobiological Factors

Microbiological Factors include consideration of the types of organisms that are locally found in the air and water available at the plant site, as well as the human population that is expected to use the facility or those that may be reasonably expected to be in the potential exposure pathway. For instance, will only young, healthy people frequent this location or is the facility a nursing home with a regular populace of older, immuno- compromised or otherwise unhealthy people? Is the cooling system design and metallurgy compatible with the use of relatively high levels of oxidants for cooling water microbial control? Is the treatment program designed and applied in a manner that discourages microbial proliferation? Are side stream filters, basin sweepers, and routine system cleaning and disinfection employed at the site? Can expected use concentrations of oxidants be discharged to the receiving stream without oxidant removal/destruction? Can high levels of demonstrably effective non-oxidizers be routinely employed and safely/legally discharged? Is the facility located in close proximity to agricultural sites where routine or periodic high levels of airborne organisms, nutrients, or bio-mass forming airborne contaminants are present?

For the past century, water treatment has been intended to promote system efficiency through the minimization of piping and equipment corrosion, scale formation, the accumulation of alluvial deposits, system wide microbial fouling and microbial induced corrosion. The sole purpose and scope of minimizing these factors has been to aid in preservation of asset value, minimization of energy and water consumption, reduction of maintenance costs and to achieve optimal heat transfer.

The cooling technology industry is facing a perpetual challenge with respect to the minimization of legionellosis risk. Cooling tower recirculating water is usually within the envelope of temperatures where Legionella thrives, and the water is often loaded with nutrients. The collective responses to Legionella related illness and proposed methods of control are continuing to evolve in terms of science, law and standards.

Whether due to increased rate of incidence or improved medical methodology, confirmed cases of legionellosis are on the rise. This has occurred in the context of traditional water treatment chemicals being restricted or banned based on environmental regulations due to the negative impact (real or perceived) on public health and environmental degradation. The water treatment industry has been forced to trade a biostatic control regimen for one that substitutes carbon, nitrogen, phosphate, and sulfur (also known as "bug food") and then employs the new chemistry at a pH control range that cripples the effectiveness of the remaining highly regulated and discharge limited oxidant chemistry. While research reveals no studies, the question must be asked whether the prohibition of the most effective water treatment chemicals and the subsequent rise of legionellosis cases is causative or coincidental.

Allegations of a legal duty to control a bacterium universally recognized to exist in all aquatic environments (including tap water) represent a significant challenge to the traditional practice or purpose of standard water treatment. Plaintiffs' experts are now attempting to create legal duties beyond those based upon system efficiency and useful life. We are entering a new world where lawyers are asserting that those with any involvement with a cooling water system have legal duties to protect the public from an organism with no known safe level that may infect only certain members of the populace who are merely present in the exposure pathway.

The absurdity of allegations of legal duty on behalf of a chemical water treater to protect the general public from a rapid recolonization bacterium is underscored by their limited access and pay. Most chemical water treaters are granted access to a particular system for a single site visit once or twice per month for which they are paid around $300 to $500 per visit. Despite these limitations, assertions of great responsibility for disease prevention are now being leveled. These accusations are being made despite the fact that there is no standard training, certification, compensation or clear standards by which the water treater is to bejudged. This is akin to conscripting plumbers to be trauma surgeons with no guidance, training, protocols, or pay.

Allegations that a chemical water treater has a legal duty to protect the public from a commonly occurring bacterium with no known safe level effectively charges the treater with being the conscience of the cooling industry in an environment where the owners are under no clear-cut requirements to comply with no legitimized road map to show them how to do so. The financial repercussions for defending a Legionella lawsuit are invariably grossly disproportionate to the payment received for water treatment services rendered. In this litigious context, it is highly advised that treaters do not undertake any Legionella related obligations and expressly disclaim the same.

Case Study (Microbiological Factors):

Five Plaintiffs alleged that they contracted Legionnaire's Disease while guests of a small hotel. They claimed they inhaled bacteria-laden mist emanating from the hotel's rooftop cooling tower. Two of the Plaintiffs died as a result. The surviving Plaintiffs and the families of the decedents filed a wrongful death lawsuit implicating the hotel owner and the chemical water treater.

There was no written contract between the treater and hotel owner. The parties had a personal relationship and entered a handshake deal. During the initial meeting, the water treater recommended a corrosion inhibitor and dual biocide (oxidizing and non-oxidizing) program. Testimony reflected that the owner opted not to purchase the oxidizing biocide citing leftover chemical inventory from a prior treater. There was no documentation to reflect that the oxidizer had been offered or refused.

Pursuant to their verbal agreement, the chemical water treater provided monthly service for over 6 years prior to the outbreak. At no point during the initial meeting or throughout the tenure of the water treater's service, did the owner and treater discuss *Legionella* or the prevention of legionellosis. During this time, the treater provided Field Service Reports for each of the months during the 6-year period preceding the outbreak.

After the outbreak, the hotel owner blamed the chemical water treater asserting that the hotel "followed every one of their recommendations to the letter" and that "we trusted them to handle our system because they're the experts." In absence of a written contract delineating the treater's duties, the conduct of the parties proved significant.

The pre-suit conducts of both the owner and treater consistently reflected that the hotel did not hire, request, or pay the treater to test for or to prevent *Legionella*. The evidence reflected that the water treater was hired by the hotel only to support a routine water treatment plan, which according to the testimony of the water treatment experts in the case, involved only recommending and selling chemicals that would accomplish the tasks of keeping the heat transfer surfaces of the equipment free of scale, corrosion, and biofilm. The experts' interpretation of the treater's job responsibilities was consistent with the widely accepted view of the industry that "most water treatment programs are designed to minimize scale, corrosion and bio-fouling and not to control *Legionella*."[1]

Furthermore, the charges by the treater and payments made by the hotel did not reflect service beyond those relating to system efficiency. For its standard monthly service, the treater was paid $190 per month. During the relevant time frame, charges relating to *Legionella* testing were $460 per test by CDC approved labs. In addition to the lack of charges for any Legionella related service, none of the 6 years of Field Service Reports made any mention of *Legionell*a or test results. Despite receiving these reports every month, the hotel owner never inquired about the status of *Legionella* in the system or any tests to that effect.

In addition, testimony reflected that the hotel never contacted the water treater to complain or to otherwise inquire about the ineffectiveness of any expected treatment after learning of the *Legionella* outbreak at the hotel. Instead, the owner first mentioned the outbreak to the treater in passing when the treater was on the premises for his normal monthly visit.

In light of the conduct of the parties, the Court found no evidence that the treater had assumed any duties with respect to *Legionella* at the hotel.

Chemical Factors

Chemical Factors include the adequacy of the treatment program to function optimally during any expected control malfunctions or during any periodic anticipated low flow or high temperature events. They also include the ability of the chemical treatment program to adequately function to protect the metallic components during expected operational variation. The chemical control specifications need to be considered to ensure that the individual control limits are appropriate for the expected operation, including variations in flow, temperature, water quality, air quality, and probable process leaks and air contamination. The control limits must be designed to ensure reliable operation with acceptable corrosion, deposition, and microbial activity given the expected environmental, process, and personnel contamination considerations that will be encountered. Chemical control recommendations should include cooling water sampling and testing that is adequate to ensure the presence of the proper treatment ingredients at the proper concentrations for the correct times and duration. For example: Is the owner willing to provide sufficient numbers of properly trained and supervised personnel to routinely conduct all of the proper sampling and testing to confirm continuous reliable operation? Are the expected make-up water quality variation excursions and frequency minimal enough to ensure that the sampling and testing program will detect and correct for such make-up water quality variation? Does the chemical feed and control system that is installed use a proxy for control of one or more program ingredients? Does that proxy insure that the intended ingredient is actually present at the correct level, or does it merely detect the presence of the tracer? Can the ingredient level vary from the tracer level?

While smart controllers have been a great aid to the establishment of tight control, they are not designed and fabricated to provide long term reliable control in the absence of routine specific control testing and calibration to verify that the ingredient or parameter of interest is being reliably controlled by the device. This responsibility logically relates back to those with regular daily access to the system (the owner or property manager). The chemical supplier should not be relegated to staking its reputation and account profitability on the controller alone without sufficient reliance on the owner who should follow proper control sampling, testing, logging and review parameters. Treaters may be forced to ask whether the account revenue justifies the acceptance of additional responsibility for reliable control and routine sampling and testing in the event the owner shirks these responsibilities.

Case Study (Chemical Factors):

A water treatment service company was providing a routine treatment program for the office building cooling towers belonging to a large iron and steel manufacturer. The towers appeared in all measured aspects to be well treated and free of any significant indication of scale, corrosion, and fouling. The cooling water and the cooling tower appeared clean and free of any microbiological fouling. The treatment program incorporated the use of two different non-oxidizing microbicides fed on an alternating basis weekly. The weekly aerobic dip slides and the monthly tests for sulfate reducers, iron bacteria, slime formers, and algae showed aerobic bacteria and anaerobic organisms at or below $1(10)^3$, and $<(10)^1$ respectively.

The building owner, out of an abundance of caution, requested that *Legionella* testing be performed. Duplicate samples showed $1(10)^3$ cfu/ml *Legionella Pneumophila* Serogroup 1. Subsequent investigation demonstrated that while the microbial control program was working well on the populations of interest, it was ineffective with regard to the control of *Legionella*.

A change in the program to incorporate products and dosages known to be effective for *Legionella* control resulted in a reduction in Legionella counts to $<(10)^1$ cfu/ml. Repeat testing over time verified that the *Legionella* count remained below detectable levels. No further issues resulted.

Conclusion

The foregoing list of issues and case studies is a non-comprehensive list of examples of mechanical, operating, environmental, microbiological, and chemical factors that may give rise to system failures despite a sound water treatment program. It is important to reiterate that duties to investigate, monitor, or "catch" these issues extend beyond that of a routine water treatment program. It is important that the water treater's roles are clearly defined and that no legal duty is undertaken by the chemical treater without adequate client consultation, proper documentation, assessment of the risks and adequate compensation.

Specifically, it is critical that in the course of educating the client about certain risks that the water treater has clearly defined its scope of work to the exclusion of all other responsibilities. Absent clearly defined roles, the water treater may be targeted in litigation based on the owner's convenient assumption that any ill that befalls the system is the treater's responsibility.

Water treaters would be well served to discuss potential issues that may arise despite proper water treatment and to accordingly educate customers. A well-documented water treatment service program will narrowly define the duties undertaken commensurate with the corresponding pay. In the event the treater is hired to provide extra-contractual services to address the issues identified in this publication, consideration should be given to the amount of service time required for a particular account based on the revenue originally anticipated from standard water treatment. It is highly preferable that this decision is deliberately made by the water treater and that additional service is not assigned to the water treater based on the owner's assumption. Regardless of the business at issue, those providing service should be compensated relative to their commensurate risk. Water treaters are no exception and should be adequately compensated.

Depending upon the circumstances and the risks identified, the treater may wish to present itself as an advisor with a limited investigatory role and not a party responsible for remediating the identified contingencies.

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[1] Ashrae Position Document On Legionellosis 7 (Ashrae 1998) (2012)

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.

CTI
LICENSED
Thermal Testing

Licensed CTI Thermal Testing Agencies

*License Type A, B**

Clean Air Engineering
7936 Conner Rd, Powell, TN 37849
800.208.6162 or 865.938.7555
Fax 865.938.7569
www.cleanair.com / khennon@cleanair.com
Contact: Kenneth (Ken) Hennon

Cooling Tower Technologies Pte Ltd
17 Mandai Estate #06-02, Hwa Yew Industrial Building
SINGAPORE S729934
+65.98251247
johnny@coolingtwrtech.com
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Cooling Tower Test Associates, Inc.
15325 Melrose Dr., Stanley, KS 66221
913.681.0027 / (F) 913.681.0039
www.cttai.com / cttakc@aol.com
Contact: Thomas E. (Tom) Weast

DMT GmbH & Co. KG
Am Technologiepark 1, 45307 Essen, Germany

+49.201.172.1164
www.dmt-group.de / meinolf.gringel@dmt-group.com
Dr. -Ing. Meinolf Gringel

McHale Performance
4700 Coster Rd, Knoxville, TN 37912
865.588.2654 / (F) 865.934.4779
www.mchaleperformance.com
ctitesting@mchaleperformnce.com
Contact: Jacob Faulkner

* *Type A license is for the use of mercury in glass thermometers typically used for smaller towers.*

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

CTI
LICENSED
Drift Testing

Licensed CTI Drift Testing Agencies

Clean Air Engineering
7936 Conner Rd, Powell, TN 37849
800.208.6162 or 865.938.7555
Fax 865.938.7569
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4700 Coster Rd, Knoxville, TN 37912
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Cooling Technology Institute Sound Testing

Cooling towers are used extensively wherever water is used as a cooling medium or process fluid, ranging from HVAC to a natural draft cooling tower on a power plant. Sound emanating from a coooling tower is a factor in the surrounding environment and limits on those sound levels, and quality, are frequently specified and dictated in project specefications. The project specifications are expected to conform to local building codes or safety standards. Consequently, it may be in the interest of the cooling tower purchaser to contract for field sound testing per CTI ATC-128 in order to insure compliance with specification requirements associated with cooling tower sound.

Licensed CTI SoundTesting Agencies

Clean Air Engineering
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Cooling Technology Institute Certification Program STD-201 for Thermal Performance

As stated in its opening paragraph, CTI Standard 201... "sets forth a program whereby the Cooling Technology Institute will certify that all models of a line of water cooling towers offered for sale by a specific Manufacturer will perform thermally in accordance with the Manufacturer's published ratings..." By the purchase of a "certified" model, the User has assurance that the tower will perform as specified, provided that its circulating water is no more than acceptably contaminated-and that its air supply is ample and unobstructed. Either that model, or one of its close design family members, will have been thoroughly tested by the single CTI-licensed testing agency for Certification and found to perform as clained 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 int he publication.

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 at 281.583.4087, or vmanser.cti.org or PO Box 681807, Houston, TX 77268 for further information

Licensed CTI Thermal Certification Agencies

Agency Name / Address	Contact Person / Website / Email	Telephone / Fax
Clean Air Engineering 7936 Conner Rd Powell, TN 37849	Kenneth (Ken) Hennon www.cleanair.com khennon@cleanair.com	800.208.6162 or 865.938.7555 (F) 865.938.7569
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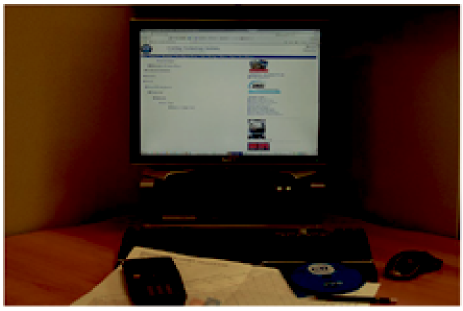
McHale Performance 4700 Coster Rd Knoxville, TN 37912	Jacob Faulkner www.mchaleperformance.com ctitesting@mchaleperformance.com	865.588.2654 (F) 865.934.4779

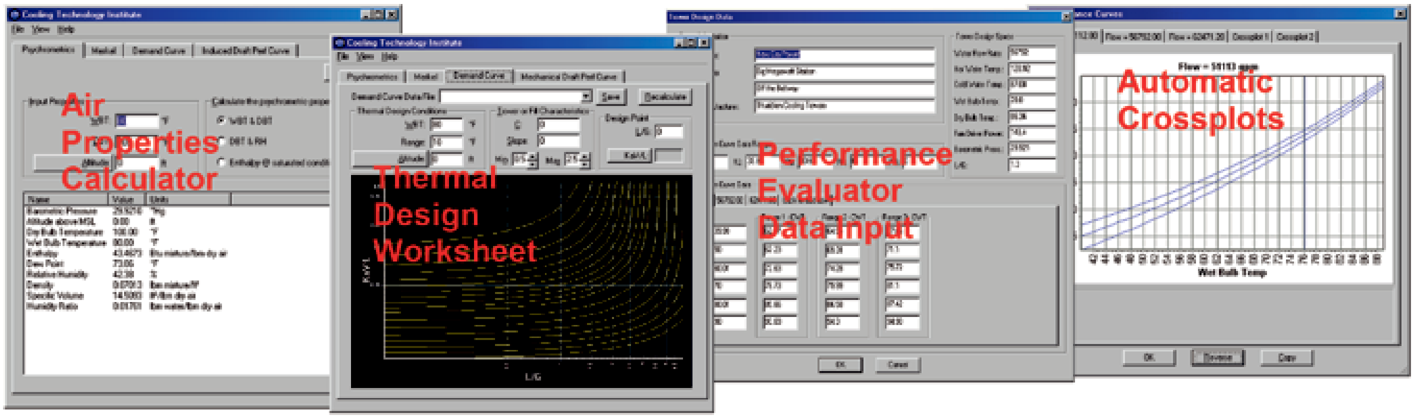
CTI Toolkit Version 3.2

...now Windows 10 compatible



Key Features of CTI Toolkit Version 3.2:

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



System Requirements - Microsoft Windows, XP, Vista, Windows 7 and 10

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

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

To Order, Call (281) 583-4087 or visit CTI's Website www.cti.org

8/8/08

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> *"The Performance Curve method is widely recognized as a more accurate method of determining tower capability from measured test data. The new CTI ToolKit Tab Application provides a quick and easy method for anyone to evaluate a performance test using the procedures prescribed in the ATC-105 code."*
>
> \- Larry Burdick, ATC-105 Task Group

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Product	Unit Price	Quantity	Total
CTI ToolKit Version 3.2 (single user license)			
CTI Member	$395		
Non-member	$450		
CTI ToolKit Version 3.2 (Upgrade from V1.0 and V2.0)			
CTI Member	$ 95		
Non-member	$120		
CTI ToolKit Version 3.2 (Upgrade from V3.0)			
CTI Member	$ 25		
Non-member	$ 40		
Shipping for Flash Drive (from Texas): *Priority mail $6; 2nd Day Air $18; Overnight Domestic $28; / International (DHL) TBA*			
Multi-user site licenses and educational institution pricing available on request			

System Requirements:
Microsoft Windows®
95/98, 2000, XP, and
Windows 10

Phone: **281.583.4087**
Fax: **281.537.1721**
Web: **http://www.cti.org**

Cooling Towers Certified by CTI Under STD-201

As stated in its opening paragraph, CTI Standard STD-201 "...sets forth a program whereby the Cooling Technology Institute will certify that all models of a line of evaporative heat rejection equipment offered for sale by a specific Manufacturer will perform thermally in accordance with the Manufacturer's published ratings..."

By the purchase of a ***CTI Certified*** model, the Owner/Operator has assurance that the tower will perform as specified*.

**Performance as specified when the circulating water temperature is within acceptable limits and the air supply is ample and unobstructed. CTI Certification under STD-201 is limited to thermal operating conditions with entering wet bulb temperatures between 10°C and 32.2°C (50°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.*

For each certified line, all models have undergone a technical review for design consistency and rated performance. One or more representative models of each certified line have been thoroughly tested by a CTI Licensed testing agency for certification and found to perform as claimed by the Manufacturer.

The CTI STD-201 Thermal Performance Certification Program has grown rapidly since its' inception in 1983 (see graphs that follow). A total of 64 cooling tower manufacturers are currently active in the program. In addition, 11 of the manufacturers also market products as private brands through other companies.

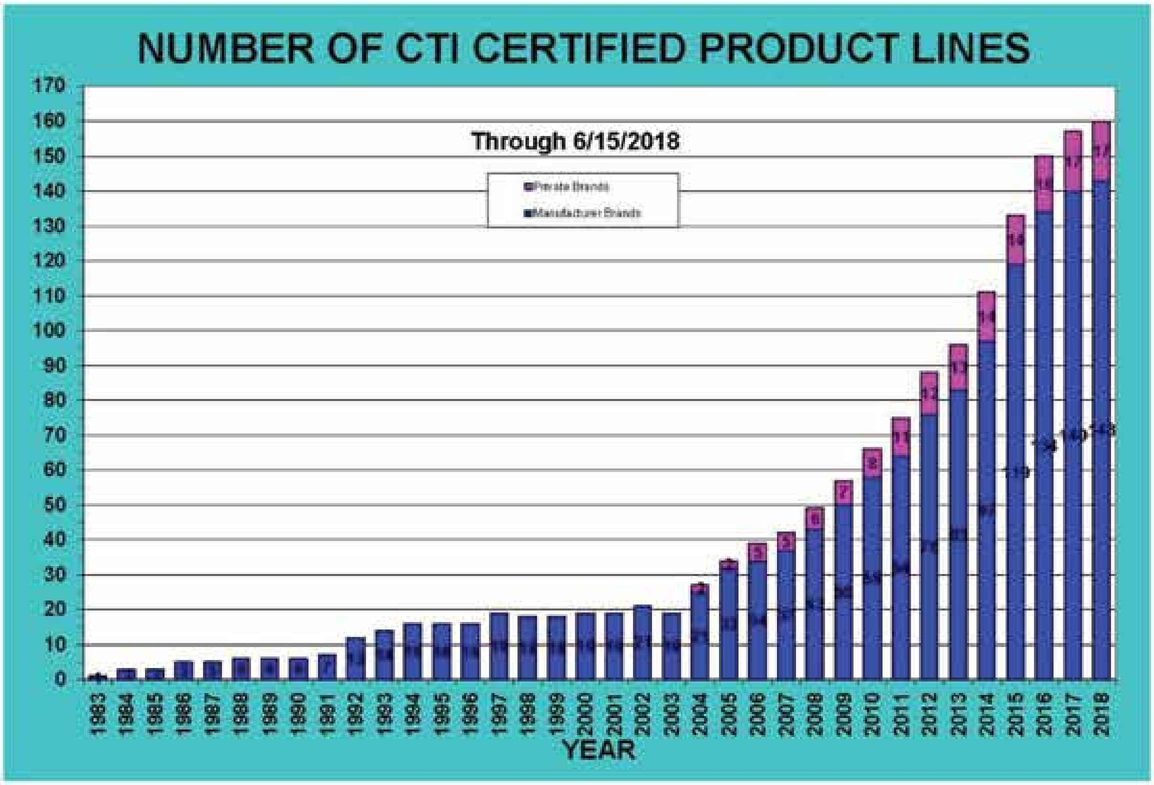
While in competition with each other, these manufacturers benefit from knowing that they each achieve their published performance capability and distinguish themselves by providing the Owner/Operator's required thermal performance. The participating manufacturers currently have 143 certified product lines plus 17 product lines marketed as private brands which result in approximately 38,000 CTI Certified cooling tower models to select from.

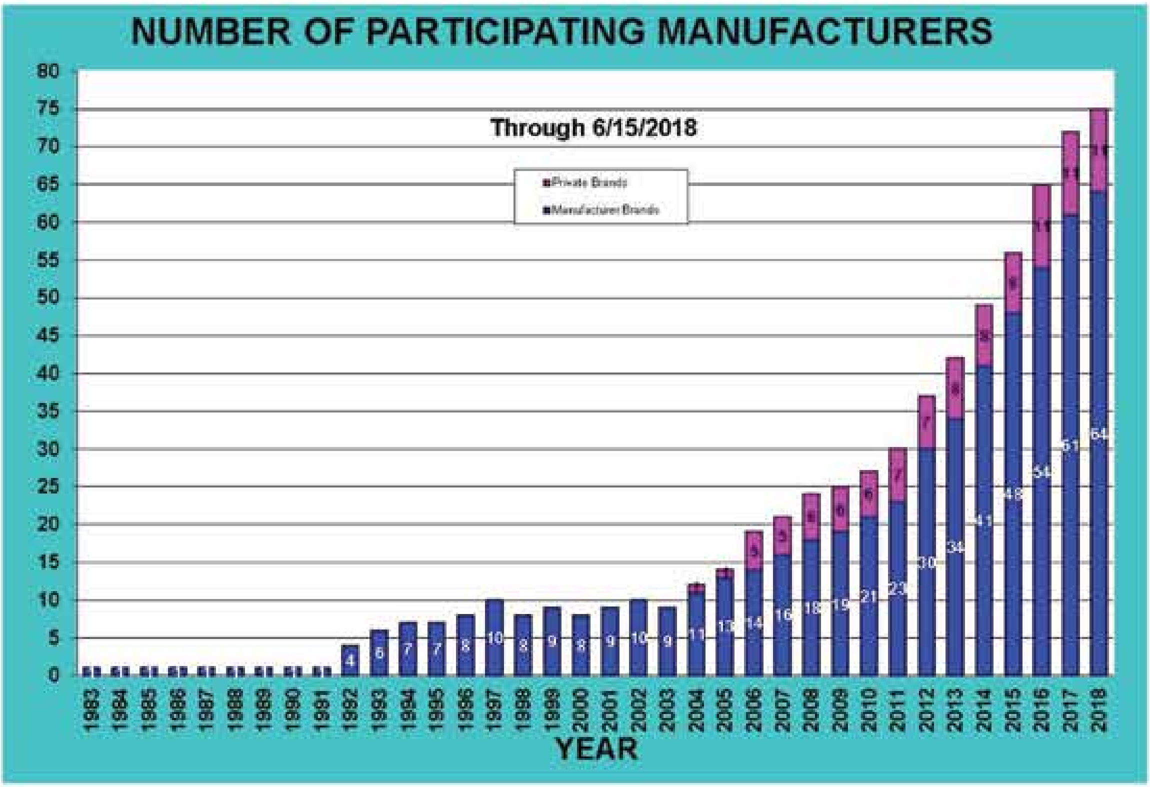
For a complete listing of certified product lines, and listings of all CTI Certified models, please see:

http://www.cti.org/certification.php

Those Manufacturers who have not yet chosen to certify their product lines are invited to do so at the earliest opportunity. Contact the CTI Administrator at vmanser@cti.org for more details.

Thermal Performance Certification Program Participation Through June 15, 2018





Current Program Participants

(as of June 15, 2018)

Program Participants and their certified product lines are listed below. Only the product lines listed here have achieved CTI STD-201 certification. For the most up-to-date information and a complete listing of all CTI Certified models please visit:

http://www.cti.org/certification.php

Current Certified Model Lists are available by clicking on the individual line names beneath the Participating Manufacturer name.

Catalog information and product selection data are also available by clicking on the links beneath each listed line.

A

Advance GRP Cooling Towers, Pvt.,Ltd.
Advance 2020 Series A *Validation No. C31A-07R03*

Aggreko Cooling Tower Services
AG Line *Validation No. C34A-08R02*

Amcot Cooling Tower Corp.
Series R-LC *Validation No. C11E-11R02*

American Cooling Tower, Inc.
ACF Series *Validation No. C38D-18R00*
ACX Series *Validation No. C38C-18R00*

AONE E&C Corporation, Ltd.
ACT-C Line *Validation No. C28B-09R01*
ACT-R/ACT-RU Line *Validation No. C28A-05R05*

Approach Engineering Co., Ltd
NS Line *Validation No. C76A-16R00*

Axima (China) Energy Technology Co., Ltd.
EWK Line *Validation No. C72C-17R00*
EWX Line *Validation No. C72A-15R02*

B

Baltimore Aircoil Company, Inc.
FXT Line *Validation No. C11A-92R02*
FXV Line *Validation No. C11J-98R10*
NXF Line *Validation No. C11Q-18R00*
PF Series *Validation No. C11P-12R02*
PT2 & PTE Series *Validation No. C11L-07R05*
Series V Closed VF1 & VFL *Validation No. C11K-00R02*

Baltimore Aircoil Company, Inc, continued
Series V Open VT0,VT1,VTL &VTL-E
Validation No. C11B-92R06
Series 1500 *Validation No. C11H-94R09*
Series 3000 A,C,D,E, Compass & Smart
Validation No. C11F-92R18

Bell Cooling Tower Pvt, Ltd
BCTI Line *Validation No. C43A-12R02*

C

Cenk Endüstri Tesisleri Imalat Ve Taahüt A.Ş.
LEON Line *Validation No. C89A-17R00*
LISA Line *Validation No. C89B-17R00*

Composite Cooling Solutions, Inc.
PLC Line *Validation No. C79A-17R00*

Cool Water Technologies
RTAi Line *Validation No. C52A-13R02*
RTi Line *Validation No. C52B-13R01*

D

Decsa
RCC Series *Validation No. C42C-14R00*
TMA-EU *Validation No. C42C-17R00*

Delta Cooling Tower, Inc.
TM Series *Validation No. 02-24-01*

Delta (India) Cooling Tower Pvt, Ltd
DFC-60UX Line *Validation No. C85A-18R00*

Dongguan Ryoden Cooling Equipment Co., Ltd
RT-L&U Series *Validation No. C71A-15R02*
RTM-L Series *Validation No. C71B-15R00*

E

Elendoo Technology (Beijing) Co., Ltd.
EL Line *Validation No. C50C-15R02*
ELOP Line *Validation No. C50B-14R02*

Ebara Refrigeration Equipment & Systems Co.
CDW Line *Validation No. C53A-13R03*
CXW Line *Validation No. C53B-14R01*

Evapco, Inc.
AT Series *Validation No. C13A-99R19*
ATWB Series *Validation No. C13F-09R09*
AXS Line *Validation No. C13K-15R03*
ESWA & ESWB Series *Validation No. C13E-06R09*
L Series Closed *Validation No. C13G-09R04*
L Series Open *Validation No. C13C-05R03*

F

Flow Tech Air Pvt Ltd
FTA Series *Validation No. C69A-16R01*

G

Genius Cooling Tower Sdn Bhd
MK Series *Validation No. C67C-18R00*
MT Series *Validation No. C67A-16R00*
MX Series *Validation No. C67B-16R00*

Guangdong Feiyang Industry Group Co., Ltd
LK Line *Validation No.C77A-17R00*

Guangdong Zhaorin Industrial Co., Ltd
SRN Series *Validation No.C95A-17R00*

Guangzhou Goaland Energy Conservation Tech Co., Ltd.
GLH Series *Validation No. C96A-17R00*
GLN Series *Validation No. C96B-17R00*

Guangzhou Laxun Technology Exploit Company, Ltd.
LC Line *Validation No. C45F-16R00*
LMB Line *Validation No. 12-45-02*
PG Line *Validation No. C45G-17R00*
PL Line *Validation No. C45E-16R01*

Guntner U.S. LLC
ECOSS Line *Validation No.C84A-17R00*

H

Hon Ming (Guang Dong) Air Conditioning Equipment Company, Ltd.
MK Series *Validation No. C66A-15R02*

Hunan Yuanheng Technology Company, Ltd.
YCF-H Line *Validation No. C40C-16R00*
YHA Line *Validation No. C40A-11R03*
YHD Line *Validation No. C40B-15R00*

HVAC/R International, Inc.
Therflow Series TFC *Validation No. C28B-09R01*
Therflow Series TFW *Validation No. C28A-05R05*

I

Industrial Mexicana, S.A. de C.V.
Series 1000 *Validation No. C60A-15R00*
Series 2000 *Validation No. C60B-16R00*
Series 6000 *Validation No. C60C-15R00*

J

Jacir
DTC ecoTec *Validation No. C46E-18R00*
KS Line *Validation No. 12-46-01*
KSF Line *Validation No. C46B-15R00*
S Series *Validation No. C46D-18R00*
VAP Line *Validation No. C46C-16R01*

Jiangsu Dayang Cooling Tower Co., Ltd.
HLT Line *Validation No. C94A-14R02*

Jiangsu Greenland Heat Transfer Technology Co.
GBH-TS Line *Validation No. C87A-18R00*

Jiangsu i-Tower Cooling Technology Co., Ltd.
REH Series *Validation No. C75B-16R00*
TMH Series *Validation No. C75A-16R00*

Jiangxi Ark Fluid Science Technology Co., Ltd.
FKH Line *Validation No. C83A-17R00*

Ji'Nan Chin-Tech Thermal Technology Co., Ltd.
CTHX Line *Validation No. C91E-16R00*
CTNX Line *Validation No. C91D-16R00*

K

Kelvion B.V.
Polacel CF Series *Validation No. C25A-04R02*
Polacel XF Series *Validation No. 13-25-02*

KIMCO (Kyung In Machinery Company, Ltd.)
CKL Line *Validation No. C18B-05R03*
Endura Cool Line *Validation No. C18A-93R08*

King Sun Industry Company, Ltd.
HKB Line *Validation No. C35A-09R04*
HKD Line *Validation No. C35B-09R04*
KC Line *Validation No. C35-11R01*
KFT Line *Validation No. C35D-16R00*

L

Liang Chi Industry Company, Ltd.

LCTD Line *Validation No. C20J-18R00*
LCTR Line *Validation No. C20H-17R00*
Series C-LC *Validation No. C20B-09R02*
Series D-LC *Validation No. C20F-14R02*
Series R-LC *Validation No. C11E-11R03*
Series U-LC *Validation No. C20D-10R04*
Series V-LC *Validation No. C20C-10R01*
TLC Line *Validation No. C20G-16R00*

M

Marley (SPX Cooling Technologies)

Aquatower Series *Validation No. 01-14-05*
AV Series *Validation No. C14D-98R03*
DTW Series *Validation No. C14N-16R01*
LW Series *Validation No. C14P-16R01*
MCW Series *Validation No. 06-14-08*
MD and CP Series *Validation No. C14L-08R07*
MHF Series *Validation No. C14G-04R08*
NC Series *Validation No. C14A-92R20*
NX Series *Validation No. C14M-15R01*
Quadraflow Line *Validation No. 92-14-02*

Mesan Cooling Tower, Ltd.

MCC Series *Validation No. C26G-12R03*
MFD Series *Validation No. C26J-16R01*
MXC Series *Validation No. C26H-12R01*
MXR-KM, MXL, MXH Series *Validation No.C26C-08R08*

MITA S.r.l.

PM Series *Validation No. C56B-16R00*

N

NIBA Su Sogutma Kulerleri San, ve Tic, A.S.

HMP-NB Line *Validation No. C55A-14R01*

Nihon Spindle Manufacturing Company, Ltd.

KG Line *Validation No. C33B-12R05*

O

OTT Company, Ltd.

OTTX Line *Validation No. 12-44-02*
OTTX-C Line *Validation No. C44D-14R00*

Ocean Cooling Tower Sdn Bhd

YC Series *Validation No. C86A-17R00*

P

Paharpur Cooling Tower, Ltd.

CF3 Line *Validation No. C51A-13R02*
OXF-30K Line *Validation No. C51B-14R00*

Protec Cooling Towers, Inc.

FRS Series *Validation No. 05-27-03*
FWS Series *Validation No. C27A-04R06*

R

Reymsa Cooling Towers, Inc. (Fabrica Mexicana de Torres, SA de CV)

HFC Line *Validation No. C22F-10R4*
RT & RTM Series *Validation No. C22G-13R05*

Rosemex, Inc.

RC (RSC/D) Series *Validation No. C54A-13R03*
RO (ROS/D) Series *Validation No. C94A-14R02*

RSD Cooling Towers

RSS Series *Validation No. 08-32-01*

Ryowo (Holding) Company, Ltd.

FRS Series *Validation No. 05-27-03*
FVS Series *Validation No. 12-27-06*
FWS and FCS Series *Validation No. C27A-04R06*

S

Shangdong Grad Group Co., Ltd.

GAT Series *Validation No. C88A-17R00*

Shanghai ACE Cooling Refrigeration Technology Col, Ltd.

AC Line *Validation No. C80A-17R00*

Shanghai Baofeng Machinery Manufacturing Co., Ltd.

BTC Line *Validation No. C49A-12R01*

Shanghai Liang Chi Cooling Equipment Co., Ltd.

LCM Line *Validation No. C62A-14R00*
LNCM Line *Validation No. C62B-16R00*
LRS Line *Validation No. C62C-16R00*

Shanghai Wanxiang Cooling Equipment Co., Ltd.

FBH/HL Line *Validation No. C54A-13R03*
FKH/FKHL Series *Validation No. C94A-14R02*

Sinro Air-Conditioning (Fogang) Company, Ltd.

CEF-A Line *Validation No. C37B-11R02*
SC-B Series *Validation No. C37C-11R02*
SC-H Series *Validation No. C37A-10R02*

Sung Ji Air-Conditioning Technology Co., Ltd.
SJCO Series *Validation No. C74B-16R00*
SJMO Series *Validation No. C74A-16R00*

T

Ta Shin F.R.P. Company, Ltd.
TSS Series *Validation No. 08-32-01*

The Cooling Tower Company, L.C
Series TCIA *Validation No. C29B-15R00*

Thermal-Cell sdn bhd
TYH Line *Validation No. C40A-11R03*

Tower Tech, a div. of CPK Manufacturing, LLC
TTXL Line *Validation No. C17F-08R04*
TTXR Line *Validation No. C17F-15R00*

Truwater Cooling Towers, Inc.
EC-S Series *Validation No. C41A-12R04*
EX-S Series *Validation No.C41B-12R04*
VXS Series *Validation No. C41C-13R01*

W

Wuxi Ark Fluid Science Technology Co., Ltd.
FBF Line *Validation C78A-16R00*

Wuxi Fangzhou Water Cooling Equipment Co., Ltd.
FHB Line *Validation C64C-18R00*

Y

York (By Johnson Controls)
AT Series *Validation No. C13A-99R19*
LSTE Line *Validation No. C13G-09R03*

Z

Zhejiang Dongjie Cooling Tower Co., Ltd.
DHC Line *Validation No. C63B-15R00*
DMNC Line *Validation No. C63A-15R00*

Zhejiang Haicold Cooling Technology Co., Ltd
SF Line *Validation No. C76A-16R00*

Zhejiang Jinling Refrigeration Engineering Co.,Ltd.
JFT Series *Validation No. C28C-16R01*
JNC Series *Validation No. C28B-09R01*
JNT Series *Validation No. C28A-05R05*

Zhejiang Shangfeng Cooling Tower Co., Ltd.
SFB Line *Validation No. C73A-15R01*

Zhejiang Wanxiang Science and Technology Company, Ltd.
WBH Line *Validation No. C96A-17R00*
WBN Line *Validation No. C96B-17R00*

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