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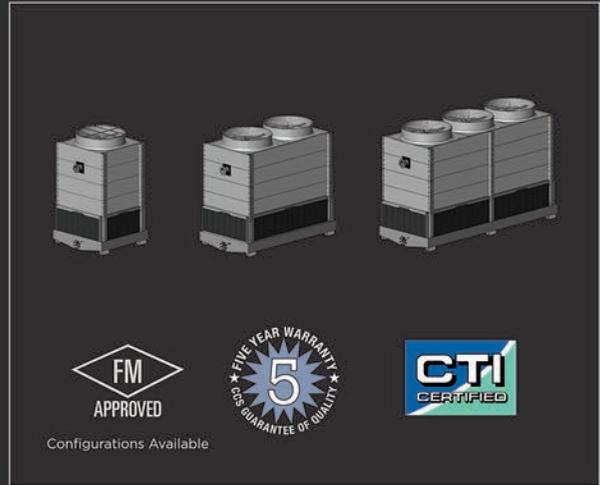


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As a broad based industry association, our mission is to advocate and promote, for the benefit of the public, the use of all environmentally responsible, commercial cooling technologies, such as wet cooling towers, air-cooled condensers, dry coolers, indirect cooling, and hybrid systems, by encouraging:

- Education on these technologies
- Development of codes, standards, and guidelines
- Development, use, and oversight of independent performance verification and certification programs
- Research to improve these technologies
- Advocacy and dialog on the benefits of cooling technologies with Government Agencies and other organizations with shared interests
- Technical information exchange

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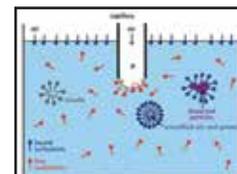
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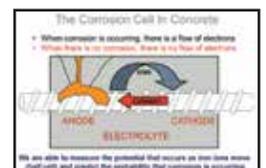
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## For Immediate Release

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

2-October-2021

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, 2021, at the CTI address listed.

## Future Meeting Dates

### Committee Workshop

July 11-14, 2021  
The Inn at Loretto  
Santa Fe, NM

July 10-13, 2022  
The Steamboat Grand  
Steamboat Springs, CO

### Annual Conference

February 7-11, 2021  
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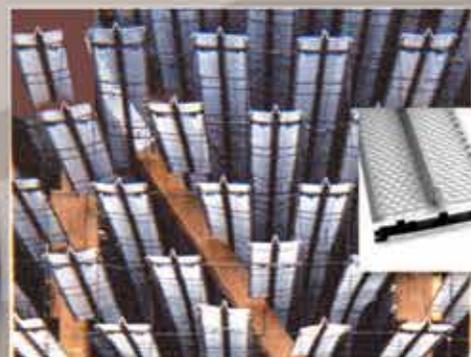
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# View From The Tower

## General thought:

“My friend, you and I have lived in serious times.”

The second president of the United States, John Adams, wrote this phrase in a letter late in his life, and it seems very suitable as I think back over the last few months. As I write this near the end of June, the death of George Floyd and its aftermath have brought racial discrimination to the forefront of consciousness in America and a lot of the rest of the world as well. Much has been said and written by many more articulate and better qualified than me, but I will say that I am proud of the way that the CTI has practically functioned as the global organization that it is. We have members from literally every continent, and in my experience, all are treated with dignity and respect even when we’ve had differences of opinion over technical matters. I have never personally observed or been aware of such behavior within CTI, but it should go without saying that discrimination or mistreatment of anyone – member, guest, conference attendee, or staff – because of race or nationality has no place in our organization. As has been said in the past, the CTI is ultimately people, all of whom are innately worthy of basic dignity and respect.

In addition to this, the ramifications of COVID-19 continue to affect life around the globe and especially the United States where virus rates are rising faster in many areas than ever before. As I write, the final pieces are being put in place to hold the first ever Virtual CTI Committee Workshop in a couple of weeks. It certainly is disappointing to not be able to meet in person, but I believe our Board of Directors’ decision is the correct one for the current environment. Thank you to Vicky, the CTI staff, and the leadership of our three Technical Committees for all the hard work they have put in to prepare for something unprecedented for us as a group. And thank you to all of you for being flexible and willing to support the good and necessary work of maintaining our Codes and Standards documents.

Speaking of getting work done, while the last three months have been completely different than anything most of us have ever experienced, the CTI has still done a lot since the conclusion of our Annual Conference in Houston in February:

Our Regulatory Oversight Task Force drafted formal comments that we as an organization submitted to the United States Department of Energy regarding a petition filed by an organization asking the DOE to impose new regulation on industrial fan efficiency. It also submitted feedback to the American Society of Mechanical Engineers regarding potential changes to its Boiler and Pressure Vessel Code.



Chris Lazenby

Our Certification Administrator continues to work with the program’s participating manufacturers to address ever-changing logistics associated with the COVID-19 pandemic. Additionally, first steps have begun toward establishing certification programs associated with Dry Cooling and Sound.

New committees were commissioned in February both to study online collaboration technology and how it could best be used to increase our productivity, especially in working on our numerous Codes & Standards and to study our aspects of our Annual Conference, including possible

ways of integrating technology into the equation. I’m sure both groups have gained much more direct experience over the last few months than they might ever have foreseen.

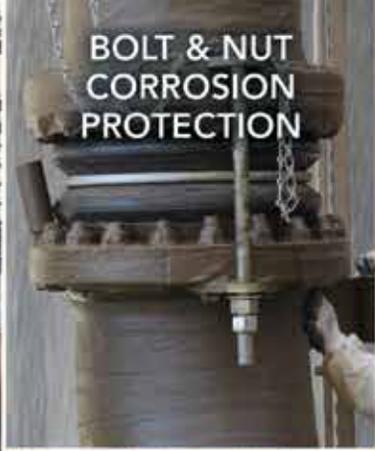
And finally, the Flexibility Award goes to the CTI Office Staff simply for keeping the day to day operation of the CTI going. Over the last several months they have worked without a physical office, doubled as homeschool teachers, gone back to the office, set up the Summer Workshop, and as I write this are contemplating having to close the office again due to ever increasing infection rates. Throughout all of this, questions have been answered, bills have been paid, meetings have been facilitated, and even derelict invoices from members who still hadn’t paid their dues at the end of May have been collected (really, I thought I had taken care of that in Houston...). Things haven’t missed a beat, so thank you very much, Vicky, Angie, Kelli, and Drew!

So, yes, the times are serious, but the CTI continues forward. Thank you for being the CTI, and please continue to stay safe!

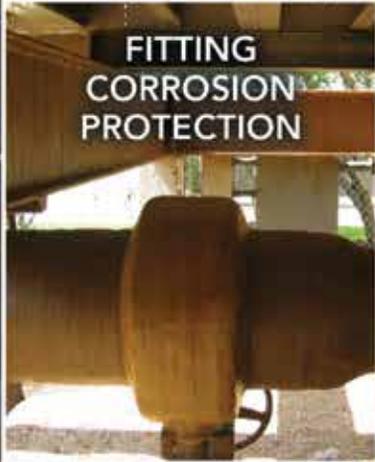




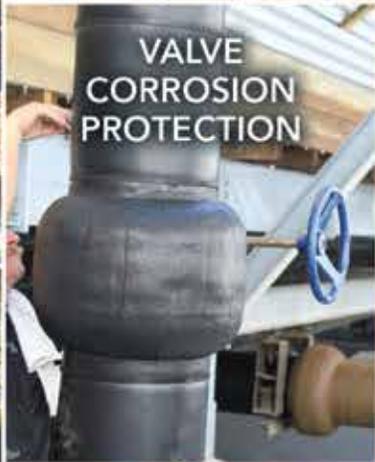
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# Editor's Corner

## Editor's Corner – July 2020

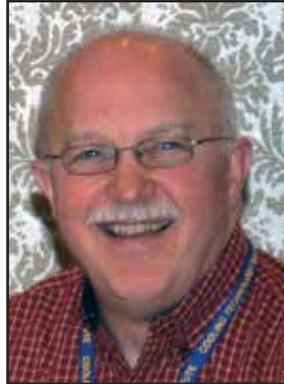
Writing this in the 4th month of pandemic impacts. I'm used to working from home, but not going out except for essentials and family support is taxing in unexpected ways. I'm sure many are feeling the impacts. On behalf of many friends who are providing health care and those who are at risk for infections, thank you to all who are wearing masks to protect others.

CTI continues to be active in working to influence governmental and other organization standards actions that impact our members. A brief overview:

California Title 24 – We believe that they will push for increased energy efficiency in future revisions, but not in the current one.

California Title 20 – It appears that they will hold to the exemption for heat rejection equipment fan efficiency requirements. We have not yet seen language to confirm that.

ASME Boiler & Pressure Vessel Code – The scope task force is still



Paul Lindahl

pushing to remove the exemptions for less than 6" vessels and for those with non-boiling water. CTI has joined other organizations in written opposition to this since other standards have evolved to cover such equipment.

Legionnaires' – CTI has published GDL-159 for evaporative heat rejection equipment (cooling towers (open and closed loop) and evaporative condensers). ASHRAE Guideline 12-2020 has been released. Both are important enhancements to writing Water Management Programs per ASHRAE Standard 188-2018. ASHRAE Standard 514P is in development to cover other building water system hazards, and CTI has official organization representatives, Helen

Cerra and Frank Morrison.

CTI R&D is continuing to be active in exploring and developing R&D projects. They should be proposed through the standing committees and program committees.

We trust that you all are being safe and looking forward to CTI's first ever virtual meeting beginning July 12. Hope to talk to many of you then!



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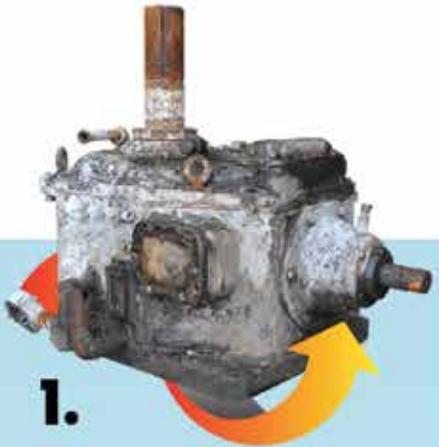
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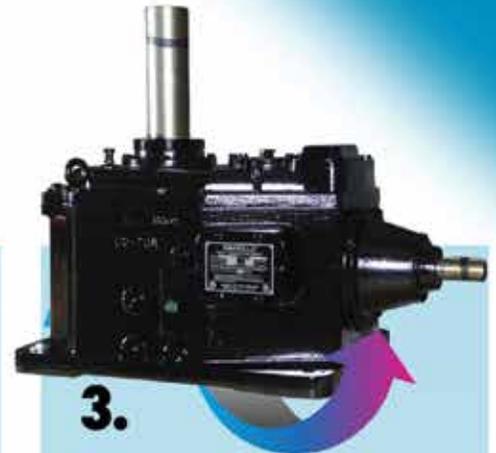
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MEMBER

# Impact Of Water Surface Tension On Drift Eliminators

Vincent Ganzitti and Jorge Rincones  
Hamon Thermal Europe

## Introduction.

Over the recent years, an increased number of cases were reported to CTI in which abnormal levels of drift were found. The reports come from various sources: end users, CTI testers, cooling tower manufacturers or suppliers of drift eliminators. They all describe a high level of drift despite a correct installation of the product. While the number of cases remains marginal (~2 per year), it is necessary to understand their origins.

This paper presents a potential explanation as well as a method to detect the situation.

## Definition Of Drift.

In the operation of a cooling tower, moving air is brought into contact with the circulating water for heat transfer. This water is distributed in the form of droplets onto fill to maximize the surface area exposed to the air. During these exchanges, small water droplets are entrained in the air moving through the tower. Droplets that are not removed from the air stream are released from the cooling tower into the environment around the installation. These droplets, which possess the same chemical composition as the circulating water, are known as drift.

It is important not to confuse drift and condensation. Indeed, the cooling tower exhaust is generally comprised of saturated air. This results in the production of small droplets of condensed water vapor when the exhaust air cools. They are not to be confused with drift, as they are made of pure water, whereas the droplets of drift have the same chemical composition of the circulating water.

## How Do Drift Eliminators Work?

The drift eliminator is made in the shape of a wave, forcing incoming air to change direction. Due to their higher inertia, large droplets (in red on the picture below) are not able to follow those sharp moves and will impact the surface of the drift eliminators. Once on the surface, they will gather in larger droplets which will be too heavy to float in the airstream. They will fall back down to the wet section of the cooling tower, therefore removing a large portion of the droplets.

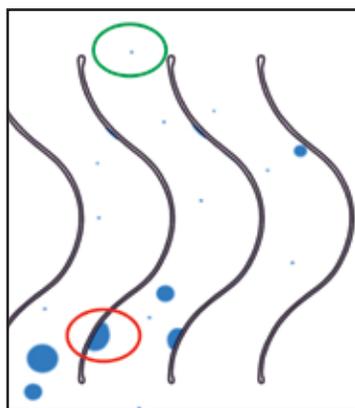


Figure 1: Drift eliminator operation in counterflow



Vincent Ganzitti

The small droplets (in green on the picture below), however, will be able to follow the air flow and will avoid collisions against the drift eliminator surface. They will be released at the tower discharge, making up its drift.

Changing the shape of the drift eliminator will change the quantity of small droplets exiting the product.

## Common Root Causes For Drift Rate Failures.

As for every component, the drift eliminators (DE) have limits in their efficiency and operating conditions. In order to have a properly working product, the following items must be respected:

- Correct installation of the DE: avoid gaps which allow air and droplets to bypass the DE, seal DE panels along the walls, around the columns, install DE panels tightly against one another, etc.
- Correct operating air velocity: if the air velocity is too high, the droplet on the surface of the DE can be brought up to the top of the blade. Then, the droplet can be lifted by the airflow and escape the cooling tower. This phenomenon is known as carry-over.
- Correct operation of the tower: the vent pipe typically installed in the water distribution headers shall not be overflowing, as it often bypasses the drift eliminator; the sprayers shall not spray on the product, otherwise circulating water might go through due to the relatively high sprayer pressure.

The cases that we will describe further in this paper remain VERY marginal and most of the drift issues find their root causes in the above reasons.

## Description Of The Situation.

Over the last 5 years several cases with very high drift rates were reported. The situation was described as a thin rain or mist coming from the cooling tower. In all cases, the drift eliminators were used within their limits of operation.

For all those cases, only sporadic information was available since they were reported by various manufacturers, end-users or third party testers. All cases were linked to more “exotic” water chemistry:

- One case was a cooling tower sharing water with an ink manufacturer. The problem was solved by adapting an unknown parameter at the ink factory.
- Another case was reported in the US, the problem was solved by adapting the water treatment. The changes were unknown.
- Two cases were reported with cooling towers using Sewage water. The cooling towers being downstream of the sewage plant.



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- One case did provide more information, as surface tension was measured at
  - 54 dyne/cm by a static tensiometer
  - 70 dyne/cm by a bubble tensiometer.



Figure 2: Picture of a drift issue with DE being within their operating limits.

The next chapter explains the difference between a static tensiometer and a bubble tensiometer. But since pure water has a surface tension of  $\sim 70$  dyne/cm, and a problem of drift was present; at this stage, it was believed that the static tensiometer was the correct way to measure the surface tension (since it has a lower value) and the bubble tensiometer was wrong (since it was reporting the water as being pure).

On May 2018, a case of abnormal drift was reported on a Hamon tower named Belchim for the sake of this study. The inspection by the erection team did not reveal any installation issues (gaps, fallen panels, etc.). A test engineer was dispatched on site and did not find any deviations from design conditions (air velocity, etc.). A special team was formed to use this great opportunity to conduct a detailed analysis of the root cause.

It took some time to narrow the problem to the water treatment. Indeed, when the dosing pump was off, the problem was not present. Within minutes of the start of the pump, the area around the cooling tower was covered in rain.

We took note of the chemical product name and sent samples for water analysis (i.e. surface tension).

## Surface Tension Basics.

### Surface tension definition.

The surface tension is, by definition, the resistance a liquid exhibits to an external force due to the cohesive bonds between its molecules. It is expressed in mN/m or dyne/cm. 1mN/m is equivalent to 1 dyne/cm. For reference, pure water has a surface tension of 72mN/m at a temperature of 25°C.

The surface tension is due to the molecules at the surface of the liquid having a different potential energy than those inside (Figure 3). Indeed, molecules that are at the surface are “missing” the neigh-

boring molecules above them with whom they would normally have attractive interactions. As a result, the surface molecules have a higher energy. Liquids will therefore minimize their surface area in order to minimize the number of higher energy molecules.

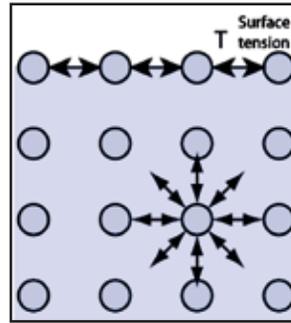


Figure 3 : Arrangement of molecules inside a liquid



Figure 4 : Visible effect of surface tension

The surface tension can be visualized by an object able to float at the interface (instead of sinking into the liquid); or when an object wants to penetrate the liquid: a certain amount of force is required to “break” the surface. Surface tension also plays a major role in the drop size generation.

When using chemical products such as surfactants, the surface tension can be reduced and can also become time dependent since an equilibrium needs to be established. Therefore, there are two different types of surface tensions:

- The STATIC surface tension is measured when the liquid is at the equilibrium.
- The DYNAMIC surface tension is measured at a different moment of the process, several values are thus reported along with a time.

## Surface Tension Measurements.

There are several methods to measure the surface tension of a liquid. The most popular are

### Capillary tube

This is the oldest method used for surface tension measurement. When immersing a thin tube (generally made of glass), the liquid rises-up proportionally to its surface tension. While being very easy to do, this method is not accurate and will not be used in this paper.

### du Noüy ring

The du Noüy ring is a technique to measure the static surface tension. This method records the maximum pull force of a probe which is slowly withdrawn from the liquid. The probe is usually a du Noüy ring or a vertical rod. The drawback of the technique is the need to account for the buoyancy of the probes. For thin rod probes the buoyancy term is relatively small and easy to correct for, while for rings, the buoyancy term is significant and its calculation is complicated due to the cross-sectional shape of the ring.

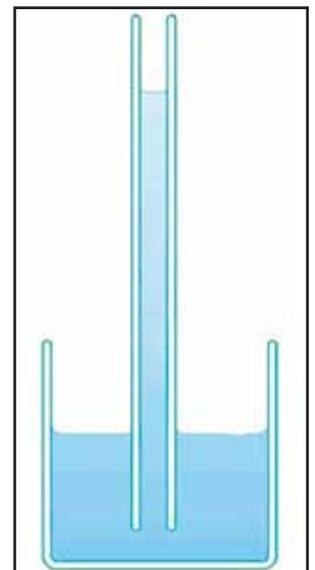


Figure 5: Schematic representation of a capillary tube

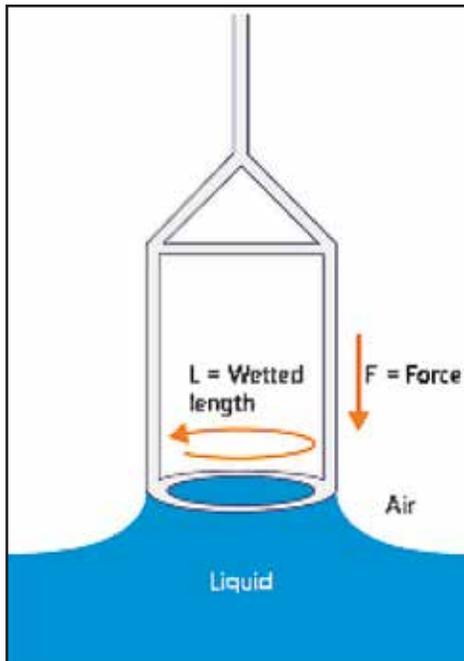


Figure 6: Schematic representation of a du Noüy ring

### Wilhelmy plate

The Wilhelmy plate measures the static surface tension. A platinum plate with known geometry and a rough surface is brought into contact with the liquid. The liquid wets the plate along a contact line and pulls on it with a certain force. This force is measured and is directly proportional to the surface tension of the liquid.

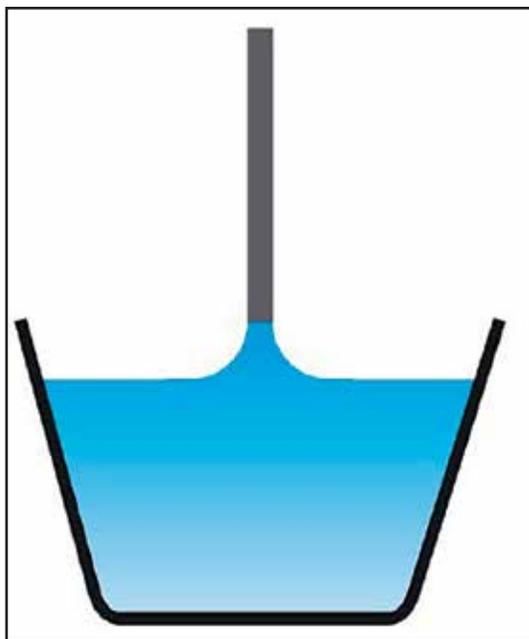


Figure 7: Schematic representation of a Wilhelmy plate

### du Noüy ring Vs Wilhelmy plate

The two tensiometer methods differ in that the duNoüy Ring is pulled through the surface during the measurement, while the Wilhelmy Plate is stationary during the measurement.

Using the Ring technique causes a non-equilibrium state in the liquid as the ring is pulled through the surface.

The Wilhelmy Plate, by contrast, is placed at the liquid's surface and a meniscus is formed on its perimeter, causing a downward pull. The Plate is not in motion, thus the entire surface is in equilibrium. The force is constant or varies only with a change in surface tension.

### Bubble tensiometer

The maximum bubble pressure method is used for measuring the dynamic surface tension. A continuous gas flow is pressed through a capillary. With this, a continuous flow of bubbles is created. It is possible to correlate the bubble radius with the pressure at the bubble interface and the surface tension. If the gas bubble is created in an immersed capillary tip, the radius of the bubble (and hence the curvature of the bubble surface) and the pressure inside the bubble vary with time. The maximum is reached when the bubble radius is equal to the capillary radius, resulting in a hemisphere the size of the capillary.

From Figure 8 we can see the immersed tip in blue and the different phases of bubble generation:

- At r1, the pressure is applied, the surface age time is set to zero and bubble-time counting starts.
- At r2 the pressure continues to increase and the bubble grows.
- At r3, the maximum pressure is reached as the bubble has the size of the capillary. The surface age time is stopped and recorded. The measurement is considered as finished.
- At r4 and r5 the bubble continues to grow and will be ultimately released. We are then back to the state r1.

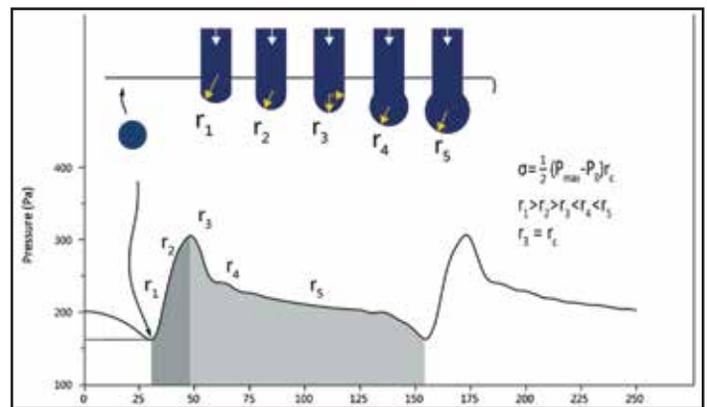


Figure 8 : Schematic representation of the bubble tensiometer principle.

### CTI ATC-140 and Surface Tension.

The current CTI ATC-140 (July 2011) recommends that the surface tension does not fall below 63 dyne/cm.

The measurement method can be any of the following options:

- ASTM D1331 : Standard Test Methods for Surface and Interfacial Tension of Solutions of Surface-Active Agents
- ASTM D3825 Standard Test Method for Dynamic Surface Tension by the Fast-Bubble Technique.
- Bubble Tensiometer

ASTM D1331 covers the measurement by du Noüy ring (Method A) or by Wilhelmy plate (Method B).

ASTM D3825 covered the bubble tensiometer but was withdrawn in 2016 due to lack of interest.

## The Belchim Case.

### Du Noüy ring Vs Wilhelmy plate.

Referring to CTI and ASTM D1331, we wanted first to determine if the method A (du Noüy ring) or method B (Wilhelmy plate) were equivalent.

Using the two methods, we analyzed samples of pure water and samples of water from Belchim.

Surface tension measurements		
	Du Noüy ring (mN/m)	Wilhelmy plate (mN/m)
Pure water	72.0	72.5
Belchim	43.7	44.3

Table 1

We could conclude that both measurements were giving similar results, even in presence of surfactant.

We could also conclude that the surface tension of the water was problematic and well below the CTI recommendation of 63 dyne/cm.

### Bubble tensiometer.

However, the measurement with the bubble tensiometer revealed that the surface tension changed considerably depending on the surface age (bubble time).

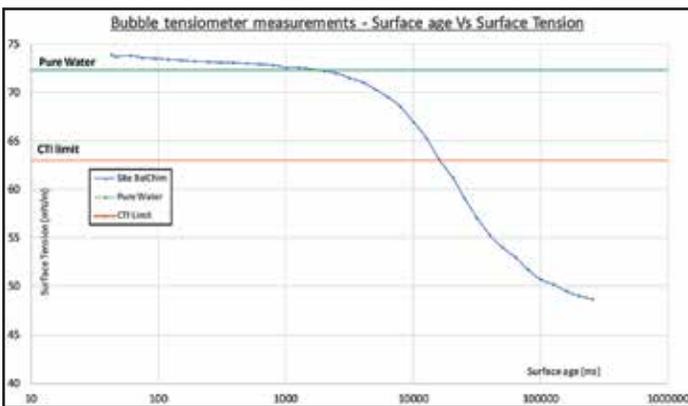


Figure 9 : Graphical representation of bubble tensiometer measurement for the water of Belchim.

## Conclusion

The measurements on the Belchim water show that the static surface tension is lower than the CTI recommendation (eg : 63 dyne/cm). This is similar to what was reported on other cases (see Chapter “Description of the situation).

However, on the previously reported cases, the dynamic surface tension was reported as normal (close to the 72 mN/m of pure water). This difference can be explained by the fact that some bubble tensiometers have a manual bubble time setting. Therefore, only one value can be reported. It is supposed that the fast surface age (below 1000ms) was reported, and not the slow surface age (above 10 000ms), which would have shown a value below the CTI limits.

For the observation above, and as the issue of the surface tension was surely visible on the static method, it was decided to continue the investigation by taking the Wilhelmy plate as a reference measurement.

## Measurement In The Lab.

### Dilution curve.

The product used at Belchim (named hereafter Product A) was supplied to us, and we made a dilution curve plotting the static surface tension versus the product concentration.

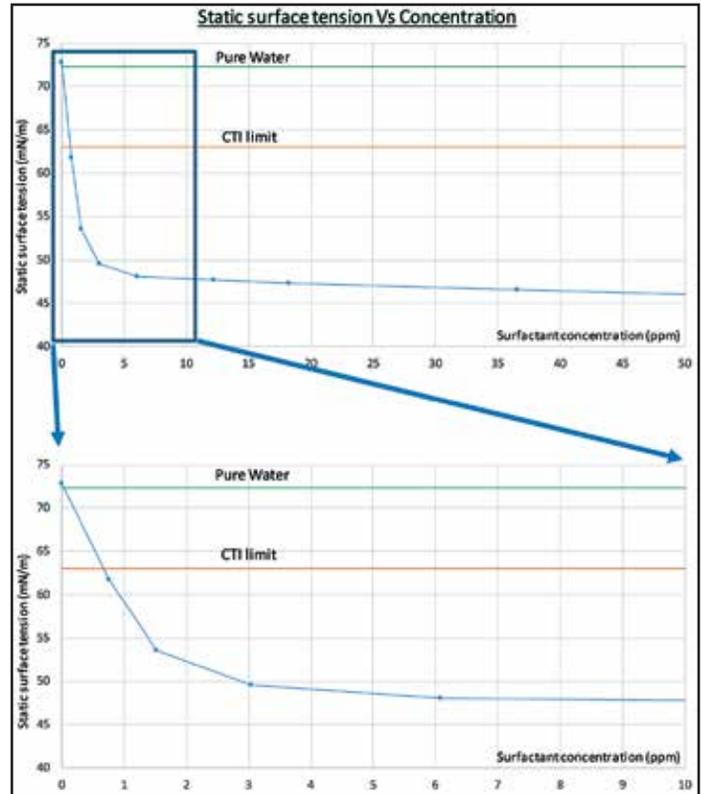


Figure 10

The surface tension very rapidly drops below the limit allowed by the CTI. This is not surprising since it is a surfactant, and its goal is to reduce the surface tension.

### Impact on drift rate.

Hamon used its own R&D laboratory, a cooling tower of 2.5m x 2.5m, to study the impact of this product on the drift rate.

We first did a visual observation of the impact of surfactant at various concentration. To do so, a strong floodlight was placed on top of the drift eliminators. The cell was provided with water and air flow.



Static surface tension : 72.5 mN/m – Surfactant concentration : 0 ppm

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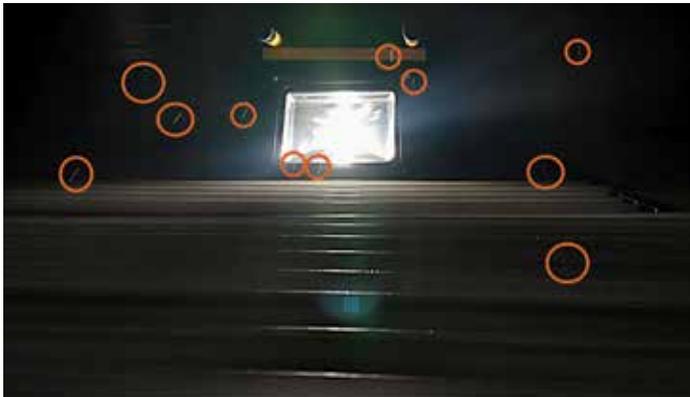
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Static surface tension : 61.2 mN/m – Surfactant concentration : 1 ppm



Static surface tension : 47.5 mN/m – Surfactant concentration : 5 ppm



Static surface tension : 46.6 mN/m – Surfactant concentration : 10 ppm  
In order not to clutter up the image, droplets have not been underlined but the reader will notice the increased number compared to 5ppm



In order not to clutter up the image, droplets have not been underlined but the reader will notice the increased number compared to 10ppm

From the visual observation we can notice a clear increase of drift with the concentration of the product. However, the observation doesn't correlate with the static surface tension.

Hamon also used the CTI ATC-140 method to measure the drift rate at different surfactant concentrations; each corresponding to different static surface tensions.

Drift ratio based on ATC-150 measurements done in R&D lab when using surfactant.		
Static surface tension (mN/m)	Surfactant concentration (ppm)	Drift increase ratio (%)
72.5	0	0 Reference
61.2	1	40
47.5	5	40
46.6	10	90
46.3	20	170

Table 2

As for the observations, there is a poor correlation between the drift level increase and the static surface tension (Figure 11). The relation seems to follow a negative logarithm. This makes the forecasting of drift level very difficult. Indeed, a very small variation of static surface tension has a very large impact on the drift rate.

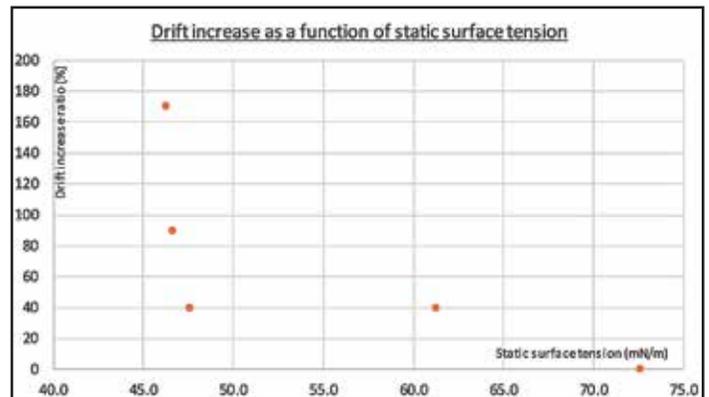


Figure 11

However, the results there seems to be a good correlation between drift level increase and surfactant concentration (Figure 12).

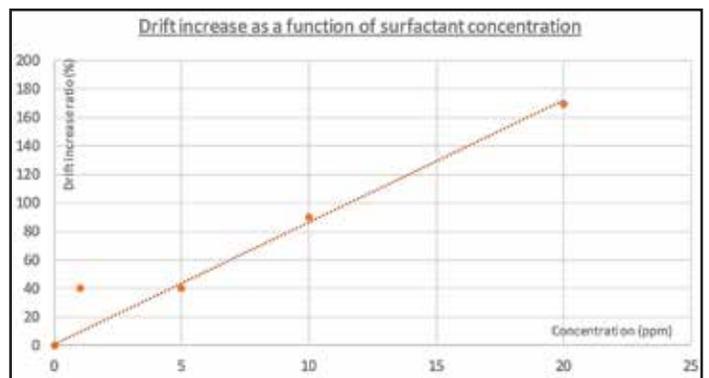


Figure 12

## Conclusion:

From this series of measurements, we can deduce the following statements which can be applied at least to this surfactant (product "A")

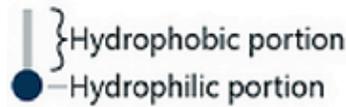
- The product has a significant impact on drift level : the more we add product, the more drift is generated.

- There is no correlation between drift rate and static surface tension: The static surface tension allows to detect the presence of surfactant but can't report accurately how seriously it will impact the drift level.
- There is a very good correlation between drift rate and surfactant concentration: Therefore, if we want to characterize the excess of drift generated due to surfactant; we need to find a way to determine the surfactant concentration in relation with the surface tension.

## Critical Micelle Concentration.

In order to have a better understanding of the results above, it is important to understand how surfactants work.

The surfactant molecule is composed of a hydrophilic and a hydrophobic portion. The hydrophilic portion will be attracted by the liquid whereas the hydrophobic will be repulsed by the liquid. The molecules of surfactant floating inside the liquid are called "free surfactant". Naturally, they will migrate to the liquid interface where they can be in equilibrium.



Once the surface is saturated with surfactant, the remaining free surfactant molecules will tend to aggregate with their hydrophobic portion in close vicinity (see Figure 13). Those aggregates are called micelles.

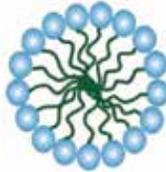


Figure 13

The point at which the surface is saturated is called the "Critical Micelle Concentration" or CMC; it is the point where the STATIC surface tension is the lowest.

Figure 14 from Krüss describes the situation :

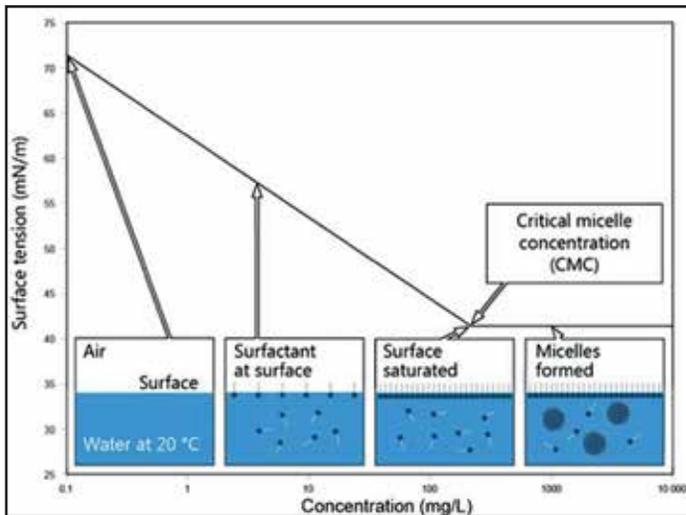


Figure 14

From this explanation, we can understand why the static surface tension does not correctly evaluate the concentration of surfactant. It is because once the surface gets saturated with surfactant; some molecules remain inside the liquid as micelles or free surfactant.

The critical micelle concentration is a public information for every surfactant. It gives us a representation of how fast the surfactant will saturate the surface and will then accumulate inside the bulk of the liquid.

Figure 15 from Sita illustrates how the free surfactants and the micelles migrate to the new interface created when using a bubble tensiometer.

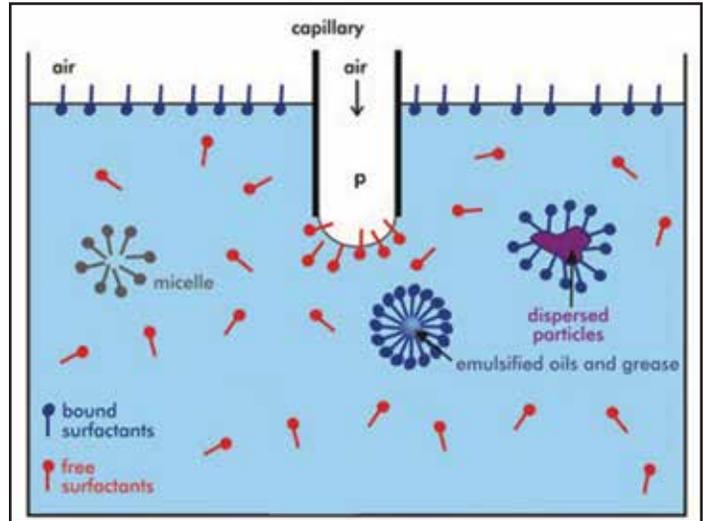


Figure 15: Surfactant states when testing with a bubble tensiometer.

## Surfactant & Bubble Tensiometer.

To challenge the static surface tension, we did similar measurements using a bubble tensiometer, and the same surfactant at various concentrations (1ppm, 2ppm, 5ppm, 10ppm, 20ppm).

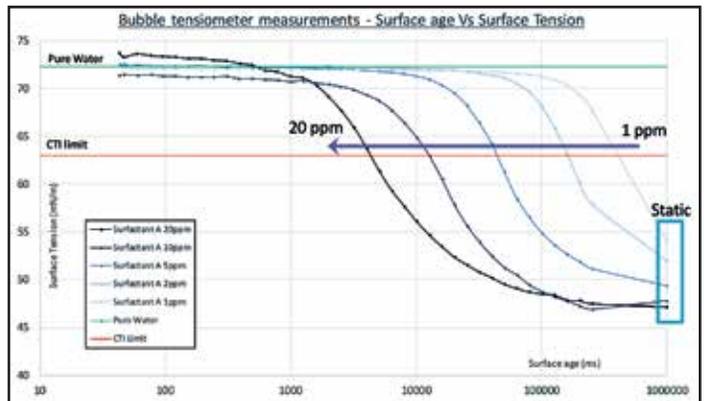


Figure 16

The instrument cannot measure above 250 000ms surface age. This surface age is sometimes called "Quasi static" as the bubble speed is so slow that it is nearly equal to the static measurement. But, we can extrapolate the dynamic surface tension beyond the "quasi static" by adding the real static measurement that we recorded with the Wilhelmy plate. This is represented in the Figure 16 in the blue rectangle (Static).

We could see that the profile was the same as the one found on the site of Belchim (a S curve).

We could also see that, for a defined surface tension, the surface age decreases with the concentration (purple arrow). This is precisely what we were looking for: a means to measure the concentration.

It is very important to notice that the concentration of surfactant can be correlated with the variation of surface age at the same surface tension (horizontal purple line in the chart above). But mainly that it doesn't correlate well with variation of surface tension at a

fixed surface age (vertical black line on the chart below). Indeed, at fixed surface age, we can have similar surface tensions for different concentrations: In the Figure 17, with a surface age of 100s, we have the same surface tension of  $\sim 48$  mN/m for both 10ppm and 20ppm concentration.

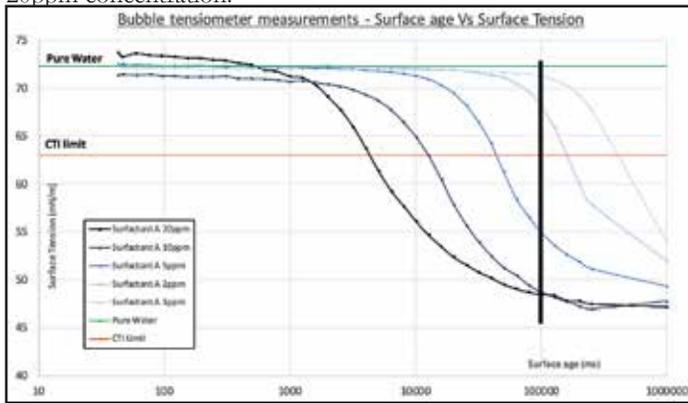


Figure 17

Thus, the current hypothesis is the following: the drift rate correlates with the surfactant concentration, the surfactant concentration correlates with the surface age. This means that the key factor for drift rate is not the surface tension but the surface age at a defined surface tension.

### Other Surfactant Dynamic Behavior.

To confirm the importance of the dynamic behaviour of surfactant, we measured the dynamic surface tension of 4 different products with the same concentration.

- Surfactant A was the one used at Belchim and the same as the above study.
- Surfactant B is known to be a slow response surfactant.
- Surfactant C is known to be a fast response surfactant.
- Surfactant D is yet another surfactant.

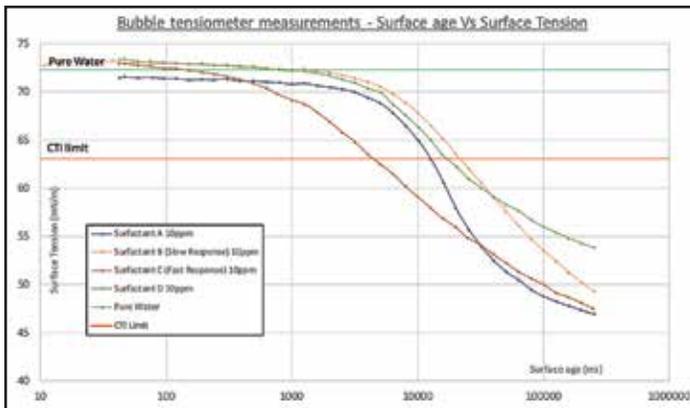


Figure 18

We can notice that A, B, D have similar curves whereas the fast response surfactant has a much faster decrease of surface tension, this would mean that it is more prone to generate drift.

Slow surfactants are typically made of large molecules like amphoterics or fluorosurfactants.

At time of writing, the drift rate measured with ATC-140 were not available for these products; but a visual comparison of the drift was made. Each of the pictures below represent the drift level at the same waterflow, same velocity and same product concentration ( $\sim 10$ ppm).



Surfactant A - concentration : 10 ppm



Surfactant B (slow) - concentration : 10 ppm



Surfactant C (fast) - concentration : 10 ppm



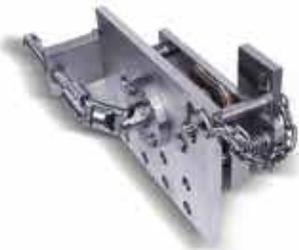
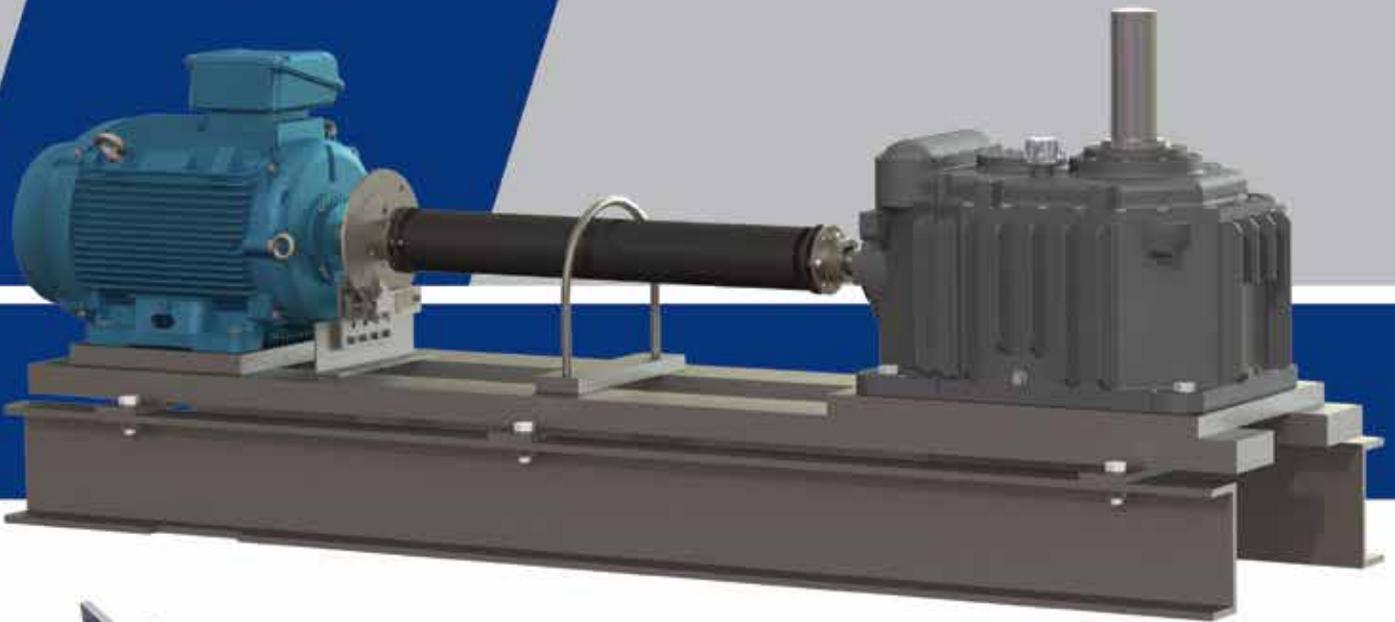
Surfactant D - concentration : 10 ppm

From the picture, we can see that surfactant “C” produces far more drift. Surfactant “C” is the one with the fastest behaviour. So not only the concentration of surfactant is important but also the type of surfactant. This behaviour is revealed during a measurement with the bubble tensiometer.

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## Physical Explanation.

The role of surfactant is to reduce the cohesive forces between the water molecules. The more there is surfactant, the more the spray film is likely to break into droplets. Those droplets will also be smaller as the cohesive forces are reduced and more air / water interface is created. Because the process is dynamic, the more surfactant that there is in the bulk of the liquid (in form of micelles or as free surfactant), the more it is likely to create a new air / water interface and thus create smaller droplets.

Figure 19 shows a high-pressure sprayer under two conditions, one without surfactant (a), one with surfactant (b). On the (b) sample, we can see that the film of water collapses earlier; forming smaller droplets. Those smaller droplets being lighter in weight will pass more easily through the drift eliminator. The result is an increase of drift due to smaller droplets.

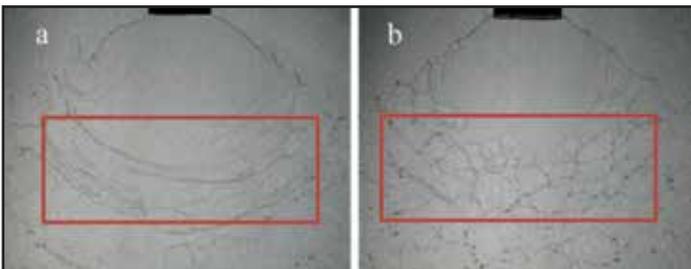


Figure 19

## Why Is Reclaimed Water More Prone To Abnormal Drift?

For most of the reported case, the issue was present when using reclaimed water. One hypothesis for this situation could be the following:

The reclaimed water often comes from sewage. Therefore, a strong biocide treatment is preferred in order to eliminate all bacteriological activity. To increase the efficiency of the biocide treatment, bio-dispersants are sometimes used. Bio-dispersants work by loosening the matrix of the biofilm. The biofilm will thus break into smaller particles and stay in suspension in the liquid rather than sticking to one place. Once in suspension, the biocide will penetrate the biofilm more easily and will thus be more efficient.

The biodispersant is also formed of hydrophilic and hydrophobic groups. They also influence the water surface tension. As such, they can create more drift if they are used in excess.

Since the bacteria content of sewage water is generally unknown but all bacteria must be killed to control the biological activity of the water, the water treatment will potentially use an over-dosage of biocide to guarantee water quality. The same over-dosage may happen with the biodispersant. Excess biodispersant has the potential to severely increase cooling tower drift rate.

## Time Between Sampling And Measurements.

We performed a time dependant analysis of the static surface tension. During 1 month, we measured the surface tension of a known concentration using the plate method. The results were not affected by the storage conditions (plastic bottles at room temperature). However, after 3 months, the results were modified. This can be explained by a slow degradation of the surfactant which was not noticeable since it was compensated by the quantity present in the bulk under the form of micelles.

When using the dynamic surface tension measurement, the samples were analysed ~5 days after sampling. The samples were stored in plastic bottles at room temperature. One sample was reanalysed after 3 months of storage and the value had changed to the one of pure water.

It was concluded that it is important to analyse the sample in a rather short period of time (~1 week).

## Bubble Tensiometer Standard.

Across this paper, we underlined the importance of a measurement made with a bubble tensiometer. Unfortunately, there is no code or standard which specifies how to measure the surface age using a bubble tensiometer. Therefore, there is no guarantee of compatibility between all the manufacturers.

Several manufacturer of bubble tensiometer exist:

Several manufacturer of bubble tensiometer exist:	
Sita	<a href="https://www.sita-process.com/">https://www.sita-process.com/</a>
Kruss	<a href="https://www.kruss-scientific.com/">https://www.kruss-scientific.com/</a>
Sinterface	<a href="http://www.sinterface.com/">http://www.sinterface.com/</a>
Kyowa	<a href="https://www.face-kyowa.co.jp/">https://www.face-kyowa.co.jp/</a>
SensaDyne	<a href="http://www.sensadyne.com/">http://www.sensadyne.com/</a>
Lauda	<a href="https://www.lauda-scientific.de/">https://www.lauda-scientific.de/</a>
Biolin Scientific	<a href="https://www.biolinscientific.com/">https://www.biolinscientific.com/</a>

Table 3

## Conclusion.

Most of the cases with abnormal drift levels are due to incorrect installation or use of the drift eliminators panels. Only a small portion of the problems are due to surface tension.

Surfactants can have a significant impact on the drift rate depending on their concentration and their ability to migrate to new interface air/liquid (fast or slow response surfactant).

The static measurement of surface tension, Du Noüy ring and Wilhelmy plate, allows to detect the presence of surfactant but doesn't accurately represent the impact on the drift level.

The bubble tensiometer is recommended to measure the impact on the drift level since it can also measure the fraction of surfactant which is present as micelles or free surfactant inside the liquid. The reported measurement shall thus not only be a surface tension but also a surface age.

Since there is no code for bubble tensiometer, it is recommended to form a R&D committee to verify the compatibility of the instruments on the market.

## Bibliography :

Krüss : <https://www.kruss-scientific.com/>

Kibron : <https://www.kibron.com/surface-tension>

Sita : <https://www.sita-process.com/>

Chemistry 301 : University of Texas :

<https://ch301.cm.utexas.edu/section2.php?target=imfs/liquids/surface-tension.html>



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# Thermal Performance Comparison Between Fan Staging And Variable Speed On Multi Fan Cooling Towers

Billy Childers, Aggreko Cooling Tower Services

## Abstract

The thermal performance of a cooling tower can be regulated by varying fan power. Typically it is possible to lower fan power significantly, while only having a minimal impact on the thermal capacity of a cooling tower. Cooling towers are designed to achieve the specified cooling capacity at the highest ambient wet bulb temperatures for the area in which it will be operated. If a cooling tower is built to achieve the design operating conditions that only occur 1% to 2% of the year, there is considerable opportunity to reduce fan energy costs the remaining 98% to 99% of the year. It is for this reason, means of controlling fan power can offer large energy savings for cooling tower owners/operators. This paper will compare thermal performance test results of two multi fan rental cooling towers of similar rated capacity, with one tower equipped with means of cycling AC direct drive fan motors off and on, and another tower equipped with variable speed EC fan motors.

## Cooling Tower Performance

Thermal performance of a cooling tower is dependent on maximizing contact between the circulating hot water that enters near the top of the cooling tower and the entering air flow that enters the side or bottom of the cooling tower. In the process of bringing the hot water in contact with the entering air, a portion of the heat is transferred from the water into the air stream and then exhausted into the atmosphere. This results in an overall reduction in the exiting water temperature.

Increasing air flow through a cooling tower results more cooling and less air flow through the tower will result in less cooling. This concept is the primary means by which operators regulate the outlet water temperatures of their cooling towers. There are various means of regulating air flow through a cooling tower. Options include;

- Cycling fan motors off and on
- 2 speed fan motors, which allow fans to be operated in high speed, low speed, or turned off.
- Variable speed drives to control fan motor speed.

All options effectively regulate cooling water temperature, but depending on the specific needs of the cooling tower operator, one may have advantages over the other.

## Cooling Tower Design and Selection

Cooling towers are designed/sized and selected to meet a predetermined set of criteria. The design criteria will include the circulating flow rate of the water that needs to be cooled, the temperature of the incoming hot water, the desired cold water temperature exiting the cooling tower, and the entering wet bulb temperature. The differential between the hot water temperature and the cold water temperature is called the “range” or “delta-t” and the differential between the cold water temperature and the wet bulb temperature



Billy Childers

is called the “approach”. The water flow rate and the heat source determine the “range” and the performance of the cooling tower will determine the “approach”.

## Cooling Tower Capacity Explained

For the purpose of this paper, cooling tower capability will be stated in the percentage of actual water flow at a given set of temperatures (hot water, cold water, wet bulb) vs the predicted or rated water flow the tower should be capable of cooling at the same set of given temperatures.

Example: If a cooling tower is designed or rated to cool 1000 Gallons Per Minute (227.12 m<sup>3</sup>/h) from 95°F (35°C) to 85°F (29.44°C) at an entering wet bulb of 78°F (25.56°C) and when the tower is tested, it is only capable of cooling 900 GPM (204.4 m<sup>3</sup>/h) at the same temperatures the tower is considered to have a capacity of 90% or it is under performing its rated capacity by 10%. (900 GPM / 1000 GPM = 90% capability)

## Case Study #1

Case Study #1: compares the cooling capability of a multi fan cooling tower that cycles fans off and on to maintain cooling water temperatures to the same model cooling tower that operates all fans but at varying fan motor horsepower.

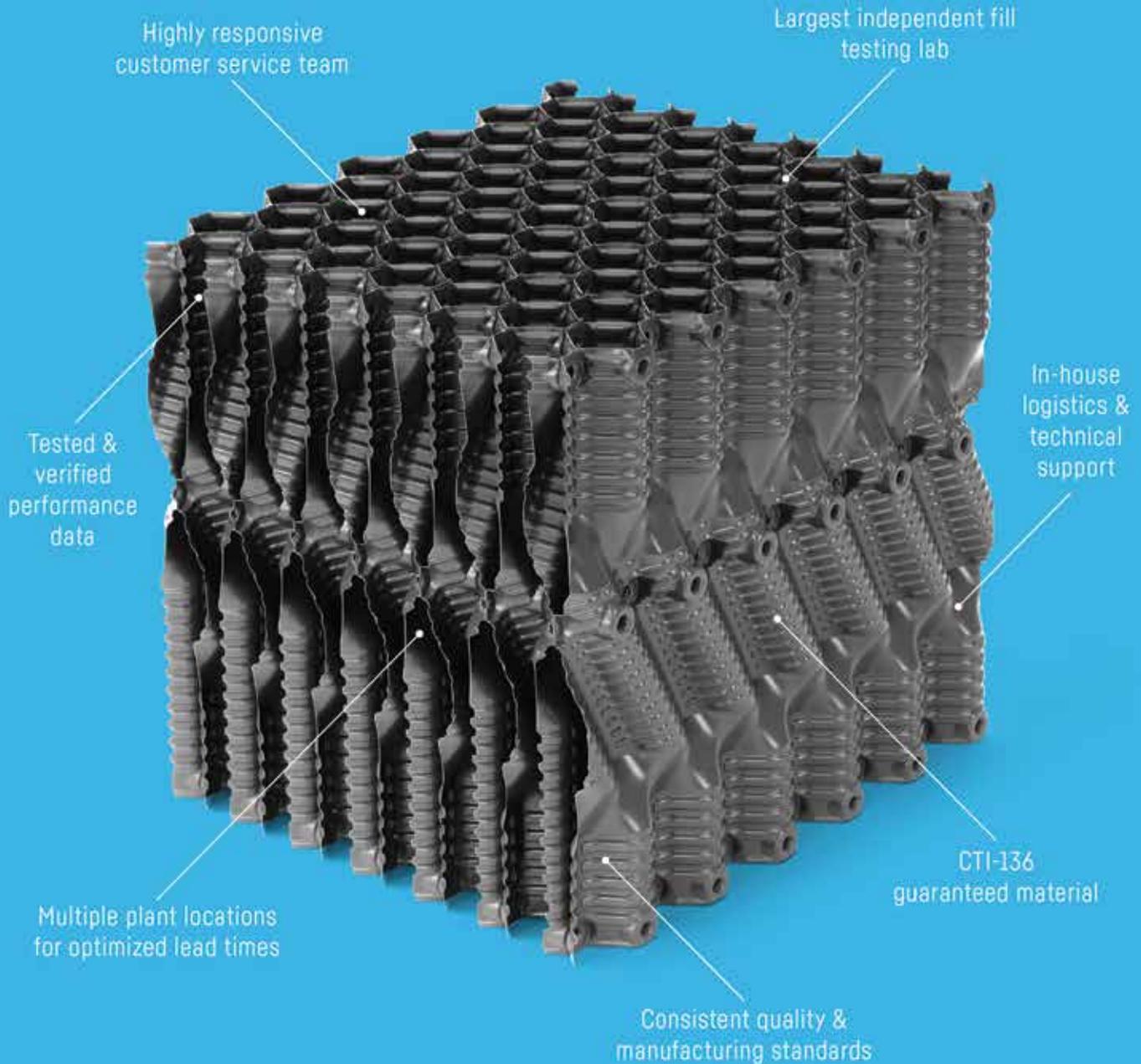
The cooling tower used for this test was an Aggreko rental cooling tower model AG-10. This tower is CTI Certified under STD-201 with the reference #08-34-01. The tower is a forced draft counter-flow cooling tower that is 12 ft (3.66m) wide, 30 ft (9.14m) long, has a fill depth of 5 ft (1.52m). The tower has 10 direct drive fans that are 57” (1.45m) in diameter and each fan is driven by a 7.5 horsepower (5.6kW) 900 RPM motor for a total fan horsepower of 75 (55.95kW) (10 x 7.5HP = 75HP).

1. Step 1 – using software establish predicted cooling capacity of the cooling tower at multiple fan horsepower points.
2. Step 2 – Test the tower at various motor horsepower points to verify the actual performance matches the predicted capacity of the software model.
3. Step 3 – test the same model tower cycling fan motors off one at a time. All 10 fans running at 7.5 HP (5.6kW) each, 9 running, 8 running, 7 running, 6, running, 5 running, 4 running, 3 running, 2 running, 1 running, no fans running.
4. Step 4 – compare the results

## Step 1

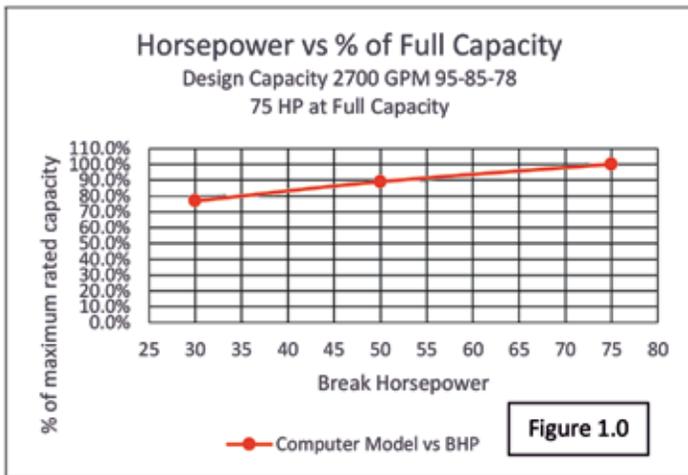
A software model for the AG-10 cooling tower was used to predict cooling tower capacity at 3 separate fan horsepower levels. The baseline design condition chosen for the modeling were a flow rate of 2700 GPM (613.24 m<sup>3</sup>/h), a hot water temperature of 95°F (35°C), a cold water temperature of 85°F (29.44°C), and an entering wet bulb of 78°F (25.56°C). See figure 1.0 below.

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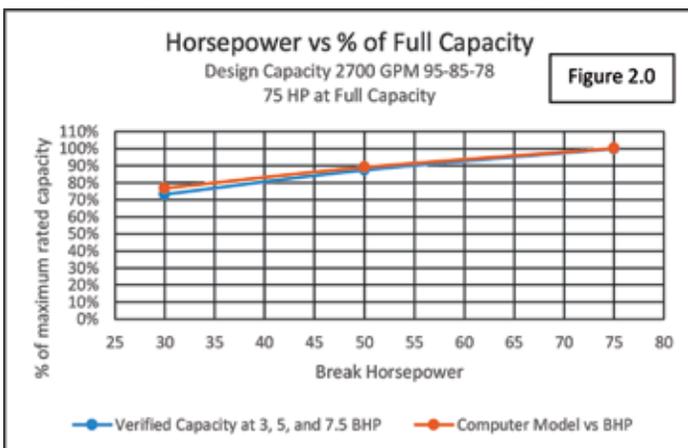
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### Step 2

Use known verified test data from the same model cooling tower at various fan motor horsepower to establish known cooling capacity for the cooling tower to match the thermal conditions used in the software predicted results in step 1.

The results identified a slight variance between the computer model and verified test results. However, the variance was very slight with only a total of 3.6% variance between tested and predicted performance when the fan motor HP was reduced to 40% of the maximum HP. Therefore, for the purpose of our evaluation, we concluded the computer model was a reliable means of predicting the cooling tower performance. See results below. See figure 2.0 below



### Step 3

A single AG-10 cooling tower was tested on 5/14/19 to verify thermal performance of the cooling tower with all 10 fans operating down to no fans operating. The tower was being used in a once through cooling application which provided for a steady hot water temperature and steady water flow rate. This unique opportunity reduced the variables often associated with thermal performance testing of cooling towers. See Figure 3.0 below.

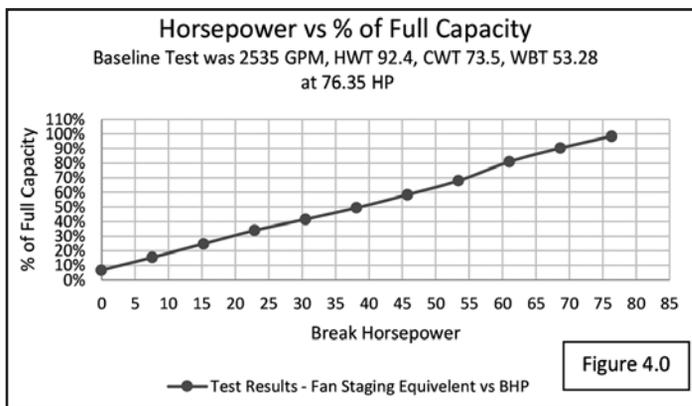


The baseline test conditions were as follows:

Water flow was measured with a Pitot tube and calculated, Hot Water Temperature (HWT) was measured by (2) 4-wire RTD's and averaged, Cold Water Temperature (CWT) was measured by (2) 4-wire RTD's and averaged, Wet Bulb Temperature (WBT) was measured by (4) 4-wire RTD's and averaged. The fan Horse Power (HP) was calculated by using kW measured by Fluke 345 PQ meter and nameplate data from the fan motor.

Baseline Test	
Water Flow (GPM)	2,535 GPM (575.76 m3/h)
Hot Water Temperature	92.4°F (33.56°C)
Cold Water Temperature	73.5°F (23.06°C)
Wet Bulb Temperature	53.28°F (11.82°C)
Fan Motor Horsepower	76.35 (56.96kW)

After completing the baseline testing of the cooling tower with all (10) fans operating, testing continued shutting off (1) fan at a time. Testing with 9,8,7,6,5,4,3,2,1, and finally tested the tower with no fans operating. The results of the testing are shown in the chart below (Figure 4.0).



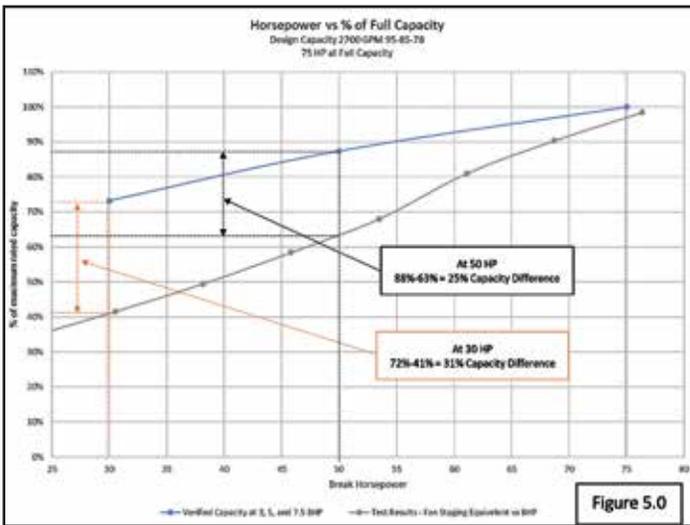
### Step 4

#### Compare the Results

To compare the results in performance the curves from both methods of fan motor power were plotted together for direct comparison. Each towers capacity was compared at 75, 50, and 30 horsepower (55.95, 37.3, 22.38 kW). At 75 HP (55.95kW), each tower is operating at full capacity and therefore there is no difference in the performance, at 50 HP (37.3kW), the tower that had all fans operating at a lower HP delivered 88% of the cooling tower's rated capacity, while the equivalent HP on the fan staging only achieved 63% of the cooling tower's rated capacity. At 30 HP (22.38kW) the test that had all fans running at reduced capacity provided 72% of the tower's rated capacity while the fan staging method only achieved 41% of its rated capacity. See chart below (Figure 5.0.)

#### Conclusion of Case Study #1 Testing

When fan controls are used to manage cooling water temperature, the comparison clearly shows that the power consumption vs cooling tower capacity is much better when all the fans are operated together versus some fans operating at full capacity with others shut off. When all fans are operating, a 1% reduction of fan power resulted in a .45% reduction in cooling capacity. However, the fan staging method resulted in an average of .95% reduction in cooling capacity for every 1% reduction in fan power.



## Case Study #2

Case study #2 compares the energy cost associated with operating two cooling towers of equivalent capacity with one cooling tower utilizing the method of turning fans off and on to control water temperature and the other cooling tower utilizing a variable speed fan motor method to control water temperature. Both towers are modular style, multi-fan cooling towers offered in the rental market and have been thoroughly tested for capacity at multiple operating conditions. The cooling tower that utilizes the method of turning fans off and on to regulate cooling water temperature uses 5 stages of fan control with each stage turning off and on 2 of the 10 fans at a time. The other tower uses variable speed control method to speed up or slow down all of the 18 fans together acting as 1 single fan. The design operating conditions chosen for comparison is a water flow of 2700 GPM (613.24 m<sup>3</sup>/h), an entering hot water temperature of 95°F (35°C), a leaving cold water temperature of 85°F (29.44°C), and an entering wet bulb temperature of 78°F (25.56°C).

The (2) cooling towers compared in this case study are described in the table below:

Description	Cooling Tower "A"	Cooling Tower "B"
Model	AG-10	GT-40
Tower Type	Counter-flow	Counter-flow
Air Delivery	Forced Draft	Induced Draft
Capacity at Design 95/85/78 (35/29.44/25.56)	2700 GPM (613.24 m <sup>3</sup> /h)	2700 GPM (613.24 m <sup>3</sup> /h)
Fan Power Control Method	5 stage temp controller	Variable Speed
Number of fan motors	10	18
Motor Type	AC	EC
Fan Horsepower each fan motor	7.5HP (5.595kW)	6.5HP (4.849)
Fan Horsepower Total for tower	75 (55.95kW)	117 (87.282kW)
Motor Efficiency	81.5%	90%
Total Input kW Required	68.66	93.69
Operating Volts/HZ	460/60	460/60
Power Factor	68.4	99.8
Full Load Amps at 480 volts	125 Amps	125 Amps
Tower Length	35 feet (10.67m)	40 feet (12.19m)
Tower Width	12 feet (3.66m)	8 feet (2.438m)
Fill Area	(12ft x 30ft) 360 sq ft	(8ft x 36ft) 288 sq. ft.
Fill depth	5 feet (1.524m)	4 feet (1.219m)
Fill Media Total	1800 ft <sup>3</sup> (50.97 m <sup>3</sup> )	1152 ft <sup>3</sup> (32.62 m <sup>3</sup> )

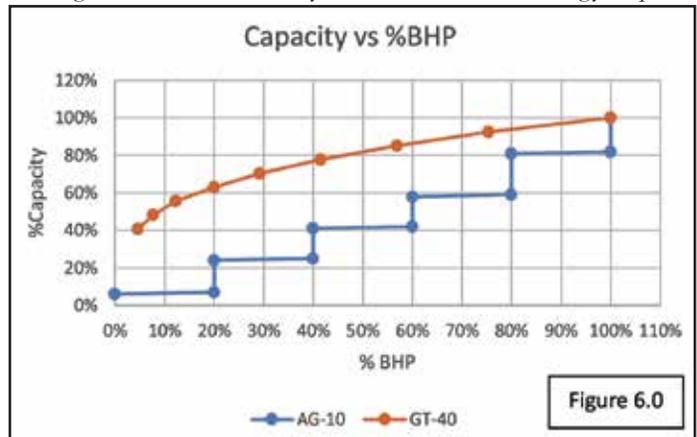
Notable differences between the 2 towers described above.

- Tower "A" is physically larger and has more fill media than tower "B" and therefore tower "B" requires more fan power to achieve the same thermal capacity as tower "A".
- Tower "B" utilizes high efficiency EC fan motors to offset some of the additional power requirements. The output power for Tower "B" is 1.56 times greater, but input power is only 1.36 times greater.
- The full load amps for both towers are the same. This is due to the fan motors in tower "A" have a power factor 68.4 versus a power factor of 99.8 for tower "B".

Using the methodology from Case Study #1 a chart was developed to show the percentage of rated cooling capacity of each tower versus the percentage of fan motor power. Cooling tower "A" utilizes a 5 stage temperature controller and cooling tower "B" uses variable speed EC motors. See figure 6.0 below

## Comparison

For purpose of comparing the fan energy cost between the two cooling towers, it is necessary to evaluate the fan energy required



to satisfy the cooling requirements for each tower at each wet bulb temperature that the towers will operate in, throughout the course of a year. The entering wet bulb temperature is a limiting factor for any cooling tower and varies by location. For this comparison historical wet bulb data for Des Moines Iowa was used. Below is a chart that represents the historical average distribution of wet bulb hours by month and total hours for Des Moines. See figure 7.0.

The wet bulb data from the chosen location was used to determine the expected number of hours that each wet bulb temperature occurs. Cooling tower sizing software was then used to determine the fan HP required to achieve the design cooling requirements for cooling 2700 GPM (613.24 m<sup>3</sup>/h) from 95°F (35°C) to 85°F (29.44°C) at each wet bulb temperature. The results are displayed in Figure 8.0

*Note: There are an additional 87 hours annually when the wet bulb is below 20°F (6.67°C) which are not displayed or evaluated, because the cooling requirements can be met without the need to operate fans in both tower "A" and tower "B".*

Steps used to evaluate energy consumption of each cooling tower.

1. Determine Fan HP required to cool 2700 GPM (613.24 m<sup>3</sup>/h) from 95°F (35°C) to 85°F (29.44°C) at each wet bulb temperature.
2. Determine input power required for each condition adjusting for fan motor efficiency.
3. Multiply input power required for each wet bulb temperature x the number of hours each wet bulb occurs x the cost for electricity. (\$10 per kW/hr was used for the comparison)

## Results

In this comparison the tower equipped with variable speed fans had a lower operating cost than the tower that utilized the fan staging method. Although Tower "B" requires 1.56 times more fan power than tower "A" at the design operating wet bulb of 78°F (25.56°C), when the wet bulb temperature drops below 76°F (24.44°C) the tower "B" requires less fan power.

- Tower "A" had an annual fan motor operating cost of \$25,421.19

Historical Number of hours for each Wet Bulb Temperature by month for Des Moines, IA													Total								
Wet Bulb	January	February	March	April	May	June	July	August	September	October	November	December	Total								
78													0								
77						3							3								
76						11							11								
75						29							29								
74						18		33					51								
73						75		55					130								
72						45							45								
71						86		94		28			240								
70						11		144		135		1	291								
69						11		144		135		1	291								
68										37			37								
67						29		111		166		160	466								
66												3	3								
65						1		131		64		12	209								
64						7		57		126		138	328								
63												93	26	4	123						
62												137			137						
61						14		87						8	109						
60												119		48	167						
59						1		110		59		87			257						
58						27		102						13	142						
57										132		72		17	221						
56						43		137							180						
55						4				15		31		94	178						
54								57						34	57						
53						1		6		60				110	177						
52										129				52	18	199					
51						12				2		10		111	135						
50						80		22							102						
49												78			78						
48						21		94							36	151					
46						3		98						1	110	284					
45						1				5				41	72	47					
44						5		10		31		53				99					
43														103		50	153				
42								110							86		196				
41						9		21		48							78				
40														13			13				
39								26						77			73	176			
38						40		96							110			246			
37						28		81										109			
36														2				2			
34						63		80		113		92		8		50	119	125	650		
31												3							3		
30						98		135		170		41			24	111	152		731		
26						103		104		102					8				317		
25										19					67				112	198	
21						97		90		66		4			2	24			72	355	
17										1										1	
16						74		60		42						9			37	222	
11						76		45		26					1				24	172	
7										13									14	27	
6						65		34							2					101	
2						54		24		5					1				10	94	
-3						36		15		1					2					54	
-8						23		6												29	
-10																				1	1
-12						8														1	9
-13						3															8
-14								1													1
-18						1		1													2

Figure 7.0

Energy Cost Evaluation										
Wet Bulb		Fan Horse Power			Kilowatt (kW)			Electricity Cost @ \$.10 per kW		
Wet Bulb	Hours	AG-10	GT-40	Variance	AG-10	GT-40	Variance	AG-10	GT-40	Variance
78	-	75	117	(42)	68	99.54	(31)	\$ -	\$ -	\$ -
77	3	75	90	(15)	68	76.57	(8)	\$ 20.48	\$ 22.97	\$ (2.49)
76	11	75	73.8	1	68	62.79	5	\$ 75.08	\$ 69.07	\$ 6.01
75	29	75	61.2	14	68	52.07	16	\$ 197.94	\$ 151.00	\$ 46.94
74	51	60	52.2	8	55	44.41	10	\$ 278.48	\$ 226.50	\$ 51.99
73	130	60	43.2	17	55	36.75	18	\$ 709.86	\$ 477.80	\$ 232.06
72	45	60	37.8	22	55	32.16	22	\$ 245.72	\$ 144.72	\$ 101.00
71	240	60	34.2	26	55	29.10	26	\$ 1,310.51	\$ 698.32	\$ 612.19
70	86	60	28.8	31	55	24.50	30	\$ 469.60	\$ 210.72	\$ 258.88
69	291	60	27	33	55	22.97	32	\$ 1,589.00	\$ 668.46	\$ 920.53
68	37	60	23.4	37	55	19.91	35	\$ 202.04	\$ 73.66	\$ 128.38
67	466	60	21.6	38	55	18.38	36	\$ 2,544.58	\$ 856.37	\$ 1,688.21
66	3	60	19.8	40	55	16.85	38	\$ 16.38	\$ 5.05	\$ 11.33
65	209	45	18	27	41	15.31	26	\$ 855.93	\$ 320.07	\$ 535.86
64	328	45	16.2	29	41	13.78	27	\$ 1,343.27	\$ 452.07	\$ 891.20
63	123	45	14.4	31	41	12.25	29	\$ 503.73	\$ 150.69	\$ 353.04
62	137	45	14.4	31	41	12.25	29	\$ 561.06	\$ 167.84	\$ 393.22
61	109	45	12.6	32	41	10.72	30	\$ 446.39	\$ 116.85	\$ 329.55
60	167	45	12.6	32	41	10.72	30	\$ 683.92	\$ 179.02	\$ 504.90
59	257	45	10.8	34	41	9.19	32	\$ 1,052.50	\$ 236.14	\$ 816.36
58	142	45	10.8	34	41	9.19	32	\$ 581.54	\$ 130.48	\$ 451.06
57	221	45	9	36	41	7.66	33	\$ 905.07	\$ 169.22	\$ 735.85
56	180	45	9	36	41	7.66	33	\$ 737.16	\$ 137.83	\$ 599.34
55	178	45	9	36	41	7.66	33	\$ 728.97	\$ 136.30	\$ 592.68
54	57	30	9	21	27	7.66	20	\$ 155.62	\$ 43.65	\$ 111.98
53	177	30	9	21	27	7.66	20	\$ 483.25	\$ 135.53	\$ 347.72
52	199	30	9	21	27	7.66	20	\$ 543.32	\$ 152.38	\$ 390.94
51	135	30	9	21	27	7.66	20	\$ 368.58	\$ 103.37	\$ 265.21
50	102	30	9	21	27	7.66	20	\$ 278.48	\$ 78.10	\$ 200.38
49	78	30	9	21	27	7.66	20	\$ 212.96	\$ 59.73	\$ 153.23
48	151	30	9	21	27	7.66	20	\$ 412.27	\$ 115.62	\$ 296.64
47	-	30	9	21	27	7.66	20	\$ -	\$ -	\$ -
46	284	30	9	21	27	7.66	20	\$ 775.39	\$ 217.46	\$ 557.93
45	47	30	9	21	27	7.66	20	\$ 128.32	\$ 35.99	\$ 92.33
44	99	30	9	21	27	7.66	20	\$ 270.29	\$ 75.80	\$ 194.49
43	153	30	9	21	27	7.66	20	\$ 417.73	\$ 117.15	\$ 300.57
42	196	30	9	21	27	7.66	20	\$ 535.13	\$ 150.08	\$ 385.05
41	78	30	9	21	27	7.66	20	\$ 212.96	\$ 59.73	\$ 153.23
40	13	30	9	21	27	7.66	20	\$ 35.49	\$ 9.95	\$ 25.54
39	176	30	9	21	27	7.66	20	\$ 480.52	\$ 134.76	\$ 345.76
38	246	30	9	21	27	7.66	20	\$ 671.64	\$ 188.36	\$ 483.27
37	109	30	9	21	27	7.66	20	\$ 297.60	\$ 83.46	\$ 214.13
36	2	30	9	21	27	7.66	20	\$ 5.46	\$ 1.53	\$ 3.93
35	-	30	9	21	27	7.66	20	\$ -	\$ -	\$ -
34	650	15	9	6	14	7.66	6	\$ 887.33	\$ 497.71	\$ 389.62
33	-	15	9	6	14	7.66	6	\$ -	\$ -	\$ -
32	-	15	9	6	14	7.66	6	\$ -	\$ -	\$ -
31	3	15	9	6	14	7.66	6	\$ 4.10	\$ 2.30	\$ 1.80
30	731	15	9	6	14	7.66	6	\$ 997.90	\$ 559.73	\$ 438.17
29	-	15	9	6	14	7.66	6	\$ -	\$ -	\$ -
28	-	15	9	6	14	7.66	6	\$ -	\$ -	\$ -
27	-	15	9	6	14	7.66	6	\$ -	\$ -	\$ -
26	317	15	9	6	14	7.66	6	\$ 432.74	\$ 242.73	\$ 190.01
25	198	15	9	6	14	7.66	6	\$ 270.29	\$ 151.61	\$ 118.68
24	-	15	9	6	14	7.66	6	\$ -	\$ -	\$ -
23	-	15	9	6	14	7.66	6	\$ -	\$ -	\$ -
22	-	15	9	6	14	7.66	6	\$ -	\$ -	\$ -
21	355	15	9	6	14	7.66	6	\$ 484.62	\$ 271.83	\$ 212.79
20	-	-	0					\$ -	\$ -	\$ -
Total	8,394							\$ 25,421.19	\$ 9,289.71	\$ 16,131.48

Figure 8.0

- Tower “B” had an annual fan motor operating cost of \$9,289.71
- The net difference between tower “A” and tower “B” was \$16,131.48.

Images of both cooling towers used for the evaluation are below. Tower “A” is Figure 9.0 and Tower “B” is Figure 10.0

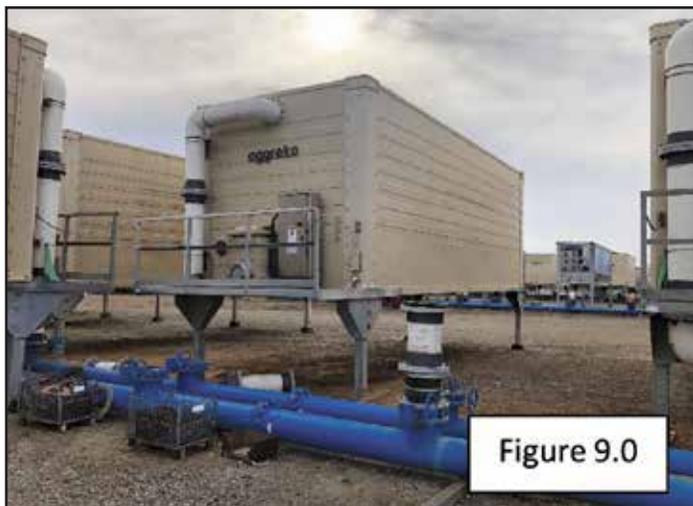


Figure 9.0

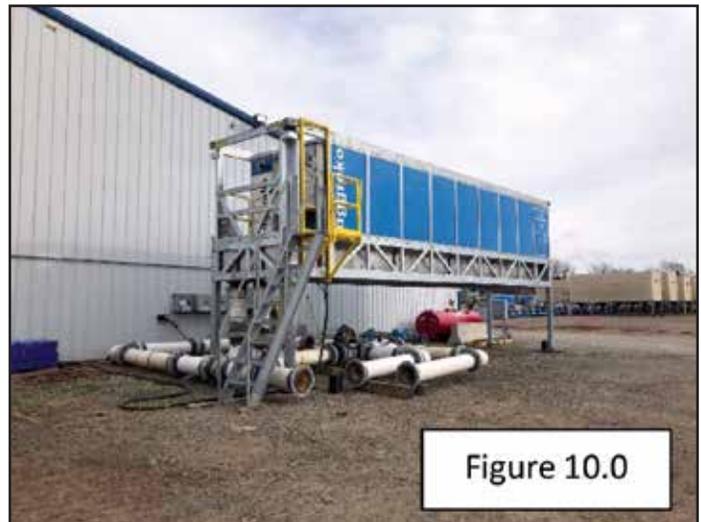


Figure 10.0

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# Retractable Screens; The Answer To Icing And Winterization Problems

Jim Baker, Galebreaker Industrial Limited

## Introduction:

The use of windscreens has been utilized in the Industrial and Agricultural Markets to provide protection against the elements of nature for well over 30 years. Most recently wind screens have been utilized on cooling towers to keep the cold weather out of the towers and some warmth inside to prevent ice accumulations. These ice accumulations can have a devastating effect on the tower structure.

Most recently, the focus has been on improving the performance of Cooling Towers in Refineries, Petro-Chemical Plants, Power Plants, Hospitals, Universities and other manufacturing facilities. Although performance is paramount in the summer, it is also vital to keep the icing out of the tower in the colder months. This can be somewhat accomplished through proper tower operation but not in severe conditions. In severe conditions, it is important to keep the warm air in the tower and the cold air out while at the same time balancing tower and plant operation.

This paper will provide some background and history of tower operation in the winter months and how ice has always been an issue. A case study will be provided to illustrate a solution for these problems.

The paper will conclude with discussion and photographs of the application of retractable wind screens as a solution in preventing structural failures in Cooling Towers in the most severe winter conditions.

## Section 1: History Of Cooling Tower Icing

### The Problem

Extreme cold weather presents its' own problems when it comes to cooling.

Cooling towers use ambient air to cool the water used in a process or system by transferring the heat across a very efficient heat transfer surface into the surrounding environment, simple and effective.

Although anti-freeze might be the ideal solution for preventing icing in cooling towers, Environmental Protection Agency regulations restrict the use of anti-freeze in open air applications such as a cooling tower and consider it as hazardous waste. Wide spread freezing can still occur even when the air moving equipment has been turned off but water still flows throughout the tower. Even though the temperature of the water increases due to the reduction of air flow, the water can still be below freezing point. Once icing begins to accumulate on the air inlet, structural damage is inevitable. If the operator is not pro-active in preventing these accumulations of ice from occurring, icing will persist throughout the winter months. Installing winter protection screens will reduce the flow of air into a cooling system and help to contain the heat within the system to reduce or prevent the effects of extreme cold.



Jim Baker

Ice accumulations have been forming in cooling towers dating back to the early Atmospheric Towers. As reversible fans were introduced, a means to de-ice was introduced. When the fans are reversed, the air is brought into the tower through the fan stack, forced over the hot water falling through the tower, and pushed out of the air inlet to melt any ice forming.

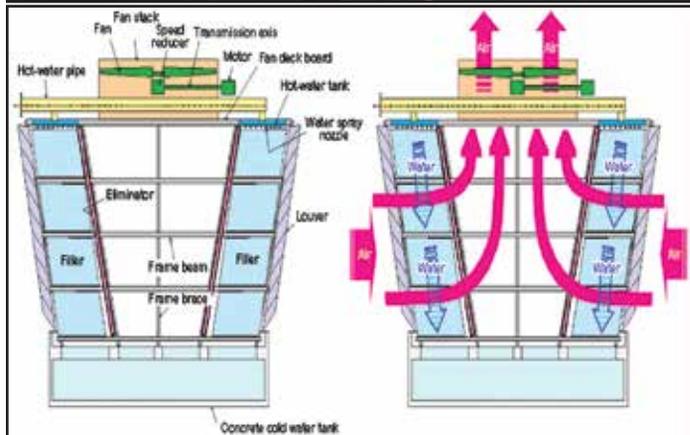
Ice build-up on any type of cooling tower can be controlled somewhat by pro-active tower operation. A program can be implemented to stagger fan operation on individual cells with a series of Hi, Low, Off, and Reverse. This can be done manually or with programmable controllers. The primary problem still lies in the reactive approach to icing

instead of pro-active approach to prevent ice completely.

## Different Types of Towers

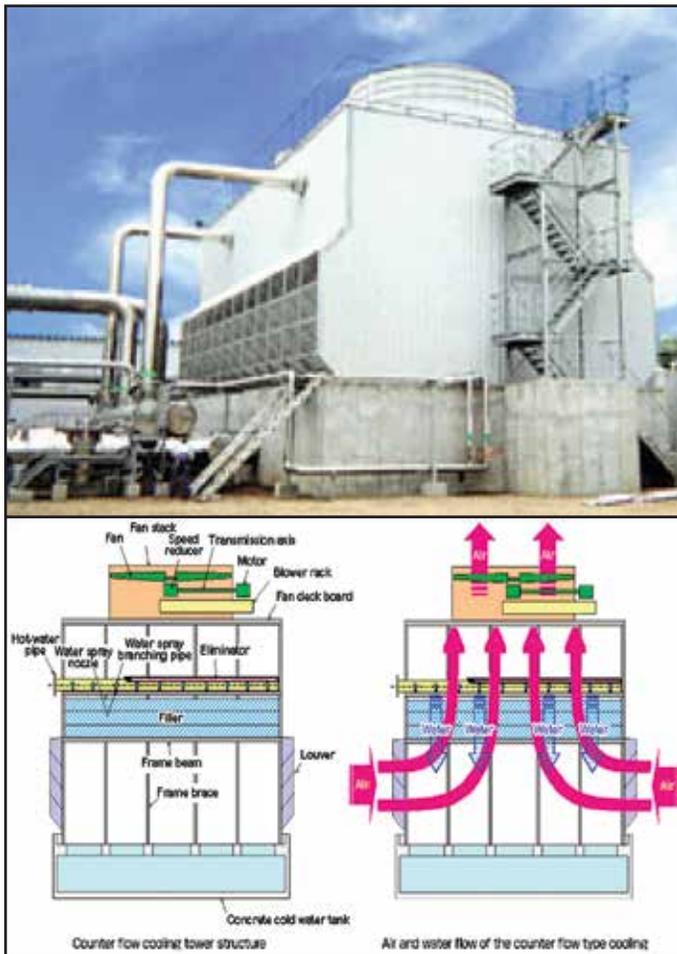
This type of cooling tower is called "cross flow" because air contacts water in a cross pattern.

### Cross Flow Cooling Tower



This type of cooling tower is called "counter flow" because air counters with water.

## Counter Flow Cooling Tower



Both types of towers have advantages and disadvantages during winter operation. While the counter flow tower has less water and structure exposed at the air inlet where icing forms, the cross flow tower can be operated by pushing more hot water down the louver face to melt ice formations off by flooding the outside with hotter water. Both types of towers must have proper and pro-active fan operation.

## Section 2: Operational Issues

When the cooler months are upon us, it is important to prepare your cooling towers for freezing temperatures. Even in extremely icy conditions, cooling towers can be operated successfully if proper precautions and protocols are followed. A frozen cooling tower is a major issue for business operations as well as from a cost standpoint.

### Winter Cooling Tower Problems

As with any outdoor equipment, ice can form and collect on cooling towers if the conditions are right. This ice can form and even be amplified by the operation of the cooling tower itself.

The location of ice formation on the cooling tower is important to understand. Ice at the air inlet and on the fans can lead to major operational issues and extensive damage, whereas ice on the structure may be less of an immediate concern.

Cooling tower fans are delicate and cannot operate optimally when obstructed. Ice formation poses as a major threat to the fans in terms of equipment damage and loss of functionality. The expansion of water as it freezes, and shear weight of the building ice can deform the fans. Even after the ice is removed, the effectiveness of the fans can be greatly diminished. Also, as fans freeze up, the efficiency of the cooling tower declines rapidly which can halt operations completely if left untreated.

Ice formation on the structure may not pose an immediate threat to the performance of the cooling tower, but it should not be overlooked. The building of ice can add tremendous weight and stress to the cooling tower supports and cause costly damage. Also, ice can dislodge from the cooling tower structure, resulting in a falling brick of ice that can damage equipment and put personnel at risk. Regardless of where ice formation is observed, actions should be taken to remedy the ice situation and implement preventative measures.

### Operating a Cooling Tower in the Winter Months

There are many different methods to successfully operate a cooling tower in winter conditions. These can vary depending on the location, operation, and other specifics of the equipment itself. Even so, there are some common themes to help make winter cooling tower operations go smooth.

**Conduct Regular Inspections** - This should be done year-round to ensure equipment is in good order and functioning properly. Increase the frequency of inspections during freezing conditions to identify ice formation before it becomes a major problem.

**Begin Cold Weather Operations Proactively** - Don't wait until the outside air temperature hits freezing to implement your cold weather protocol. It is much easier (and less costly!) to prevent the formation of ice rather than be reactive to ice that is already present.

**Maintain Heat Load** - Ensure there is a constant heat load on the cooling tower during cold weather to prevent ice from forming.

**Sustain Flow Rates** - Low flow rates increase the likelihood of freezing. Maintain flow rates above the design minimum to help prevent the cooling tower from freezing.

**Manage Airflow** - Control flow rate of air in each individual cooling tower cell to keep temperatures above freezing. Differences in airflow between cells can create localized freezing.

**Do Not Manually Remove Ice** - Ice buildup on the cooling tower should be allowed to melt off in order to prevent damage to equipment that could occur during ice removal. Furthermore, falling ice can occur when removing ice from a cooling tower and this is a significant personal safety hazard.

**Consult Manufacturer Guidelines** - Check the manufacturer recommendations for cold weather instructions to ensure operational procedures of the specific cooling tower are not overlooked.

Winter temperatures pose a serious threat to cooling towers, but these risks can be mitigated with a proactive and proper approach to cold weather management.

Huge ice loads can build up on structures sometimes with catastrophic effects leading to collapse. This tower has been operated too long with no means to de-ice. Major failures with the structure are inevitable.



### SECTION 3: Case Study for Retractable Screens

The subject cooling tower was a 3-cell counter-flow tower located in the Chicago area. The tower was first inspected in February of 2018 where excessive icing was found at the air inlets. The owner attempted to install tarps to keep the heat in the tower and the ice melted. This was a temporary fix, and not a very good one that had to be removed and reinstalled on a yearly basis. In December of 2018, a permanent solution was installed. The solution was retractable winterization screens which could be deployed in the winter and retracted back up in the summer. The owner was extremely satisfied with the finished product.

Any distribution leaks or broken header pipe leaks can result in an ice berg down below where it is exposed to the cold air flow.



This photograph was taken in February of 2018. These were the temporary tarps installed seasonally to keep the warmth inside the tower and the cold air out.

Plant personnel is attempting to remove the ice with high pressure steam. Although this can be successful, it is a temporary solution and can cause structural damage.



A photograph of the south end of the tower. This end had numerous obstructions thus making it impossible to cover with screens. In order to install any type of retractable device, the area must be

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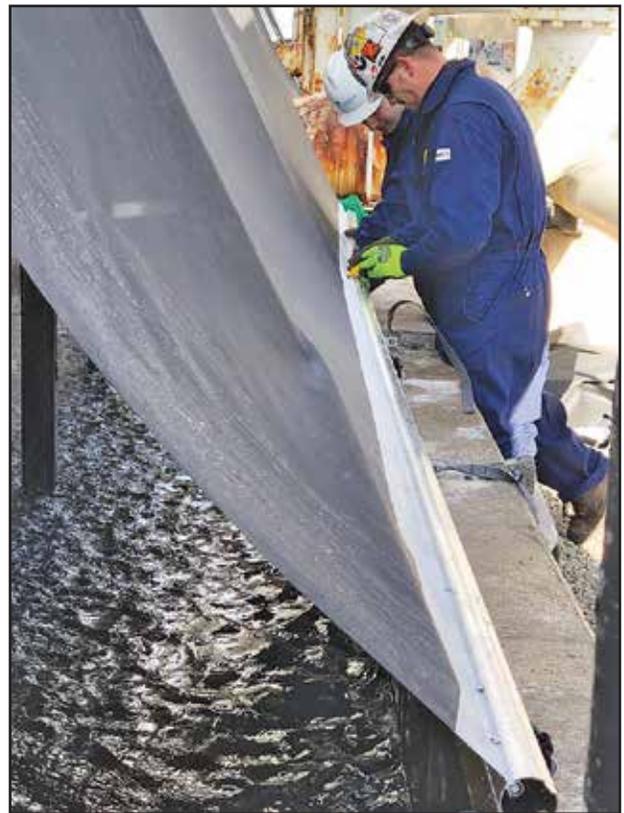


clear of any piping or conduit. If the area must be covered, a fixed screen with cut-outs can be custom fitted. In this particular application, icing was not an issue on this south end so no screens were installed.



Next the screens are installed into the aluminum tube at the bottom that provides the stability directly above the basin curb. This tube will attach to the gear drive and be the mechanism to roll up the screen when not in use.

All towers with potential winterization screen applications are surveyed and exact dimensions are taken. The screens are then custom made to fit the openings and the Retractable Kador Profiles. A Kador Profile is a channel groove designed in an aluminum strip in which a bead molded into the screen is installed. The bead is inserted into the channel and held secure.



This photograph shows the screens installed in the aluminum tube in the Kador Profile.



The aluminum strip is then installed at the top of the air inlet. It is attached to a longitudinal support member. The top of the the air inlet screen is then installed into the channel of the Kador Profile.



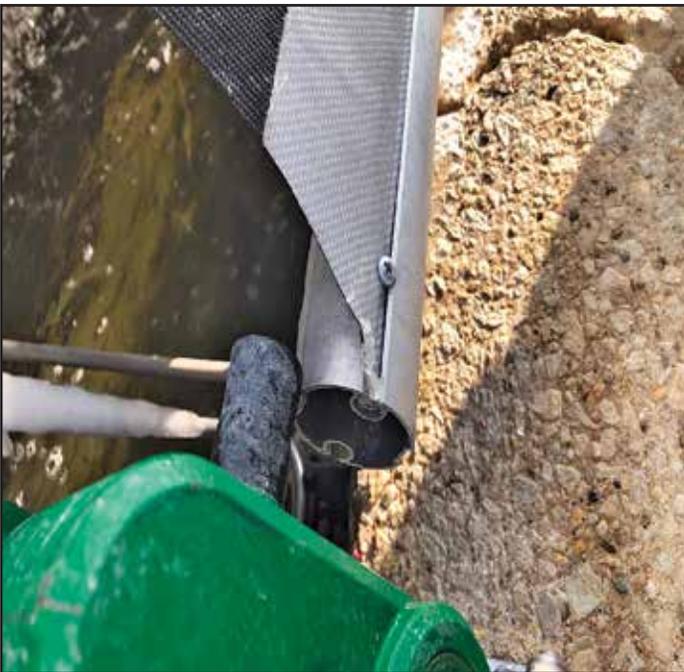
The railing and the gear drive are installed. This railing is bolted into the concrete curb and attached to the longitudinal support at the top of the air inlet. This is the railing that the retraction takes place by means of the manual gear drive shown at the bottom. This manual gear drive can either be chain or handle driven.



The screens are attached to the concrete curb and pulled tight by means of stainless steel ratchets and straps around the aluminum tubes. The ratchet size and spacing are designed to the wind loadings on the screens.



This photograph shows the installed screen on the north end wall. Note the gap at the bottom which does allow for some airflow if the fans are variable speed or left on. This operator had no problems running one fan on variable and two fans down while the screens were deployed.



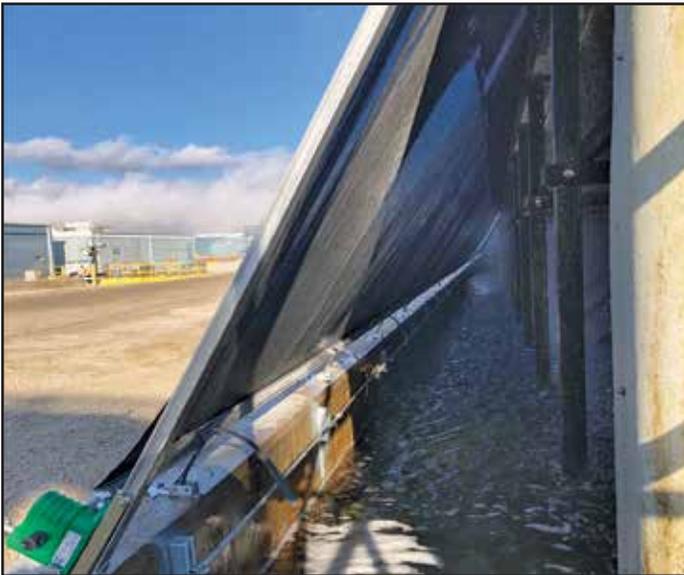
This photograph is of the aluminum tube with the screen installed into the Kador Profile. This tube attaches to the shaft shown on the gear drive.



This photograph shows the installed screens on the west side of the tower. These three cells were covered with two screens, 144-feet (44 meters), per screen. The three cells could have been covered with one screen but because of water treatment lines entering the tower at the concrete basin in the center, two screens were used.



This photograph shows the east side of the tower. Obviously there are numerous obstructions such as by-pass lines, conduits, etc. Instead of utilizing only two screens as was needed on the west side, the east needed five separate screens at various lengths. Icing was still controlled in sub-zero conditions on this east side.



This photograph shows behind the screens on the west side. This particular day the temperatures were in the low 20s degrees F, (-7 degrees C). Note the opening on the end corner. This can be closed with attaching eyelet flaps if needed. So far, none have been needed.

These two photographs show the finished product on the west side where the most severe of the icing occurs.



## Conclusion:

In conclusion, the overall project was a huge success. The need for the installation of temporary tarps to be installed annually to protect the structure from huge ice accumulation was eliminated. The cost to install and remove these tarps was eliminated. With temperatures in the minus 20's F (-29 C), the ice was eliminated on the structures at the air inlet.

Always the best practice for ice attenuation is pro-active operation of the fans. Unfortunately, this does not always happen so these retractable screens are the answer. A combination of proper fan operation and deployment of Winterization Screens will help you operate your tower safely and pro-long the life of your cooling tower structure.

Local environment and weather has a huge impact on the design of cooling systems and their long term operation. The result of the environment on cooling can be seen in every system around the world. Some plants require more regular attention and have more stringent design requirements. These plants can benefit from seasonal and environmental protection.

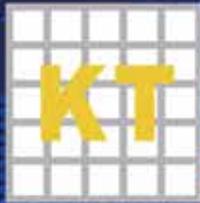
Installing seasonal protection devices can help to prolong the life of the equipment, reduce downtime, and increase performance.

With the development of larger, more cost effective and user friendly systems it makes these add on devices more accessible for equipment of all sizes.

One size does not necessarily fit all so each and every system should be reviewed on its' own particular situation to determine whether any protection is required. The use of wind screens can provide an alternative solution which merits evaluation.



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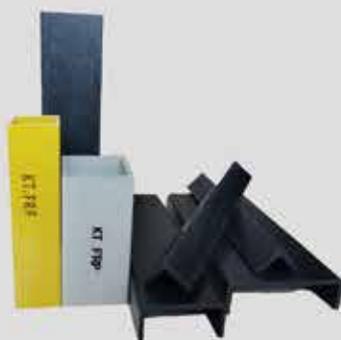
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# AEP/Buckeye Power Cardinal Unit 3 Natural Draft Cooling Tower Shell FGD Discharge

Frank Michell

## Abstract

The first installation of routing the discharge from a wet flue gas desulphurization (FGD) system into a natural draft cooling tower shell in the Western Hemisphere was completed at the 620 MW supercritical coal fired Unit 3 at AEP/Buckeye Power's Cardinal Plant in Brilliant, Ohio in 2011. The cooling tower was also converted at the time from a cross-flow to a counterflow configuration with a fiberglass fill support structure (FRP). This paper will describe the process for determining the scope of the retrofits, highlight construction challenges and the successful operation of the FGD and the cooling tower conversion.

## Background

Cardinal Power Plant has three supercritical, coal-fired generating units with a total generating capacity of 1,800 MW. The plant is situated on the Ohio River in Brilliant, Ohio, about 50 miles west of Pittsburgh, Pennsylvania and 15 miles north of Wheeling, West Virginia. Cardinal is co-owned with Unit 1 owned by American Electric Power's subsidiary, AEP Generation Resources. Units 2-3 are owned by Buckeye Power, utility cooperative. The plant began operations in 1967 (Fig 1).

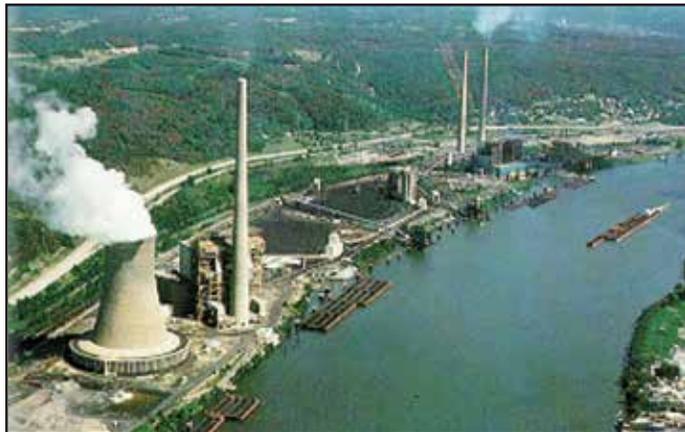


Fig 1. Cardinal Plant Prior to FGD Retrofit

The FGD System removes SO<sub>2</sub> from the exhaust flue gases from the boiler combustion process in coal fired power plants. FGD retrofits were completed on Units 1 & 2 in 2007 to reduce unit sulfur dioxide (SO<sub>2</sub>) emissions. A new stack was installed to accommodate the saturated flue gas discharge from the FGD system on the units. Unit 3 required retrofit of an FGD system by 2012 to meet environmental regulations. Units 1 & 2 incorporate "once-through cooling" from the Ohio River. Unit 3 incorporates a natural draft cooling tower for condenser cooling.



Frank Michell

## Cardinal Unit 3 FGD Retrofit Site Constraints

Within the bounds of the Cardinal 3 site, the only viable location for a new stack designed to handle the saturated flue gas from the new FGD system is in close proximity to the cooling tower and in the path of prevailing wind direction of the tower plume (Fig 2).

Analytical analysis indicated that ice accumulations would be expected on the new stack if located where it needed to be due to site layout constraints (Fig 3).

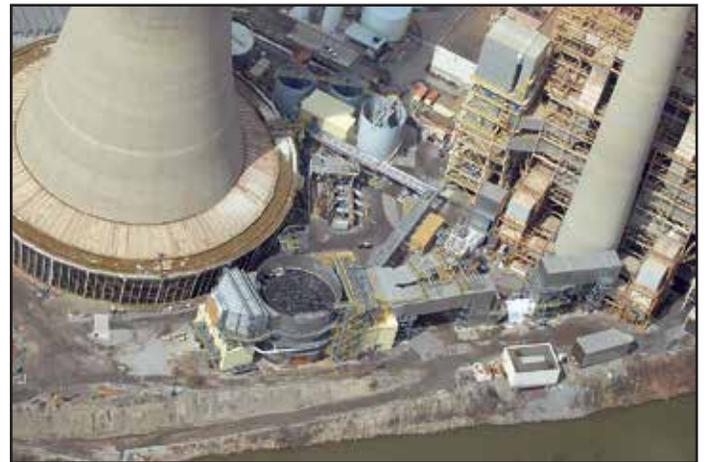


Fig 2. Unit 3 Cooling Tower with Existing Stack

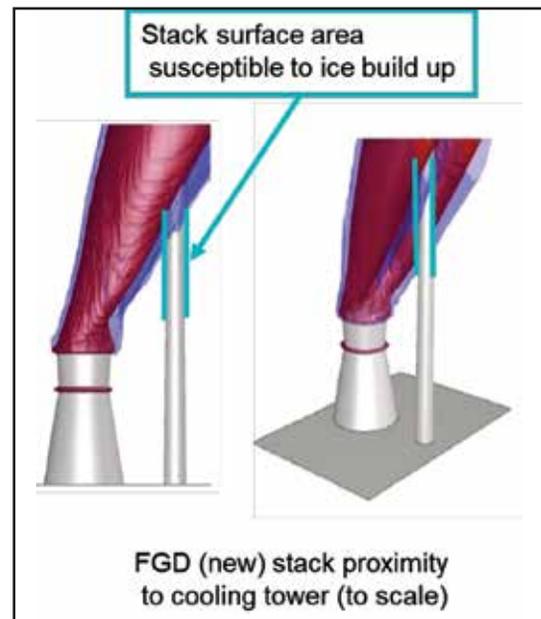


Fig 3. Icing Study

In cold weather the moist cooling tower plume would likely cause ice buildup on the proposed stack. Analyses indicate that the ice could build six or more inches thick on the stack surface along several hundred feet of the upper stack. This ice would likely break off in sheets creating a serious safety hazard.

Historical weather records and results from computer modeling indicate that icing on the stack could occur approximately 20 days per year.

Due to this safety concern, it was decided to discharge the flue gas directly into the cooling tower shell in lieu of constructing a new stack. Introducing FGD discharge into the cooling tower shell was a technology in use in Europe at the time. This would be the first and, to date, the only application of the technology in The Western Hemisphere.

By design, a cooling tower plume is extremely buoyant and creates a strong updraft flow into the atmosphere. The lift created by a cooling tower plume is much greater than the lift created by the flue gas, by itself, emitted through a stack (Fig 4).

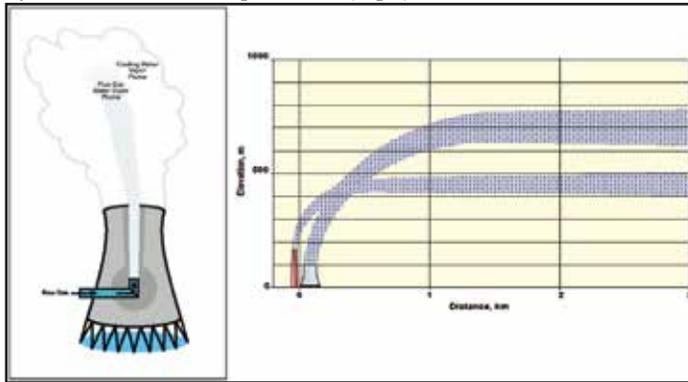


Fig 4. Plume Buoyancy

## Unit 3 Cooling Tower

The Cardinal Unit 3 crossflow, natural draft cooling tower was originally constructed with a precast concrete hot water distribution system and a “hanging” fill arrangement consisting of PVC splash (“M”) bars supported by plastic coated carbon steel wire grid that was hung from underneath the hot water deck. Due to failures of the hanging fill system, a new fill support structure was retrofitted in 1985 supported off the cold-water basin floor. The retrofitted wood structure incorporated wood splash fill bars supported on stainless steel wire grid.

The precast concrete hot water flume and nozzle deck structural components were requiring significant maintenance to avoid major failures. In addition, the wood fill and fill support structure were experiencing localized failures. Rebuild of the cooling tower fill system was planned in conjunction with completing the Unit 3 FGD retrofit project. The cooling tower counterflow conversion and FGD discharge into the cooling tower shell project was completed by SPX Cooling Technologies.

To optimize/limit outage duration and cost the decision was made to incorporate a counterflow fill system with an FRP structure and bottom supported PVC low fouling fill for the cooling tower rebuild scope. All structural support system fiberglass shapes were manufactured in compliance with CTI STD-137 and CTI STD-152. The FRP components incorporated flame retardant vinyl ester resin infused with ultraviolet (UV) inhibitor additives. Hardware was specified to be made of Alloy 2205 material.

To accommodate the counterflow fill support structure the cold-water basin floor had to be strengthened to handle the design loads that were not present for the original crossflow tower. A new concrete floor was poured over the existing cold-water basin floor during an outage prior to the FGD retrofit/cooling tower rebuild Fall ‘2011 outage (Fig 5).



Fig 5. Cold Water Basin Upgrade

During a planned maintenance outage prior to the FGD retrofit/cooling tower rebuild outage, the interior of the cooling tower shell was epoxy coated to protect the concrete from long term exposure to the flue gas that will be mixing with the cooling tower plume. The top 50 ft of the shell exterior was also epoxy coated for protection against “down washing” of the plume during high wind conditions.

Pre ‘2011 outage work included reinforcing the area of the cooling tower shell where the 30+ft diameter hole would be cut to facilitate installation of the FGD fiberglass flue gas duct (Fig 6).



Fig 6 Concrete Shell Flue Duct Opening Reinforcement

Sections of the fiberglass flue gas duct were fabricated at a facility off site and delivered to the plant on barges for on-site assembly. The FGD structure was constructed with the unit in service (Fig 7).



Fig 7 FGD Duct Pre Outage Work

## FGD Retrofit/Cooling Tower Counterflow Conversion Outage

All materials for the cooling tower counterflow conversion were delivered to the site prior to the outage. Due to site constraints, only a minimal amount of prefab work could be done. All cooling tower work and the FGD tie-in needed to be completed during a scheduled 15-week long unit outage.

Demolition of the old cooling tower counterflow fill system was initiated as soon as the turbine was cool enough to take the circulating water system out of service and the cold-water basin drained. Heavy duty, mobile equipment was staged around the tower to accomplish the demolition (Fig 8).



Fig 8 Demolition

A critical early activity involved cutting the hole in the concrete shell and constructing the platform for supporting the flue gas duct inside the cooling tower. The flue duct had to be inserted into the shell before most of counterflow system installation could be completed (Fig 9).



Fig 9 Installing Fiberglass Flue Duct

Cooling Tower counterflow conversion proceeded along with final construction and tie-in of the FGD system (Fig 10 & 11).



Fig 10 Counterflow Conversion Work in Progress



Fig 11 FGD Construction

The FGD retrofit and cooling tower counterflow conversion outage was completed on schedule and within budget. The FGD discharge and cooling tower performance have performed as designed with no ground level flue gas detected by air monitoring stations in the vicinity of the plant (Fig 12).



Fig 12 Unit 3 Back in Service

When the unit returned to service ice accumulations were experienced from the cooling tower/FGD discharge plume on the upper elevations of the old stack when operating during freezing ambient conditions with prevailing winds in the direction of the stack. Being out of service, the old stack concrete surfaces were at ambient temperature which resulted in the saturated plume engulfing the stack to cause ice to form resulting in a safety hazard (Fig 13). The old stack was reduced in height to eliminate the ice accumulation from occurring during subsequent winters.



Fig 13 Old Stack Icing



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# Advances In The Monitoring And Control Of Cooling Systems Chemistry

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Chemtreat, Inc.

## Abstract

Monitoring and control of cooling water chemistry has improved considerably over the past few decades. Initially, chemicals were metered into the cooling water in proportion to blowdown water flow. The blowdown flow was either measured directly or, more typically, imputed from a makeup water flow meter. The concentration of water treatment chemical was controlled by manually adjusting the delivery rate of a metering pump by timing the drawdown using a calibration cylinder valved into the pump suction. Samples of the cooling water were collected, generally once per shift, and trekked to a chemistry lab where a trained operator performed a wet chemistry analysis for one or more of the treatment chemical components. Based on the results of the wet chemistry tests, the operator would then adjust the metering pump using stopwatch and drawdown cylinder.

Over the past three decades, the chemical feed process has been improved by automating pump calibration, adding flow sensors to the metering pumps, providing on line wet chemistry analyzers, and coupling the feed system to powerful software systems that collect, calculate, control, and communicate the results, often in real time. Advanced reagent-free sensors and inert tracers have also begun to displace the more maintenance-intensive wet chemical analyzers.

Considering all the challenges associated with the current chemical monitoring techniques, a multi-year research & development project was undertaken and developed a reagent less method for testing the active deposit control agent (DCA) in the cooling system. This online test method immensely improves the performance of the DCA by monitoring and maintaining the required level of actives at all times. This development also provides economic advantages for the customers, including the optimization of DCA levels and water savings. The initial DCA development work has been focused on calcium carbonate scale control, since phosphorus-based corrosion inhibitors are being displaced by more effective and environmentally benign chemistries. This paper will describe the effect of various cooling system operating conditions on the online DCA measurement.

## Introduction

Cooling systems are an important component of any industrial facility. Three main challenges associated with successful operation cooling systems are controlling:

1. Corrosion
2. Deposition and
3. Microbiological growth.

All three challenges are interrelated. Industrial water technologists use a variety of chemical additives to mitigate corrosion, scaling/fouling and microbiological growth. The type of chemistries that are applied mainly depends on factors such as makeup water chem-



Prasad Kalakodimi

istry, operating conditions (such as temperature, pH, etc.), system metallurgy and regulatory requirements. Many recirculating cooling towers are being operated to conserve more water due to environmental restrictions on discharge, escalating water costs and water scarcity. Industries are tightening up their systems to run high cycles of concentration and with minimal or no blowdown. Many sites are compelled to use gray waters containing higher levels of impurities. Both scenarios place additional stress on the corrosion and deposit control chemistries to maintain the cooling system equipment life and heat transfer, and ensure that

production goals are not compromised.

As the water evaporates across the cooling tower, pure water vapor is lost and the dissolved minerals and other impurities are concentrated in the remaining water. If this concentration cycles are allowed to continue too far, the solubilities of various minerals exceed their saturation and form deposits, often in the cooling tower fill and in the hotter areas such as heat exchangers. Deposits consists of six general types:

1. crystalline or amorphous mineral scales (e.g. calcium carbonate, calcium sulfate, calcium phosphate, amorphous silica, and metal silicates),
2. fouling due to suspended solids (e.g. mud and silt in the makeup water and airborne dust)
3. transient corrosion products such as iron oxides and hydroxides,
4. microbiological deposits
5. process contamination such as hydrocarbon leaks, and fouling related to corrosion inhibitors such as calcium phosphate, zinc phosphate, and zinc hydroxide.

The major cause of industrial water system failures is the deposition of unwanted materials on the surface of the equipment. Deposits cause reduction in system performance and cause unexpected shutdowns, environmentally challenging cleaning operations, and associated costs

Calcium phosphate and calcium carbonate are the most common mineral scales in the cooling systems. Both these salts have inverse solubility (solubility decreases with increase in temperature and pH) and tend to lay down as thick scales on the heat exchangers. Though every type of industry suffers with scaling issues due to improper operating, this scaling problem is especially prevalent in "heavy" industries such as refineries, petrochemical plants, steels, etc., which commonly have very hot heat exchangers and low water velocities. Water treatment professionals use combinations of several chemical additives to control deposition in cooling systems. Most common deposit control agents are either non-polymeric phosphorous containing chemicals (phosphonates, phosphinates, polyphosphates, etc) or polymeric compounds (homo polymers, co-polymers, terpolymers, oligomers, etc.) containing various functional groups, principally carboxylic, sulfonate, amide, and hydroxide. Common functional groups used to synthesize these polymers are shown below in Figure 1:



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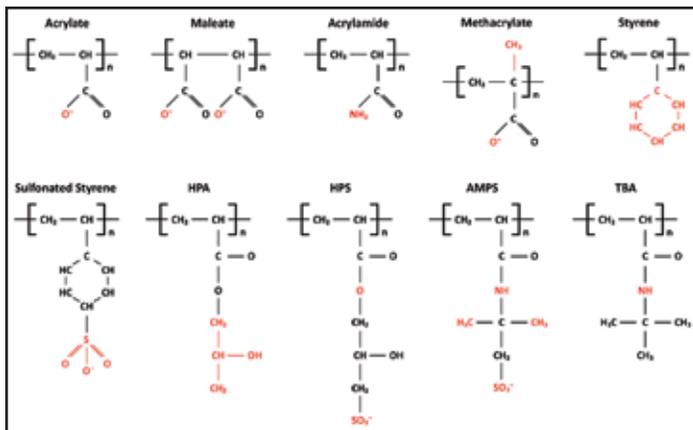
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**Figure 1: Main functional groups used to synthesize cooling water deposit control agents (HPA: Hydroxypropyl acrylate, HPS: 2-hydroxypropylsulfonate, AMPS: 2-Acrylamido-2-methylpropane sulfonic acid, TBA: ter-butyl acrylate)**

The reliable operation of any plant depends not only on choosing the appropriate deposit control agent (DCA) for mitigating the deposit, but also maintaining adequate residual chemistry in the system at all times. Real-time monitoring of the deposit control agent is critical for performance and economic reasons. As mentioned above, it is not only important to match the right chemistry for the type of scale, but also to maintain proper chemical residuals at all times. Lack of adequate levels of the deposit control agent can lead to severe scaling, reduction of heat transfer efficiency, loss of production and can lead to plant shutdown and added costs for cleaning the deposits.

It is important to realize that deposit control agents can be consumed by deposition and other stresses in the cooling system. For example, as calcium carbonate begins to precipitate, the precipitate incorporates some of the calcium carbonate deposit control agent. This leads to even lower levels of calcium carbonate scale inhibitor and even faster rates of calcium carbonate deposition. One consequence of this behavior is that the concentration of calcium carbonate DCA relative to the concentration of a reference can be used to indicate the onset of a precipitation event, and to initiate a corrective response as part of a control algorithm. The corrective response might be to increase the dosage of calcium carbonate scale inhibitor or reduce the scaling tendency by decreasing cycles of concentration or pH. Similar feedback behavior is exhibited with  $\text{CaCO}_3$  DCA in the presence of calcium phosphate scale, silt dispersants subjected to high concentrations of suspended solids and with calcium phosphate dispersants subjected to calcium phosphate deposition event.

There has been research and applications of real-time measurement of deposit control agent. This was achieved by incorporating a fluorescent monomer into the backbone of the deposit control polymer and using a fluorometer to measure and control the active DCA levels in the system.

Until now this online monitoring was practiced only for a calcium phosphate scales and has never been done for other mineral scales. Calcium phosphate scale is mainly due to the result of feeding inorganic and organic phosphates as corrosion/scale inhibitors in cooling systems which form a protective calcium phosphate and/or iron phosphate film on the steel surface.

For four decades, phosphate based corrosion and scale inhibitor programs emerged as the cooling water treatment technology of choice when the industry was strongly encouraged to eliminate chromates some 35 years ago. At that time, we were certainly aware of the many troublesome issues associated with phosphorus based programs: the precise control required to prevent phosphate depos-

its on hot bundles, inadequate admiralty brass corrosion using only azoles, escalating dispersant demand due to phosphate precipitation with well water iron and aluminum carryover, and excessive algae growth on the towers and the associated chlorine demand. Today's phosphate chemistries perform adequately in most circumstances, but demand precise control. The concentration of phosphate must be balanced carefully with calcium, polymeric dispersant, pH, and temperature. If all five factors are not perfectly balanced at all times and at all points in the system, either corrosion or fouling will occur. This is particularly problematic in the chemical industry due to the prevalence of high temperature, low flow bundles together with steel piping operating at much lower temperature. 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.



**Figure 2: Toxic Algae Bloom in Lake Erie, 2011. National Aeronautics and Space Administration, Washington, USA. Available from <https://earthobservatory.nasa.gov>**

Phosphate also drives algae growth in cooling towers, increasing chlorination costs and the production of undesirable chlorinated organics.

At some locations now, phosphorus discharge is limited. Also being restricted is discharge of USEPA toxic pollutants [1] and priority pollutants [2] including zinc; a common key ingredient in phosphate/phosphonate formulations for additional corrosion inhibition. Due to growing concerns with the discharge of phosphorus to natural bodies of water, and the effects such discharge has on proliferation of toxic algae blooms, there has been considerable research in the development of non-phosphorus and non-zinc corrosion inhibitor technologies [3] [4]. Adding to the environmental concerns is the impact of calcium phosphate and zinc deposition on heat transfer surfaces. With many industries striving for longer times between outages, depositing corrosion inhibitors based on phosphate and zinc are becoming less popular. As the industry adopts more environmental friendly, high performance non-phosphorus technologies, the demand of the calcium phosphate scale inhibitors has decreased. Since there is much higher levels of carbonate/bicarbonate alkalinity in the water compared to phosphates, calcium carbonate ( $\text{CaCO}_3$ ) deposits tend to grow faster and thicker than calcium phosphate.  $\text{CaCO}_3$  is also a much harder scale than calcium phosphate. Considering these factors, the main emphasis moving forward will be on non-phosphorus deposit control agents for controlling  $\text{CaCO}_3$  scale. In this paper, the authors describe a new non-phosphorus, calcium carbonate deposit control agent and the reagent-free, online measurement and control of this chemistry



Figure 3: Algae hanging from cooling tower fill

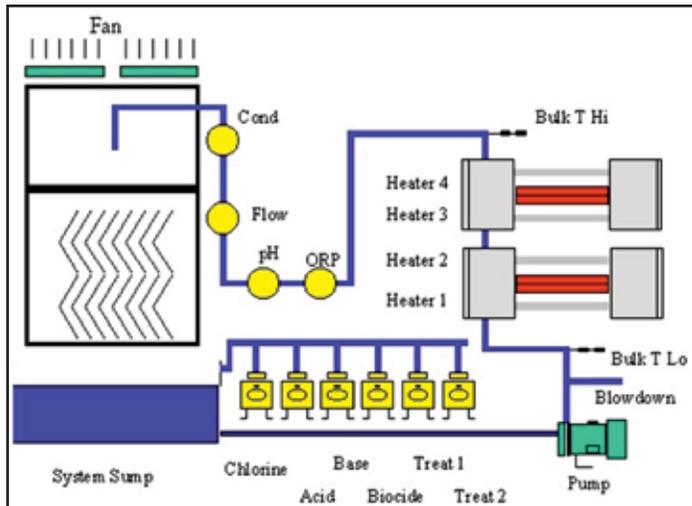


Figure 5: Pilot cooling tower schematic

## Scale Inhibitor Development

Organic phosphates have been the primary calcium carbonate scale inhibitors used by the industry since the mid-1970's. They also serve an additional role as cathodic corrosion inhibitors for steel. Our first goal was to identify and evaluate non-phosphorus chemistries for calcium carbonate scale inhibition. Initial screening studies were conducted in the form of bottle tests. Water chemistry used for testing the performance of the  $\text{CaCO}_3$  scale inhibitors in the bottle tests was 700 ppm Ca as  $\text{CaCO}_3$ , 400 ppm Mg as  $\text{CaCO}_3$ , 400 ppm M-alkalinity as  $\text{CaCO}_3$ , 400 ppm  $\text{SO}_4^{2-}$ , 400 ppm Cl<sup>-</sup> at a pH of 8.75 and at a temperature of 60 °C. These conditions correspond to a very challenging Langelier Saturation Index (LSI) of 2.9. Figure 4 shows the comparative  $\text{CaCO}_3$  inhibition data of various polymers tested.

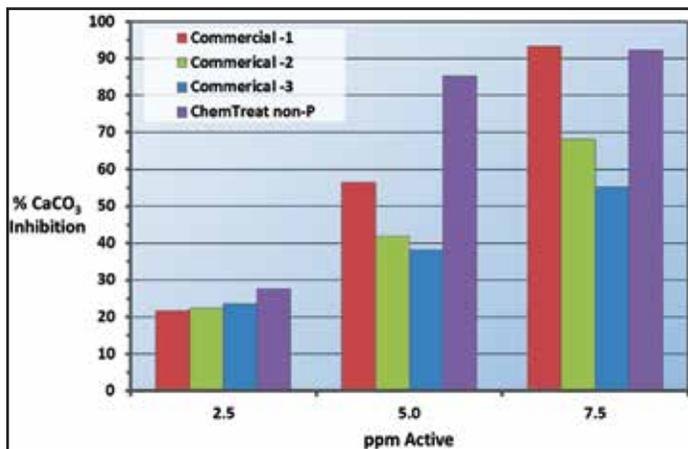


Figure 4:  $\text{CaCO}_3$  scale inhibition performance of ChemTreat non-P DCA compared with three commercially available DCA's

It is clear from Figure 4 that the non-P antiscalant exhibited superior performance in mitigating  $\text{CaCO}_3$  scale under these aggressive test conditions. This non-P deposit control agent (DCA) was evaluated against one of the commercial  $\text{CaCO}_3$  inhibitor more carefully in a matched pair of fully instrumented pilot cooling towers (Figures 5-7).



Figure 6: Pilot cooling tower heat exchanger and instrumentation.



Figure 7: Pilot cooling towers

The pilot cooling towers each have a 15 gallon (56.7 L) sump and evaporate 45 gallons (170 L) daily, with a cold supply water temperature of 100 °F (37.8 °C) and a hot return temperature of 107.5 °F (41.9 °C). For the purpose of these experiments, heat exchanger skin temperatures were maintained in the range of 135-142 °F (57-

61 °C) with a heat flux of 26,100 Btu/hr-ft<sup>2</sup> (82,319 W/m<sup>2</sup>). Test cooling towers did not have any galvanized parts. Superficial water velocity in the annular flow space was maintained at 4 fps (1.2 m/s). The test methodology was to add the scale inhibitor chemistry and cycle up the makeup water (Table 1) gradually over a three-week period until a “crash point” was reached, as indicated by scale formation on the heat exchanger tubes (Figure 8). Figure 9 indicates that the best of the non-phosphorus scale inhibitors could achieve an LSI of 2.96, corresponding to 5.5 cycles of concentration on the test water.

Analyte	Value
pH	7.8
Conductivity, µmhos	480
P-Alk, as CaCO <sub>3</sub> , mg/L	8
M-Alk, as CaCO <sub>3</sub> , mg/L	105
Ca, as CaCO <sub>3</sub> , mg/L	104
Mg, as CaCO <sub>3</sub> , mg/L	25
Total P, mg/L	<0.2
Na, mg/L	90
Cl, mg/L	66
SO <sub>4</sub> , mg/L	54
SiO <sub>2</sub> , mg/L	25

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

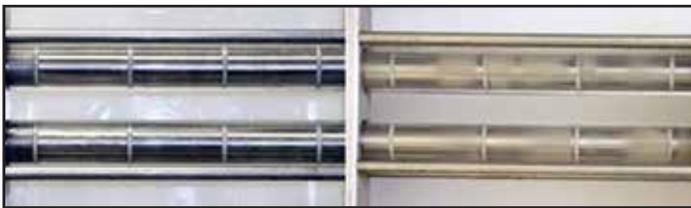


Figure 8: Appearance of test heat exchanger surfaces before and after scale development “crash point”

After the development of the non-P deposit control agent (DCA) for CaCO<sub>3</sub>, the DCA was chemically modified so that its concentration in the cooling water could be continuously monitored using a solid state sensor, without reagents. The tagging process consists of a minor amount (0.1-0.25 mole percent) of additional monomer (referred to as a tag) is incorporated into the backbone of the DCA. The low percentage of tag was shown not to impact its deposit control performance and this was confirmed by various laboratory studies. Handheld and online probes were developed to accurately measure the response from the tagged DCA. The tagged calcium carbonate DCA was subjected to various cooling system operating conditions to confirm the stability of the tag and the ability to measure the polymer accurately using the solid state sensor. The calcium carbonate antiscalant was evaluated to determine its performance under normal and upset conditions. It is not within the scope of this paper to describe the manufacturing method and chemistry of the tagged DCA.

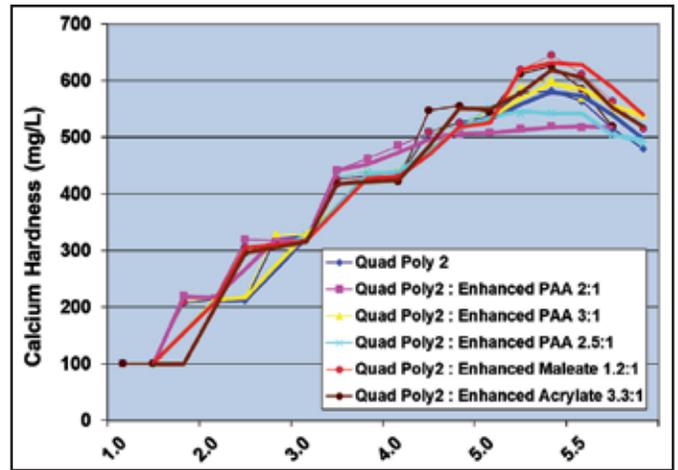


Figure 9: Pilot cooling tower study – Calcium achieved vs. cycles of concentration

## Long-term Stability

10 ppm of active DCA with the tag was added to a test beaker and the response from the tag was measured over a period of 30 days. The water chemistry used for this study was 500 ppm Ca as CaCO<sub>3</sub>, 400 ppm Mg as CaCO<sub>3</sub>, 150 ppm M-alkalinity as CaCO<sub>3</sub>, 400 ppm SO<sub>4</sub><sup>-2</sup>, 400 ppm Cl, 5 ppm O-PO<sub>4</sub> at a pH of 8.0 and at a temperature of 50 °C. Figure 10 shows the active polymer (measured using the response from the tag) over the 30 days test period.

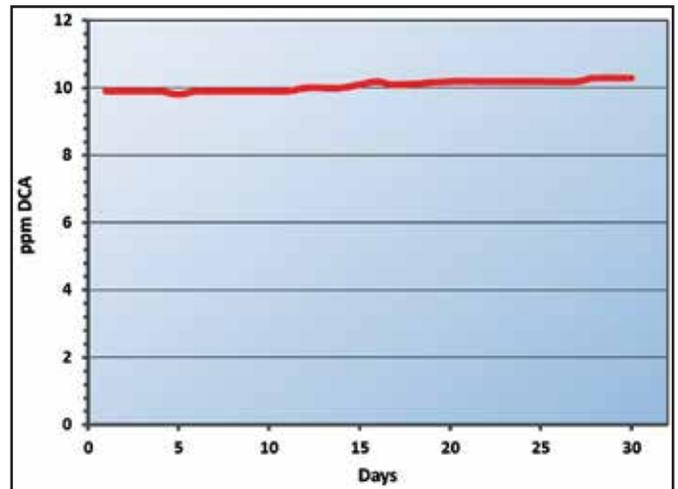


Figure 10: Active DCA (measured using the response from the tag) over 30 days

It is clear from Figure 10 that the tag and the response from the tag exhibits excellent long-term stability. This is especially critical for cooling system applications which have high holding time index.

## pH Stability

Cooling systems typically operate in the pH range of 7.0-9.0. A 10 ppm active tagged DCA was added to a test beaker with the water chemistry 500 ppm Ca as CaCO<sub>3</sub>, 400 ppm Mg as CaCO<sub>3</sub>, 40 ppm M-alkalinity as CaCO<sub>3</sub>, 400 ppm SO<sub>4</sub><sup>-2</sup>, 400 ppm Cl, 5 ppm O-PO<sub>4</sub> at a pH of 7.0 and at a temperature of 50 °C. The water was then titrated with either 1N H<sub>2</sub>SO<sub>4</sub> or 1N NaOH solution to various pH values between 6 and 9, while measuring the response from the tag and DCA concentration at each pH values. Measurements were taken for at least one hour at each pH value. Figure 11 shows the active DCA measured using the response from the tag vs. pH.

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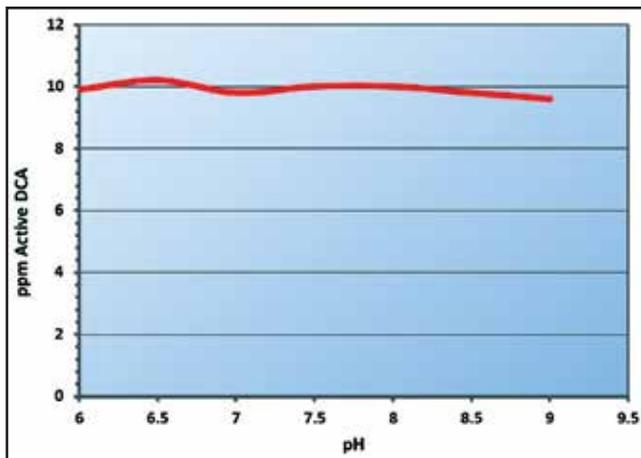


Figure 11: Active DCA (measured using the response from the tag) vs. pH

Figure 11 clearly demonstrates that the tag and the response from the tag is very stable across the normal operating pH range of cooling systems. As expected the response decreased at pH 9 as the system started to become unstable and bulk phase precipitation started to occur. This data is very important, since it is very common to have pH upsets in the cooling systems, either due to poor operational controls, overfeed or underfeed of chemistries, process leaks, etc. This data clearly shows the active DCA levels can be monitored and controlled online to minimize the impacts of pH upsets and thereby protecting the assets from either severe corrosion or scaling.

## Temperature Stability

The cooling system operating temperatures varies considerably depending on the type of industry. Chemical industry (refineries, petrochemical plants, fertilizers, etc) tend to have very high temperature heat exchangers due to high process temperatures. This results in the DCA experiencing high water and metal skin temperatures. High metal skin temperatures also can lead to severe scaling. So it is very essential to accurately measure and control the active DCA under these severe conditions. Figure 10 shows the effect of temperature on the active DCA calculated from the response from the tag. The system was kept at each temperature for about 30 min before measuring the response from the tag.

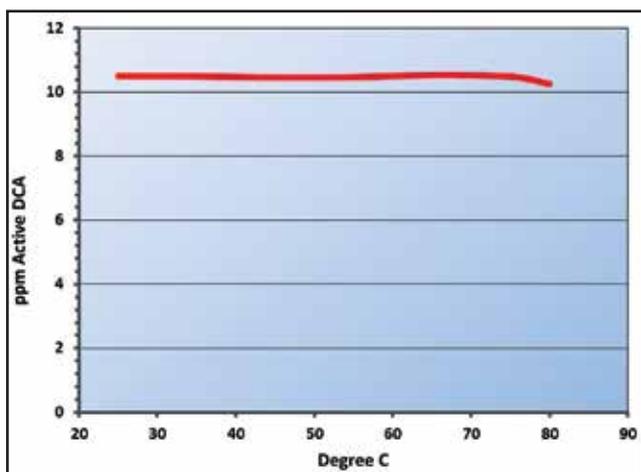


Figure 12: Active DCA (measured using the response from the tag) concentration vs. bulk water temperature

As can be seen from Figure 12, the tag and hence the concentration of the DCA are very stable even at high temperatures. As expected, at temperature close to 80 °C, the DCA response began to decrease as the system chemistry became unstable, resulting in bulk phase precipitation and loss of DCA.

## Oxidizing Biocide Stability

Oxidizing and non-oxidizing biocides are key components of cooling system treatment program. Consequently, any new corrosion or scale inhibitor chemistries that are fed into the system need to be stable to these highly oxidizing chemistries. Though the non-P DCA is very stable to oxidizing biocides, the aim of this study was to determine the effect of these oxidizing chemistries on the tag and the response from the tag. A 10 ppm DCA solution with the tag was made in water with 500 ppm Ca as  $\text{CaCO}_3$ , 400 ppm Mg as  $\text{CaCO}_3$ , 40 ppm M-alkalinity as  $\text{CaCO}_3$ , 400 ppm  $\text{SO}_4^{2-}$ , 400 ppm  $\text{Cl}^-$ , 5 ppm O- $\text{PO}_4$ . The baseline response from the tag was measured before adding the oxidizing biocides. Then various oxidizing biocides were added to this water and the response from the tag was measured after 4 hours and 24 hours. Using the response at the beginning and after the biocide addition, the % reduction in the response was calculated and tabulated below in Table 2.

It is clear from Table 2 that the tag and the response from the tag is very stable to various oxidizing biocide chemistries at both pH 7 and pH 9. Again, this data is very critical for industries which need to carry higher levels of oxidizers or due to process leaks or for Legionella control. 1.5 ppm of free halogen is typically the highest level under extreme conditions.

Oxidizer	% Reduction in the Response			
	pH 7		pH 9	
	4 hr.	24 hr.	4 hr.	24 hr.
Bleach – 1.5 ppm as $\text{Cl}_2$	1.1	2.7	0.8	1.1
HOBt – 1.5 ppm as $\text{Cl}_2$	3.3	5.4	1.9	2.4
Stabilized Bromine – 1.5 ppm as $\text{Cl}_2$	0	0.1	0	0
Chlorine Dioxide – 2 ppm	1.4	1.4	1.5	1.4
Monochloramine – 1.5 ppm	1.4	2.5	0.7	2.8

Table 2: Stability of the tagged DCA in the presence of oxidizing biocides

The stability of the tag towards various non-oxidizing biocides was also measured and found that the tag is very stable to all the commonly used non-oxidizers. For example, 1.5 ppm of active isothiazolone has resulted in 1.6% reduction in the tag response at pH 7 and 1.2% reduction in response at pH 9.

## Effect of $\text{CaCO}_3$ precipitation

One of the key advantages of measuring the active DCA in the system online is to control and maintain the DCA levels in case of system upsets. Apart from various operating factors described above, another key factor is the bulk phase precipitation of  $\text{CaCO}_3$ , which can affect the residual DCA in the system. It is known that, as the mineral solubility exceeds saturation and  $\text{CaCO}_3$  forms in the bulk phase, a part of the active DCA will also precipitate out with the  $\text{CaCO}_3$  scale. This concept was demonstrated in Figure 13. A 7.5 ppm tagged DCA solution was made in the water containing 800 ppm Ca as  $\text{CaCO}_3$ , 400 ppm Mg as  $\text{CaCO}_3$ , 100 ppm M-alkalinity as  $\text{CaCO}_3$ , 400 ppm  $\text{SO}_4^{2-}$ , 400 ppm  $\text{Cl}^-$ , and 100 ppb PTSA (1,3,6,8-pyrenetetrasulfonic acid) at 50 °C. This solution was then titrated with 1N NaOH to increase the pH steadily. While doing this, the response from the tag and active DCA level was measured continuously along with the filtered (F) and unfiltered (UF) calcium concentration (Unfiltered calcium is equivalent to the total calcium concentration in the water). As the pH increases and bulk phase  $\text{CaCO}_3$  precipitation begins to occur (as evident from the increase in split between total and filtered Ca), the active DCA levels starts to decrease as well. This is because the deposit control agents are consumed on the  $\text{CaCO}_3$  precipitate. As calcium carbonate begins to precipitate, the precipitate incorporates some of the calcium carbonate deposit control agent. The online DCA test is extremely important since this test can serve an early warning of  $\text{CaCO}_3$  precipitation and trigger prompt corrective action. This will give the in-

dustries opportunity to safely operate at more alkaline pH, without concern for potential  $\text{CaCO}_3$  scaling. If the active DCA level starts to drop, the response can be relayed to the DCA feed pump and the active DCA can be readjusted to mitigate the scale issues. Measuring the concentration of active DCA is superior to the common alternate control practice based on the addition of a fluorescent tracer dye to the formulation. The drawback with tracer dye concept is illustrated in Figure 13. The inert tracer (1,3,6,8-pyrenetetrasulfonic acid, aka PTSA) response does not change much as  $\text{CaCO}_3$  precipitation is occurring. Hence, if the water treater relies solely on PTSA reading, they will ignore the fact that the active polymer levels in the system are dropping and that deposition may be occurring.

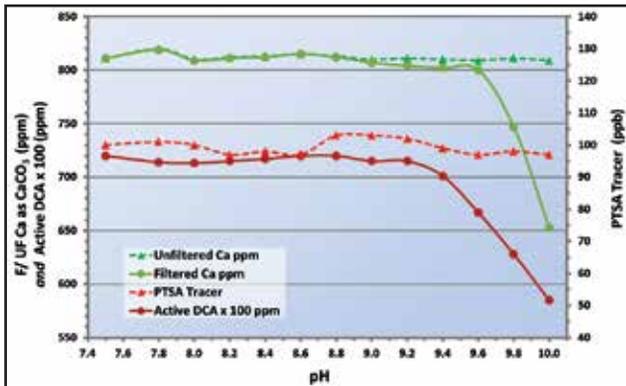


Figure 13: Effect of  $\text{CaCO}_3$  precipitation on the active DCA concentration. 100 ppm PTSA was added to the test solution

To confirm that the drop in active DCA levels in the above test was not just due to pH impact, another experiment was conducted at lower pH with a higher Ca concentration. This water contained 1600 ppm Ca as  $\text{CaCO}_3$ , 1200 ppm Mg as  $\text{CaCO}_3$ , 125 ppm M-alkalinity as  $\text{CaCO}_3$ , 300 ppm  $\text{SO}_4^{2-}$ , 300 ppm Cl-, and 100 ppb PTSA at 55 °C. The results of that study are shown in Figure 14.

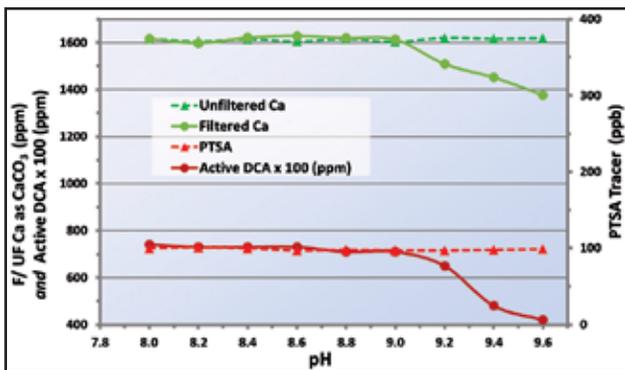


Figure 14: Effect of  $\text{CaCO}_3$  precipitation on the active DCA concentration. 100 ppb PTSA was added to the test solution

The data is similar to what was observed in Figure 13, with the split between filtered and unfiltered phosphate mirroring the split between PTSA tracer and active DCA. However, the drop in active DCA concentration occurred at lower pH, due to the higher calcium concentration in this test condition.

It is also known that not only the bulk phase  $\text{CaCO}_3$ , but the bulk phase  $\text{Ca}_3(\text{PO}_4)_2$  precipitation will also make the DCA to drop out of solution with the precipitate. This was demonstrated in the experiment shown in Figure 15. A 4 ppm active DCA solution containing the new tagged monomer was made in water with 500 ppm Ca as  $\text{CaCO}_3$ , 400 ppm Mg as  $\text{CaCO}_3$ , 100 ppm M-alkalinity as  $\text{CaCO}_3$ , 400 ppm  $\text{SO}_4^{2-}$ , 400 ppm Cl-, 5 ppm  $\text{O-PO}_4$ , 4 ppm PBTC, 100 ppb PTSA, at 50 °C. The phosphonate (PBTC) was added to prevent any possibility of  $\text{CaCO}_3$  scale formation.

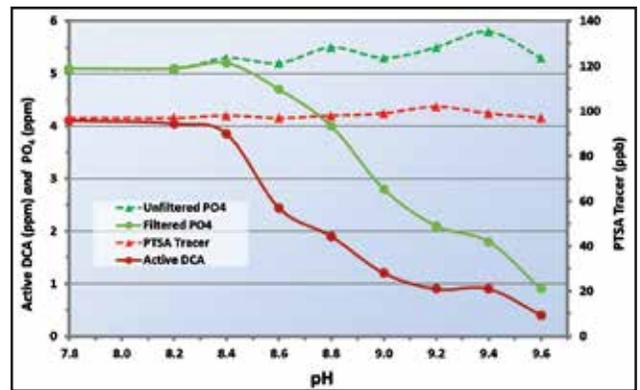


Figure 15: Effect of  $\text{Ca}_3(\text{PO}_4)_2$  precipitation on the active DCA concentration. 100 ppb PTSA was added to the test solution.

The solution was titrated with 1N NaOH to gradually increase the pH while measuring the response from the tag and total and filtered  $\text{PO}_4$  readings. As can be seen from the Figure 15, as the split between total and filtered  $\text{PO}_4$  starts to widen, the active tagged DCA level begins to decrease, indicating the loss of DCA with  $\text{Ca}_3(\text{PO}_4)_2$  formation. This data is extremely important and provides great confidence that the method developed to measure the active DCA levels is accurate and responds to calcium phosphate precipitation in the system as well. This allows the active DCA concentration to be monitored, controlled and adjusted automatically in response to stress in the system.

## Commercial applications

Following the successful laboratory evaluations, advanced controllers utilizing on-line probes that measure the tagged DCA were developed and applied at industrial plant cooling tower systems. The control systems include advanced hardware and software capabilities to measure the DCA levels, document changes and control the treatment chemistries remotely.

Chlorine stability data from one of the field trials is shown below. The free chlorine residual was increased in steps over 3 days from 0.5 ppm to 1 ppm to 1.5 ppm while the active DCA concentration was monitored online. The data collected by the controller in Figure 16 shows that each step increase in free chlorine resulted in a very slight 1.4% decrease in the concentration of both the tagged DCA and a PTSA tracer added to the formulation. This is consistent with the laboratory results reported in Table 2. In each case the controller responded by increasing the product concentration to the established setpoint.

We anticipate presenting additional data from these plant applications at CTI next year. Photographs of the controllers used in some of the industrial plant applications are shown in Figure 17.

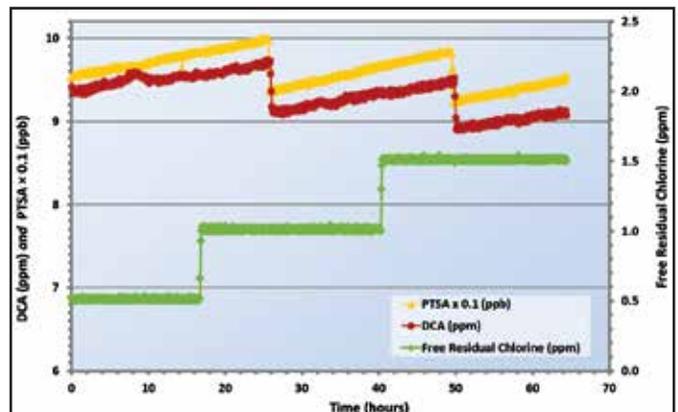


Figure 16: Response of the tagged DCA and PTSA tracer to step changes in free chlorine concentration



Figure 17: Controllers used in plant applications of tagged DCA

## Conclusions.

A tagged deposit control agent (DCA) for calcium carbonate has been developed and evaluated in laboratory and industrial cooling towers. The high-performance, non-phosphorous DCA is able to maintain an LSI of 2.9. The tag is stable across the pH and temperature range used in industrial cooling systems, and is stable in the presence of oxidizing biocides. Solid state sensors and controllers

have been developed to enable the DCA concentration to be accurately monitored and controlled on-line without reagents. Unlike inert fluorescent tracer dyes like PTSA, the tagged DCA responds to increases in system stress, allowing the automation system or a trained operator to make timely adjustments before performance-reducing deposition occurs. Moreover, there is no additional requirement to add a costly inert tracer chemical that contributes nothing to product performance. Alternatively, the tagged DCA can be used as a second product of a multi-product application, allowing the tagged DCA product to be monitored and controlled independently.

## References

- [1] US Code of Federal Regulations, Title 40, Chapter I, Subchapter N, Part 401, §401.5
- [2] US Code of Federal Regulations, Title 40, Chapter I, Subchapter N, Part 423, Appendix A.
- [3] Development of Next Generation Phosphorus-Free Cooling Water Technology. R.M. Post, R.H. Tribble, & J.R. Richardson, International Water Conference, IWC-10-23. Engineers Society of Western Pennsylvania, San Antonio, 2010.
- [4] Development and Application of Phosphorus Free Cooling Water Treatment. R.M. Post, R.P. Kalakodimi, & R.H. Tribble, CTI Journal Vol. 35, No. 2, pp. 52-67, 2014.

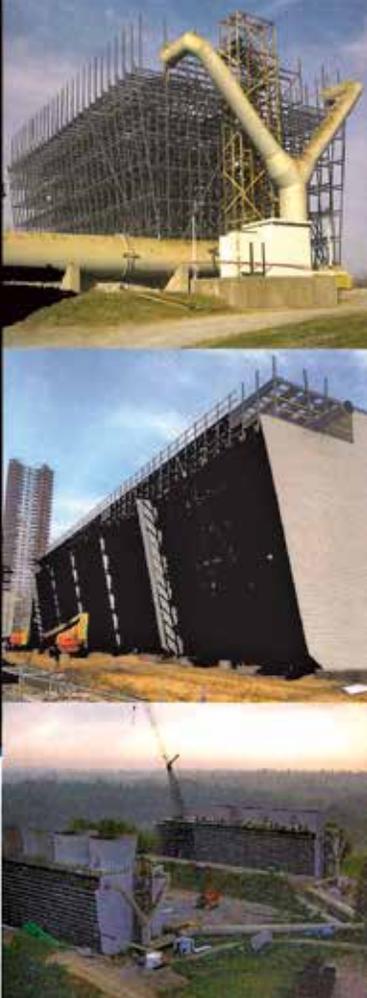


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INDUSTRIAL AIR MOVING EQUIPMENT

# A Structural Inspection And Condition Assessment Methodology For Concrete Cooling Towers

Mark E. Williams, Ph.D., P.E. & Narendra Gosain,  
Ph.D., P.E.  
Walter P. Moore And Associates, Inc.

## Abstract

Concrete cooling towers experience various levels of concrete deterioration due to exposure to atmospheric conditions, cooling water chemistry, and various methods used to extend their service life. Despite being a critical asset, many cooling tower structures are inspected on an ad-hoc basis after problem conditions are discovered, often leading to more extensive repair conditions. This paper defines a standardized process and procedures for conducting inspections and condition assessments of concrete cooling towers. Inspection procedure recommendations are provided to aid a qualified team leader in carrying out the planning, observation, classification, and documentation of the physical condition of concrete cooling towers. Condition assessment procedures are then discussed to determine the need and priority of maintenance, repair, or rehabilitation actions based on information obtained from the structural inspection. The intent is to provide a systematic and proactive program for managing and maintaining cooling tower assets.

## Introduction

Throughout their service life, cooling tower structures are exposed to harsh conditions due to moisture and environmental extremes which vary from extremely hot and arid conditions to very cold and sub-freezing temperatures. Coupled with such extremes may also be locations which are subject to hurricane speed high winds and intense seismic forces. In many instances, cooling towers are located in coastal regions or adjacent to large bodies of water that increase the risk of exposure to high humidity and harmful chlorides. This is regardless of whether the cooling towers are used in industries like power plants, petro-chemical complexes, and manufacturing facilities or commercial structures like high rise buildings, medical facilities, universities or other campus like enterprises. Unplanned shut down of the operations of cooling towers either due to sudden mechanical or electrical failures or structural distress can lead to huge economic loss and in some situations even exposure to possible lawsuits. It stands to reason that proactive maintenance based on scheduled structural inspections will be far more economical with planned shutdowns rather than resorting to reactive repairs due to deferred maintenance or no knowledge of the condition of the structure over a period of time. An article by Gosain published in 2008 highlights the high cost associated with low maintenance (Reference 1). In 2015, Gosain and Drexler published a paper on issues pertaining to deferred maintenance of cooling towers (Reference 2).

Generally, the designers and manufacturers are very particular about providing operating and maintenance manuals for mechanical and



Mark E. Williams

electrical components of the cooling towers. Regrettably, the structural frame and other structural elements that are essential to support the various other components are ignored. These are literally left to the owners or operators of the cooling towers to come up with a plan to inspect and maintain the integrity of the structure. This requires planning and budgeting some of the resources for such activities and then following up on the plan. In order to avoid seeing this activity disappear in a black hole, the mantra needs to be “Plan the Work and Work the Plan”. Of course there will be pressures to defer this for later due to inadequate staff to manage such task,

disruption of operations not acceptable or lack of understanding of consequences of not carrying through with the plan. It can also be due to confusion or ignorance of how inspections and condition assessments of their cooling towers should be conducted. Indeed, one can resort to industry standards or get professional help.

Keeping the needs of the industry in view, Cooling Technology Institute has published a Cooling Technology Manual. Chapter 13 in this manual covers the topic on Inspection of Cooling Towers (Reference 3). Article 6 of this Chapter 13 is on Inspection of Reinforced Concrete Members of Cooling Towers. The introductory statement in this article reads “The structural condition assessment of concrete cooling towers is essential to identify conditions that represent safety and process concerns, determine root cause of the deterioration/damage and develop repair/protection recommendations.” This section of the manual then proceeds with a brief discussion on field investigative approach with some basic description of non-destructive evaluation (NDE) techniques which are sometimes also referred to as NDT (non-destructive testing). Other useful laboratory testing to determine chloride contamination in existing concrete is described as well as petrographic examination to determine the overall quality of concrete and to determine other distress causes. Suggestion is also made to quantify the distress such that estimates of repair and protective measures can be undertaken. Prioritization of the corrective work can then be done within the budgetary constraints and the scheduled outages on operation of the cooling towers.

The above is a very rudimentary approach to protect and prolong the life of cooling towers. Given the fact that concrete cooling towers have been around for over a century, it is certainly worthwhile to have an uptick in our thinking on how to perform structural inspections and condition assessment of concrete cooling towers. As a reference, there are other structures that are exposed to very aggressive environment and extremes of temperature. Williams and Gosain in their 2019 paper on life cycle cost analysis (Reference 4) drew parallels between bridges and cooling tower structures. Significant resources were expended by the federal government to devel-

op life-cycle cost analysis for improvement of the nation's bridges which are easily adapted to cooling towers. Likewise, with the funds provided by several public agencies, American Association of State Highway and Transportation Officials (AASHTO) developed a guide for commonly recognized structural elements of bridges in 1998 (Reference 5). This subsequently led to the development of AASHTO manual of bridge inspection (Reference 6). AASHTO had recognized that in order to have a meaningful understanding of the structural state of bridges, the various structural elements needed to be carefully assessed.

The bridge custodians have recognized the importance of detailed assessments, deterioration forecasting and benefits of element level inspection protocols that are referenced in the above two AASHTO documents. It is not surprising that the same concept has also been picked up for maritime facilities inspection where docks and wharves are constantly being battered by corrosive seawater. Port of Houston Authority has recently published a manual that describes the elemental approach to inspections (Reference 7). A similar approach for concrete cooling towers is also doable and will be discussed herein.

## Distress Conditions

The axiom that all concrete cracks is not necessarily true. It is however a common belief. Several techniques are available which can minimize cracking or even eliminate cracking in concrete. However, this topic is beyond the scope of this paper.

What is true that the majority of the distress conditions in concrete emanate from concrete cracking. Thus, a very brief narrative on this issue is discussed below.

Cracks in concrete occur whenever the tensile stress of concrete is exceeded (Figure 1). This could be due to external forces caused by gravity loads or lateral forces due to wind and earthquakes. Foundation movement issues also lead to cracking in the superstructure. Tensile stresses in concrete can also be exceeded due to internal factors such as thermal movements, moisture changes, and chemical reactions often related to alkali silica reaction and sulfate attack. Poorly designed concrete mixes can have extensive cracking due to exposure to freeze-thaw conditions also. Use of high water/cement ratio has the potential of causing shrinkage cracks and low durability.

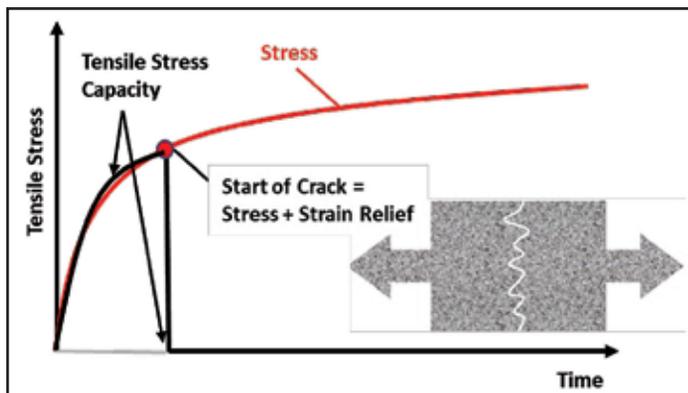


Figure 1: Cracking of Concrete Elements (Courtesy of Fred Goodwin, Fellow Scientist, BASF Construction Chemicals, PowerPoint Presentation, International Concrete Repair Institute, Tempe, Arizona 2009)

Regardless of the many factors that lead to cracking of concrete, once cracking starts, a path is opened up for moisture infiltration into the concrete. If and when the cracks penetrate to the location where the reinforcing bars are located, the water helps chlorides attack the reinforcing steel bars and corrosion activity begins (Figure 2). Since steel is not a thermodynamically stable material, it has a tendency to revert back to its natural iron ore condition. Simply stated, this process is called corrosion.

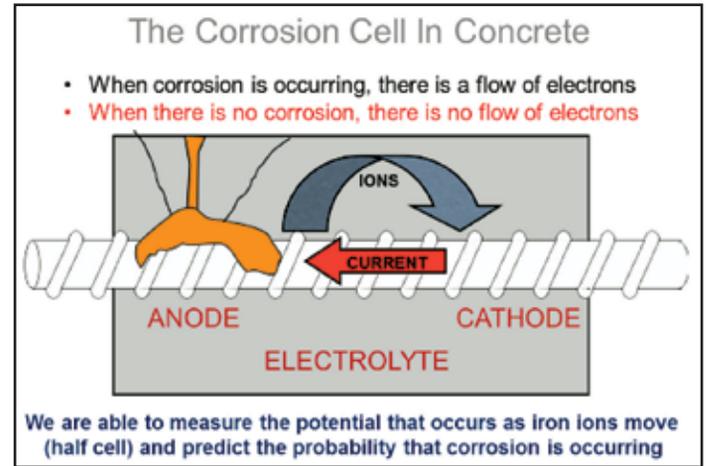


Figure 2: Initiation of Rust due to Corrosion

The products of corrosion activity have a much larger volume than the original steel element as shown in Figure 3. The end product, rust, has the potential of volumetric expansion of 6 to 7 times that of the original steel section. This volumetric expansion creates high tensile stresses within the concrete that results in cracking of the concrete as shown in Figure 4. Pieces of concrete bounded by cracks eventually loosen up from the parent concrete mass as spalls and fall off (Figures 5 and 6). When corrosion activity is not stopped by remediation, spalls continue to propagate along the length of the reinforcing bars resulting in delamination of concrete and exposure of corroded bars (Figure 7). Remediation of such a situation can be very costly for the facility owners and operators.

Looking at the advanced condition of distress in a concrete cooling tower shown in Figure 7, it does make sense that a proactive approach to early detection and remediation would be far more economical. This is certainly possible by setting up a program of structural inspections and assessment followed by targeted remediation program as discussed below.



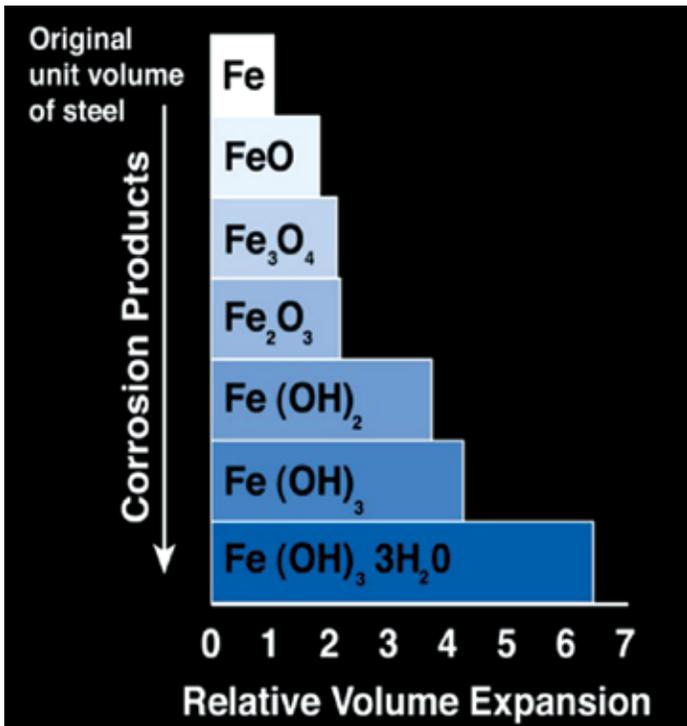


Figure 3: Volumetric Expansion of Corroded Steel

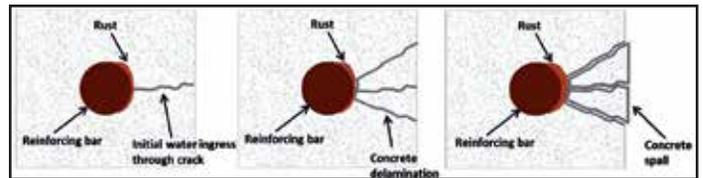


Figure 5: Spalling of Concrete Illustration



Figure 6: Spalled Concrete in Cooling Tower



Figure 4: Cracking of Concrete due to Corrosion



7: Cooling Tower Shell - Extensive Spalling Caused Delamination of Concrete with Exposed Corroded Reinforcing Bars

## Types Of Cooling Tower Structural Inspections

Highway bridges and cooling towers are subject to similar environmental exposure conditions. Accordingly, their deterioration mechanisms are similar and similar methods can be employed to evaluate both types of structures. The Federal Highway Administration (FHWA) has well established criteria for bridge inspections. This could be used as the basis for cooling tower inspections. There are five basic types of structural inspections that can be deployed for cooling towers--initial, routine, in-depth, damage, and special.

### Initial Inspection

The first inspection to be completed should be an "initial" inspection. The purpose of this inspection is to provide all the struc-

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ture inventory and conditional appraisal information, to establish baseline structural conditions, and to identify and list any existing problems or any locations in the structure that may have potential problems.

## Routine Inspection

The “routine” inspection is the most common type of inspection performed. While there is no standard interval for these inspections, a two-year inspection cycle is common. The purpose of “routine” inspections is to determine the physical and functional condition of a cooling tower on a regularly scheduled basis.

## In-Depth Inspection

An “in-depth” inspection is a close-up, hands-on inspection of one or more members outside and/or inside the cooling tower to identify potential deficiencies not readily detectable using routine inspection procedures. This type of inspection is typically performed during a scheduled outage. Additional structural analysis may be performed to further evaluate in-place conditions.

## Damage Inspection

A “damage” inspection is an emergency inspection conducted to assess structural damage immediately following a localized failure or resulting from unanticipated environmental factors.

## Special Inspection

Finally, a “special” inspection is used to monitor, on a regular basis, a known or suspected deficiency. This type of inspection could be integrated with a structural health monitoring program (Reference 8).

## Element-Based Inspection

### Cooling Tower Element Types

CTI Chapter 13 provides a list of structural elements described in the matrix of Figure 13.1 (Reference 3) as given below:

1. Fan Deck
2. Eliminators
3. Fill Supports
4. Partitions
5. Siding
6. Louvers
7. Stairways
8. Access Ladders

It is to be noted that the items listed above can have various components. As an example, a precast concrete fan deck can have a topping slab, precast concrete panels, a shroud curb and a fan shroud. A partial Figure 13.1 from Reference 3 is given in Appendix 1. As can be seen, this document also provides periodicity of inspections such as annual (A) or semi-annual (S). However, the manner in which the inspections are made and documentation of the assessment is left to the inspector’s preference. For a single owner or corporation with multiple cooling towers whether in the same facility or other geographic locations, this may cause confusion when several inspectors are involved that may not be working with the same standardized basis of inspection and documentation. Confusion may also arise when an attempt is made to compare the condition of similar cooling towers within diverse ownerships. Thus it may be worthwhile

for the cooling tower industry to consider a standardized approach that is similar to bridges (Reference 6).

## Element Condition

As adapted from Reference 6, the collection of data for the various elements in a concrete cooling tower inspection and condition assessment program can be broken down as follows:

1. Description: Provide functionality of the element and describe whether it’s a primary or a secondary member.
2. Quantity Calculation: The documentation of the element inspected should be in linear, area, or volume dimensions. Quantities of cracks to be repaired are generally stated in linear feet. Spalls can be measured by surface area when approximate depths of spalls are reasonably known or by volume of concrete to be replaced by repair material. Measurement of delaminations are done similar to spalls. The extent of replacement of corroded reinforcing bars that need to be replaced by new bars are measured in diameter and linear feet.
3. Condition State of the Element: Describe whether element is cracked, spalled, or delaminated or whether there are any signs of efflorescence. Where possible, determine whether distress is related to corrosion or defective design or construction issues. Four condition states for concrete elements in cooling towers are suggested as adapted from Reference 6. See Table 1 below which is generic in layout. It could apply to the various structural elements of a cooling tower.
4. Element Defect Severity Guide: Guidelines to the inspector for defect severity categorization to minimize subjective nature of assessment. See Table 2.
5. Possible Corrective Options: The actions cooling tower owner can take to correct the defect.
6. Element Commentary: This section allows the inspector to provide information about the accessibility of the element inspected and what special precautions were taken if in a confined space. It also allows the inspector to comment on whether the entire element was looked at or some interpretations or extrapolations made from sections of elements viewed (Table 1).

Each of these levels of deterioration in Table 1 is called a condition state. When a cooling tower is inspected, the total quantity of each element is allocated among the condition states based on the visual observations of the inspector. As an example, if the inspector determines that 80% of the fan deck precast planks have no visible issues, then that value will be included in Condition State 1. If in the remaining segment of the fan deck precast planks, there are moderate amount of spalls with very few cracks, then a 20% value needs to be inserted in Condition State 2.

Note that cracking described in Table 1 as “hairline”, “narrow” and “medium” size or the spalls described as “moderate” and “severe” may have a different meaning to different inspectors and owners. Similarly, the intensity of cracking described as “low intensity” or “high intensity” really do not have any quantitative value. It is thus worthwhile to quantify these descriptors. Table 2 adapted from Reference 6 defines these descriptors.

Condition state data gathered from the inspection of the various cooling tower components can be systematically recorded in tabular format. A sample table is shown in Table 3.

Defects	Condition State 1		Condition State 2		Condition State 3		Condition State 4
	Description	Cause	Description	Cause	Description	Cause	
Cracks	None to hairline, isolated cracks	UN	Narrow size, low intensity of cracking	UN	Medium size, high intensity of cracking	CO	Beyond Condition State 3. Warrants detailed structural review to determine strength and serviceability of cooling tower. May require field detailed non-destructive evaluation and partial destructive laboratory testing
Spalls, Delaminations	None	UN	Moderate	UN	Severe spalls	CO	
Efflorescence	None	UN	Moderate without rust	UN	Severe with rust stains	CO	
Load Capacity	No reduction	UN	No reduction	UN	Possible reduction	DE	
UN: Unknown    CO: Corrosion    DE: Design							
Element Commentary							

Cracking	Hairline	Narrow	Medium
	< 0.016"	0.016" – 0.031"	0.031" – 0.062"
Cracking Intensity	Isolated Cracks	Low Intensity	High Intensity
	Spaced > 3.0'	Spaced 1.0' – 3.0'	Spaced < 1.0'
Spalls	None	Moderate	Severe
	Not applicable	< 1" deep or < 6" diameter	> 1" deep or > 6" diameter
Delaminations	None	Moderate	Severe
	Not applicable	No exposed rebar	Some exposed rebars
Efflorescence	None	Moderate	Severe
	Not applicable	White residue but no leaching	Intense leaching with rust stains

## Crack Width Measurement

Crack widths can be conveniently and rapidly measured by the inspectors using Crack Comparator cards that are available commercially. A crack comparator used by the authors is given in Figure 8 below. Crack widths can be measured in fraction of an inch or in millimeters.

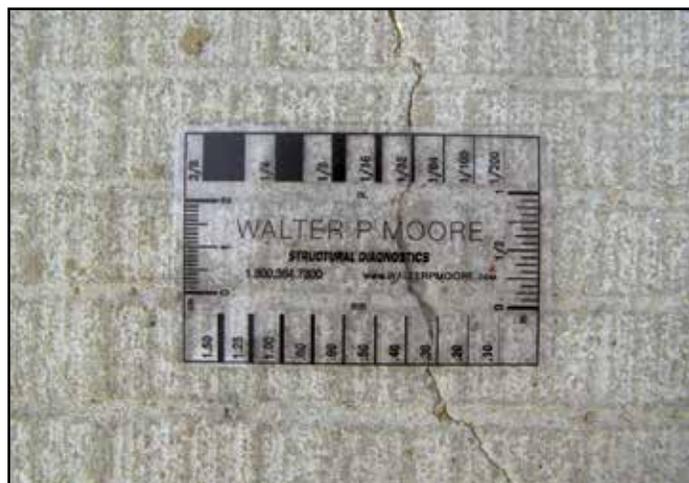


Figure 8: Crack Comparator for Measuring Crack Widths

	Concrete				Anchorage			Waterproofing			Condition State Per Element [1 to 4]		
	Cracks	Spalls	Delamination	Corroded Reinforcement	Efflorescence	Corrosion	Bearing Deterioration	Bearing Pad Movement	Anchor Deterioration	Missing Sealants		Sealant Deterioration	Coating Deterioration
<b>1) Casing</b>													
a) Louvers													
b) Corbels													
c) Fill supports													
d) Frames													
<b>2) Hot Deck</b>													
a) Exterior ring wall/beam													
b) Deck planks													
c) Interior ring wall/beam													
d) Fill box / flume													
<b>3) Fan Deck</b>													
a) Roof precast tees													
b) Fan shrouds													
<b>4) Interior</b>													
a) Roof beams													
b) Columns													
c) Interior basin													
d) Drift eliminator supports													
<b>5) Basin</b>													
a) Concrete wall													

## Condition Assessment Approach Reasons for Condition Assessment

Condition assessment is a systematic collection of information and data of a structure as a whole and/or parts and portions of the structure such as slabs, beams, columns and foundations. The assessment may be done as a routine inspection for maintenance related purpose or after an extreme event such as a tornado, hurricane, blast, earthquake, fire, flood or blizzard.

The condition state data collected during the assessment on a routine basis provide a direct indication of physical performance, which can be used for costing and budgeting decisions. Also, for systematically collected data on a routine basis, the effects of treatment and corrective actions can be tracked over time because of the consistency and uniformity of the condition assessment data. However, element-level condition data need further evaluation in order to be suitable for other types of management decisions. Examples of these potential applications include:

- Development, evaluation and testing of new repair or maintenance techniques
- Corrective action options with possible consideration of life-cycle cost analysis
- Project priority setting and scheduling during upcoming or future planned shut-downs
- Budgeting
- Funding allocation
- Long-range planning

## Qualifications

The inspection and condition assessment of existing concrete cooling tower structures requires specialized knowledge and experience to ensure that the results of the evaluation are objective and repeatable, and provide the information necessary for the intended asset management purposes. The inspection and condition assessment of cooling towers introduces additional complexities in terms of unique or customized structural types that range from roof top for commercial facilities to large multi-cell towers in industrial facilities to mammoth hyperbolic cooling towers in power plants. The environmental exposure conditions and often the need for inspection while the towers are operational pose some challenges. Inspection of such facilities typically requires knowledge and experience different from that required for the evaluation of existing building structures.

CTI Chapter 13 (Reference 3) states that “condition assessments should be conducted by structural engineers who specialize in forensic evaluation of structures and have an understanding of process occurring within cooling towers, especially since oftentimes the process becomes the driver for the deterioration and damage”. Thus the inspection and condition assessment of concrete cooling towers should be carried out by a team with the appropriate specialized knowledge and experience, including:

- Evaluation and repair knowledge specific to cooling towers
- Design requirements specific to concrete cooling towers, both current and at the time of construction
- Understanding of structural behavior and analytical techniques
- Ability to recognize serviceability, stability and imminent failure condition of the structure or structural elements
- Use of nondestructive testing techniques
- Use of partially destructive material sampling and laboratory testing for strength and petrographic testing
- Damage modeling and its impact on structural performance and integrity. In the case of hyperbolic cooling towers, finite element modeling analytical techniques are very helpful. Under certain cooling tower situations, it will be worthwhile for the team to have experience in non-linear analytical techniques as well.
- Corrosion modeling
- Concrete durability and life-cycle cost analysis for critical review of various repair options
- Site documentation and reporting techniques
- Preparation of clear and concise construction documents to get competitive repair and restoration bids when needed

As a point of reference, CTI document ESG-123 (Reference 9) has aptly indicated that services of a “registered design professional” are needed in the various steps involved in a repair project. In particular, when safety is an issue, the document states “Structural Safety. Before starting repair projects involving the removal of existing concrete, the effect of the removal on the structural integrity should be reviewed and approved by the registered design professional prior to commencing concrete removal activities”.

## Structural Assessment Process

A general guideline for assessment of buildings is given in SEI/ASCE 11-99 (Reference 10). Cooling towers obviously do not fit this category but general principles are similar. The authors are not aware of any document that describes in detail the process for assessment of cooling towers other than CTI Chapter 13 (Reference 3). SEI/ASCE 11-99 recommends that the condition assessment be done in two phases:

Phase 1: Preliminary Assessment - This generally consists of detailed discussion with the facility owner and their maintenance staff pertaining to past history of issues and previous repairs, document review and visual walk-through with photo-documentation but no analytical work. This assessment is to note visual signs of distress and visually gauge structural adequacy followed by an estimate of opinion of probable cost and an engineering report. The report would then provide recommendation of more detailed assessment that would be included in Phase 2.

Document review becomes an important part in this phase where the following documents, if available are reviewed:

- Record drawings
- Specifications and project manual
- Geotechnical report
- Shop drawings
- Reports of material testing during construction
- Previous engineering reports, if any
- Maintenance history

Phase 2: Detailed Assessment – This would generally be desired when Condition State 4 is noted as described in the aforementioned Table 1. This will lead to an enhancement of reliability by conducting an in-depth structural analysis and conducting additional confirmatory non-destructive evaluation (NDE) and incising cores for partial destructive testing for concrete strength and petrographic analysis. Taking these additional steps will also provide a better opinion of probable cost that could be put together in a report for management review and budgeting purposes.

The third party engineering report should describe problems discovered, tests performed, condition state of facility, list if items not reviewed, opinion of probable construction cost and disclaimers. However, there is a word of caution about opinion of probable construction cost. This costing should preferably be done by professional cost consultants in collaboration with or by contractors well versed in such repairs. Accessibility of the cooling tower for repairs and the time required for completing the repairs can be significant cost items.

In general, if third party engineers are retained to do the assessment for a pre-agreed scope of work, the report has to be carefully crafted so that the only the agreed on scope is covered.

## Remedial Measures

Once the inspection is done and the facility owner has the documentation of the state of the various conditions of the cooling tower, a decision needs to be made as to what corrective actions should be taken. This is usually done on the basis of available funds, availability of personnel to manage the project, the value the asset



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to the owner, the consequence of not proceeding with the needed corrective action and the various other maintenance issues that need to be executed during the scheduled shut-down period. Of course, the owner always has the option to take no action and defer the corrective work to a future undefined date. In general, the various corrective options are given in Table 4 which is adapted from Reference 6.

Condition State	Corrective Options				
	Do Nothing	Protect	Repair	Rehabilitation	Replace
1	X	X	X		
2	X	X	X	X	
3	X	X	X	X	
4	X	X			X

It is well established that a structural design of any structure or element has to be designed keeping in view the strength and serviceability. Strength is to ensure that the structure has the ability to support or resist the various imposed loads that include gravity and lateral loads. Serviceability is a limit state that renders the structure or structural element useful or serviceable for which it was designed. Serviceability includes deflections, vibrations, cracking and durability. A structure that has strength may sometimes lack serviceability. Thus in many instances when certain elements of the concrete cooling tower develop serviceability issues such as cracking, spalling and even corrosion of reinforcing bars, the unit continues to function. As an example, the cooling tower shown in Figure 7 continued to function in spite of severe serviceability issues which required multi-million dollar restoration effort at a certain point of time.

As it has been suggested for bridges (References 5 and 6), cooling towers can also have a similar single scale that reflects the most common processes of deterioration and the effect of deterioration on serviceability. In general, the scale of deterioration is as follows:

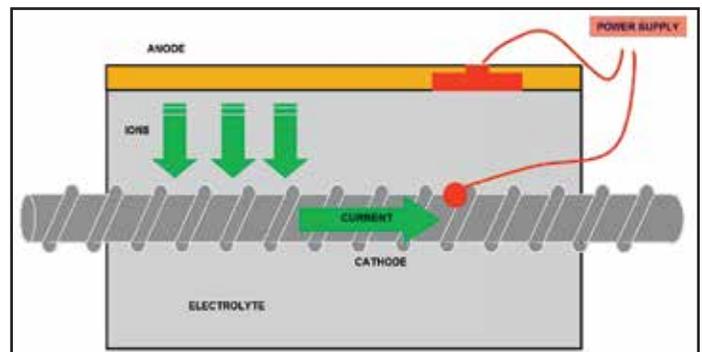
1. Protected: The elements have protective materials or systems that have protective coatings, anodic sacrificial zinc elements or impressed current cathodic protection that are sound and functioning as intended to prevent deterioration of the element.
2. Exposed: The protective materials or systems such as protective coatings or cathodic protection have partially or completely failed leaving the element vulnerable to deterioration resulting in cracks and spalls.
3. Attacked: The element is experiencing active attack by environmental factors initiating corrosion, but is not yet distressed to cause serviceability issues and impair strength.
4. Damaged: The element has lost significant amounts of concrete and reinforcing bar section loss, such that its serviceability is impaired.
5. Failed: The element no longer has the strength and serviceability as originally designed. It requires structural analysis and possible rehabilitation.

### Supplemental Protective Measures

Many different strategies are available to protect reinforced concrete structures from chloride penetration that initiate corrosion of

reinforcing bars and other embedded metal objects while the cooling tower is in service. These include migrating corrosion inhibitors, electrochemical chloride removal, protective coatings or sealers, sacrificial cathodic protection, and impressed current cathodic protection. The method of protection will depend on the type of structure, existing conditions, and exposure of the structure, among other criteria. Impressed current cathodic protection (ICCP) is one of the most effective methods of corrosion mitigation and has been used effectively in the protection of the veil of some power plant hyperbolic cooling towers that had severe corrosion issues. In brief, ICCP consists of installing an inert material on the surface of the concrete and inducing a current through it. Figure 9 (Reference 11) illustrates the corrosion cell that incorporates an impressed current protection system to protect the embedded reinforcing steel. A detailed description of the use of ICCP approach used in a hyperbolic cooling tower is given in Reference 11.

Other strategies using externally bonded carbon fiber reinforced polymer (CFRP) wrap materials have been used extensively in restoration and upgrade of concrete structures. American Concrete Institute document ACI 440.2R (Reference 12) is available for recommendation in engineering and construction using CFRP. The authors are unaware of any published papers on using CFRP in cooling towers. Regardless, details of such techniques and other methods are outside the scope of this paper.



**Figure 9: Schematic of Impressed Current Cathodic Protection on Reinforced Concrete (From Reference 11)**

### Conclusions

A standardized structural inspection and condition assessment enables cooling tower owners to develop comprehensive, logically consistent frameworks for management decision support and communication of tower inventory performance. The principles discussed herein for concrete cooling towers can be applied to different types of cooling towers and similar assets, providing a rational foundation to advance the state of the art in cooling tower maintenance management. This is also a step forward to move away from a subjective reporting of issues to a more objective reporting.

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## Appendix 1

Partial View of Figure 13.1 from CTI Chapter 13 (Reference 3)  
(With permission from CTI): [www.cti.org](http://www.cti.org)

CTI INSPECTION SCHEDULE																									
Components	Trip Clearance	Blade Tracking	Noise	Vibration	Erosion	Corrosion	Vent	Hardware Condition	Repaint	Seals	Oil Level	Moisture/Sludge In Oil	Change Oil	Guard	Plugging	Gear Backlash	Gear Tooth Pattern	Covers in Place	Amp Load	End Bell	Water Levels	Nozzles	Deterioration	Sag	
<b>Mechanical</b>																									
Fan Blades - Cast (C), Plastic (P), Hollow (H)	S	A	D	D	A	A	(H)	A	S																
Fan Hub						A			R																
Hub Cover					A		S	R																	
Gear Reducer			D		A	M	A	R	A	D	M	S			A	A									
Driveshaft			D	D	A	A		A	R				S												
Unitized Support						A		A	R																
Fan Stack				D	A	A		A															A		
<b>Electrical</b>																									
Motor			D	D		A		A	R										S	A					
Receptacles						A													S						
Lights						A			R																
Push Button Sta						A					S														
Conduit						A			R																
<b>Structure*</b>																									
Structure Members					A	A		A															A	A	
Fan Deck						A																	A	A	
Eliminators					A	A									S								A	A	
Fill					A	A									S								A	A	
Fill Supports					A	A		A															A	A	
Partitions					A	A																	A		
Siding					A	A		A															A		
Louvers					A	A		A															A	A	
Stairways						A		A															A		
Access Ladders						A		A															A		
<b>Water</b>																									
Cold Water Basin																					D				
Hot Water Distribution Counterflow								A							A							A			
Hot Water Distribution Crossflow															D			S			D	D		A	
Lightning Protection																									
Fire Protection									R																

**Material Types**

\*W - Wood

\*M - Metal

\*P - Plastic, Cement Fiber Board, etc

\*FRP\* Fiber Reinforced Plastic

\*C\* Concrete

**Inspection Intervals**

D - Daily

M - Monthly

S - Semi-Annual

A - Annual

R - As Required

# Non-Phosphorus Water Treatment Program Enhances Heat Exchanger Performance

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Baker Hughes Company

## Abstract

Scale formation and deposition are fundamental problems in cooling water systems. Scale interferes with heat transfer by forming an insulating barrier on heat exchange surfaces. Scale also promotes localized corrosion and restricts water flow. Consequently, scale formation and deposition may result to huge economic losses due to their impact on heat exchanger operations, mitigation measures and unscheduled equipment shutdown.

One of the most prevalent scale in industrial water systems is calcium phosphate that is formed from calcium hardness and from orthophosphate. Recently, the problem of calcium phosphate scaling in industrial water system has become increasingly important. Higher orthophosphate levels are being encountered in cooling water systems due to increased water reuse, use of low quality make-up water such as wastewater treatment plant effluents and the use of organic phosphonate scale and corrosion inhibitors that are degraded to orthophosphate. The increased orthophosphate levels, combined with alkaline operating conditions and higher surface temperature can lead to the formation of highly insoluble calcium phosphate scale deposits.

This paper discusses the use of a non-phosphorous corrosion inhibitor program in alkaline conditions. Eliminating one of the sources of phosphate allows for better performance of heat exchanger tubes as evidenced by lower approach temperatures. In addition, utilizing a non-phosphorous corrosion treatment program extended the exchangers' cycle on turnaround even for heat exchangers that are ran with lower water velocity.

## Background

Fouling of heat exchangers may reduce heat transfer efficiencies and may result to huge energy losses. The buildup of fouling can increase the resistance of the fluid passing over the surface amplifying the pressure drop across the heat exchanger and thereby reducing the flow rates. Furthermore, depending on the type of fouling deposits, corrosion of the surface may occur shortening the life of the heat exchanger. To resume to the desired operating conditions, fouling deposits should be removed from the surface.

Among the most common deposits include calcium carbonate, calcium sulfate, calcium phosphate, magnesium silicate, and silica. In industrial heat transfer operations, significant fouling can occur because of deposition of calcium phosphate salts. Possible sources of phosphate in recirculating cooling water systems are low quality make-up water, reversion of phosphonates scale inhibitors, and the use of phosphate-based corrosion inhibitors.

Orthophosphate is the primary corrosion inhibitor for cooling water treatment programs. To control the possible formation of calcium phosphate deposits, the application of inorganic phosphates for steel corrosion control requires the use of polymeric disper-



Mary Jane Felipe

sants. For systems that have high scaling potential, i.e. high hardness water, orthophosphate is being used with a combination of lower pH and higher levels of polymeric dispersants. Such water systems require a good control of phosphate residual to minimize the need for higher amounts of dispersants.

The rising global demand for water and increasing water scarcity have been driving the use of reclaimed water as make-up for recirculating cooling systems. Oftentimes reclaimed water contains high level of minerals that greatly impacts scaling and corrosion tendencies. As the water evaporates, the corrosive and scale forming minerals concentrate in the recirculating cooling system. As the process continues, the water becomes more corrosive and exceeds the solubility

of the dissolved minerals resulting in the precipitation of mineral salts. To alleviate the mineral salt precipitation and severe corrosion, the cycles of concentration (COC) are typically limited when using reclaimed or reuse water.

To mitigate calcium phosphate scaling, this paper discusses the use of non-phosphorous based corrosion inhibitor water treatment program. This mitigation process not only proves to inhibit corrosion effectively but removing the orthophosphate source has increased the heat exchanger performance at various conditions.

## Experimental

Corrosion inhibition studies were performed using a simulated Title 22 water (Table 1). Performance tests on corrosion inhibition were carried out using Linear Polarization Resistance (LPR) monitoring, Dynamic Scale Test Unit (STU) attached to a corrator tips and an in-house built pilot cooling tower. Further, the fouling tendencies were evaluated using a deposition accumulation test system (DATS) fouling monitor in a pilot cooling tower test unit.

Composition	Makeup Water	Cooling Water	
		4 cycles	5 cycles
Chlorides, ppm	350	1400	1750
Nitrate (as N), ppm	41	164	205
Sulfates, ppm	160	640	800
Iron, ppm	0.51	2.05	2.56
Potassium, ppm	23	91	114
Calcium, ppm	58	234	292
Magnesium	28	114	142
Total Alkalinity, ppm as CaCO <sub>3</sub>	92	368	460
Bicarbonate, ppm as CaCO <sub>3</sub>	92	368	460
Total Hardness, ppm as CaCO <sub>3</sub>	260	1040	1300
Silica, ppm as SiO <sub>2</sub>	13.6	54	68
Total Phosphorous, ppm	0.12	0.5	0.6
Total Phosphate	0.37	1.5	1.85
Conductance	1900	6500	7500

Table 1. Water make-up and cooling water composition at 4 cycles and 5 cycles used in screening.

LPR is an electrochemical method of measuring general corrosion by monitoring the relationship between the electrochemical potential and the current. This technique measures corrosion inhibition efficacy by monitoring the corrosion rate. The lower the corrosion rate, the better is the performance of the corrosion inhibitor. Cor-

rosion inhibition was evaluated by sweeping the voltage from -0.02 V to 0.02 V at a scan rate of 0.50 mV/s.

Dynamic laboratory testing was performed to assess corrosion inhibition and scale inhibition in an in-house STU apparatus (Fig. 1b) for 5 days using a carbon steel coupon at 79 °C (175 °F). For the treated water, a 16-L tank treated with the non-phosphorous corrosion inhibitor was circulated for 1 day. Following the initial corrosion inhibitor treatment, 0.5 ppm as FRC (free residual chlorine) oxidizing biocide was maintained in the system for the final 3 to 4 days. The simulated cooling water also contains 2.0 ppm Fe.

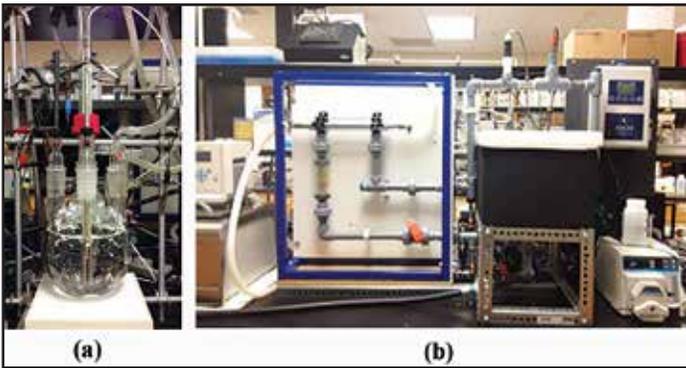


Fig. 1: Experimental set-up used to assess the non-phosphorous corrosion inhibitor (a) 3-electrode corrosion test and (b) Dynamic Scale Test Unit (STU).

To assess fouling tendencies, a non-phosphorous based water treatment program versus a phosphate water treatment program was run on an in-house-developed pilot cooling tower unit which is a miniaturized replica of an actual cooling tower. The pilot cooling tower is a small open recirculating system equipped with a commercial tower capable of handling flows up to 30.0 gpm (114 L/min) at a bulk water temperature up to 54 °C (130 °F). This system is equipped with automatic blowdown, bulk water temperature controller, free chlorine, and pH controllers. Chemical feed of a tagged dispersant package is controlled by an on-line analyzer. The monitoring devices include a coupon rack, corrotor, a heat transfer monitor and a phosphate analyzer. The heating element on the heat transfer monitor can produce a skin temperature of up to 77°C (170 °F). The system is controlled and monitored using an in-house built automatic controller. Fig. 2 shows photos of the pilot cooling tower test unit.



Fig. 2: Pilot test unit including the piping, deposition accumulation test system (DATS), pilot cooling tower and pilot cooling tower control screen.

Test water was synthetically prepared following a Title 22 cooling water make-up in a western US refinery.

## Results and Discussion

After screening corrosion inhibition performance using LPR, the best non-phosphorous based inhibitor treatment was further assessed using a dynamic test for corrosion inhibition on an in-house built STU apparatus. Five cycles of Title 22 makeup water was prepared and this was circulated with 2 ppm of iron and the non-phosphate corrosion inhibitor. The test was run at 79 °C (175 °F) maintaining a free chlorine residual of 0.5 ppm for 5 days. Fig. 3b shows excellent corrosion inhibition for carbon steel coupons and carbon steel mimicking a heat exchanger tube with corrosion rate of 0.7 mpy for non-phosphorous program treated water system. On the other hand, phosphate-treated program (Fig. 3a) showed corroded coupons and heat exchanger tube.



Fig. 3: Dynamic corrosion test results (a) phosphate-treated and (b) non-phosphorous-treated CS 1010 coupons and CS 1010 tube mimicking as heat exchanger.

## Pilot Cooling Tower Test

Corrosion inhibition performance of the non-phosphorous based corrosion inhibitor was also assessed using the pilot cooling tower to mimic more the flow dynamics of water in an operating industrial cooling water system. Table 2 below are the test conditions used in the Pilot cooling tower. The non-phosphorous based corrosion inhibitor program was tested on a 5-cycle Title 22 water at 54 °C (130 °F).

Parameter	Reading
Heat Transfer Monitor Flow rate:	3.3 ft/sec (1.0 M/Sec)
Bulk water temp:	35°C (95°F)
HTM Skin temp:	71°C (160°F)
pH range :	7.3 – 7.6
Free Chlorine, ppm as FRC	0.4 – 0.6
Calcium Hardness, ppm as CaCO <sub>3</sub> :	500 – 750
Chlorides, ppm as Cl	1400
Sulfates, ppm as SO <sub>4</sub>	640
Conductivity, µmhos	6000 – 7500 (varied cycles)
Cooling Tower Cycles of Concentration	4 or 5 cycles

Table 2. Pilot Cooling Tower Test conditions.

As shown in Fig. 4, the use of a non-phosphorous based corrosion inhibitor did not exhibit any increase in heat transfer resistance. This observation demonstrates that the use of non-phosphorous based corrosion inhibitor mitigates the formation of calcium phosphate scaling of the heat exchanger. Removing the source of phosphate will effectively inhibit the possible fouling of the heat exchanger surfaces.

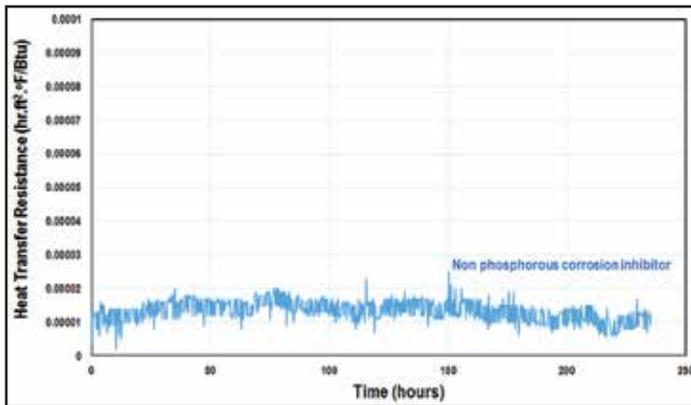


Fig. 4: Pilot cooling test results for the fouling studies of the non-phosphorous corrosion inhibitor at 54 °C (130 °F) for 5 cycles of concentration of Title 22 reuse water.

Fouling studies were also conducted to compare phosphate-based corrosion inhibitor program and a non-phosphate based corrosion inhibitor program (Fig. 5). Using 4 cycles of Title 22 water, and 71 °C (160 °F) skin temperature, the phosphate-based treatment program exhibited a significant increase in heat transfer resistance whereas the heat transfer resistance did not change with the non-phosphate corrosion inhibitor. This suggests that phosphate-based corrosion inhibitors can contribute to the fouling of the system by precipitating calcium phosphate whereas a non-phosphate based corrosion inhibitor program mitigates possible fouling.

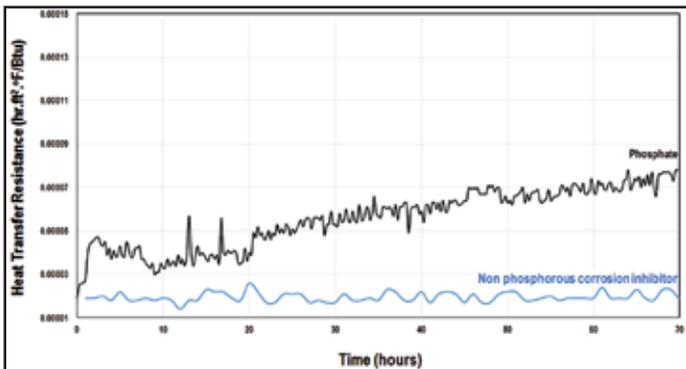


Fig. 5: Pilot cooling test results for the fouling studies at 71.°C (160 °F) for 4 cycles of concentration for Title 22 reuse water.

## Field Trial Test

A true test of a water treatment program is the performance of the heat exchangers. A field trial was conducted in a Midwest refinery where the cooling towers were operated on an alkaline program. Every year a couple of heat exchanger bundles are taken down for cleaning. These heat exchangers limit production due to fouling and poor heat transfer.

Figure 6 below shows the performance of a heat exchanger that is operating at 140 °F (60 °C) Process Inlet temperature. The trial was started in mid February 2017. The approach temperatures in 2016 were 15-20 °F above the target of 0°F. With the non-phosphorous corrosion treatment program, the approach temperature remains the same at 0 °F. Moreover, the Process Outlet temperature of the heat exchangers are lower by 20-25 °F.

Fouling due to precipitation of salts like calcium phosphate is influenced strongly by system parameters, such as water and skin temperatures, water velocity, residence time, and system metallurgy. The most severe deposition is encountered in process equipment operating with high surface temperatures and/or low water velocities. Fig. 7 illustrates the effectiveness of using a non-phosphorous based corrosion inhibitor program in mitigating calcium deposit fouling. These heat exchangers operate with a Process Inlet temperature of about 200 °F (93 °C) and a velocity of 1.5 ft/sec (0.45 m/s). As observed, the approach temperatures remains flat in 2017 and there were no cleaning of these heat exchangers needed for one year. The process flow rates were also higher than in the past even during the hotter summer months. In addition, the Process outlet temperature is below 100 °F which is lower than in the previous year.

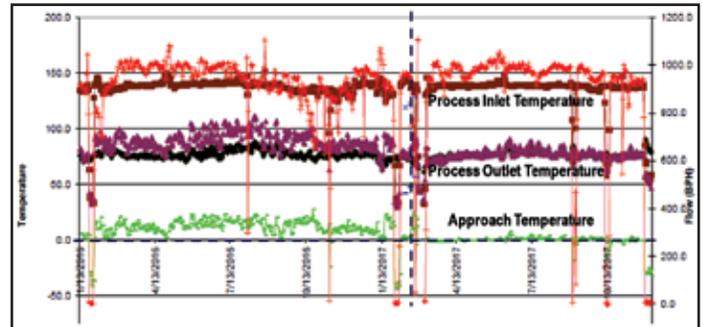


Fig. 6: Heat Exchanger bundles operating at 140oF (60 °C).

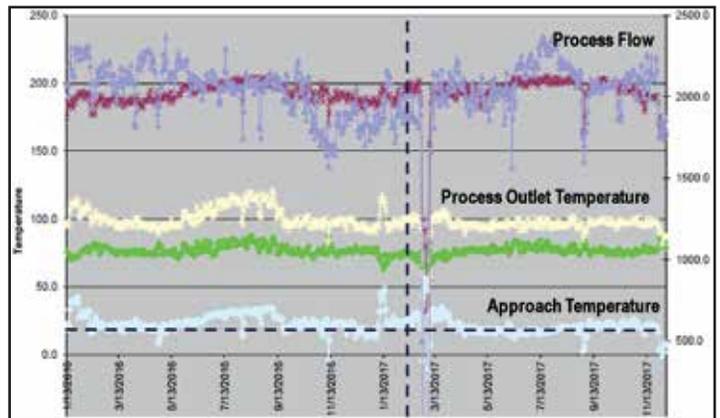


Fig. 7: Heat Exchanger bundles operating at 200oF (93 °C).

## Conclusion

Scale formation, deposition, and fouling can be mitigated in various ways. Among the scale deposits contributing to industrial water cooling system is calcium phosphate. This study shows that using a non-phosphorous based water treatment program can mitigate fouling of the heat exchangers. Mitigation by removing one of the sources effectively ensures a better heat exchanger performance even during summer months and low velocity conditions.

## Acknowledgement

The authors would like to express their gratitude to the entire Baker Hughes Industrial Water group especially Khac Nguyen and Chelsea Eaton.



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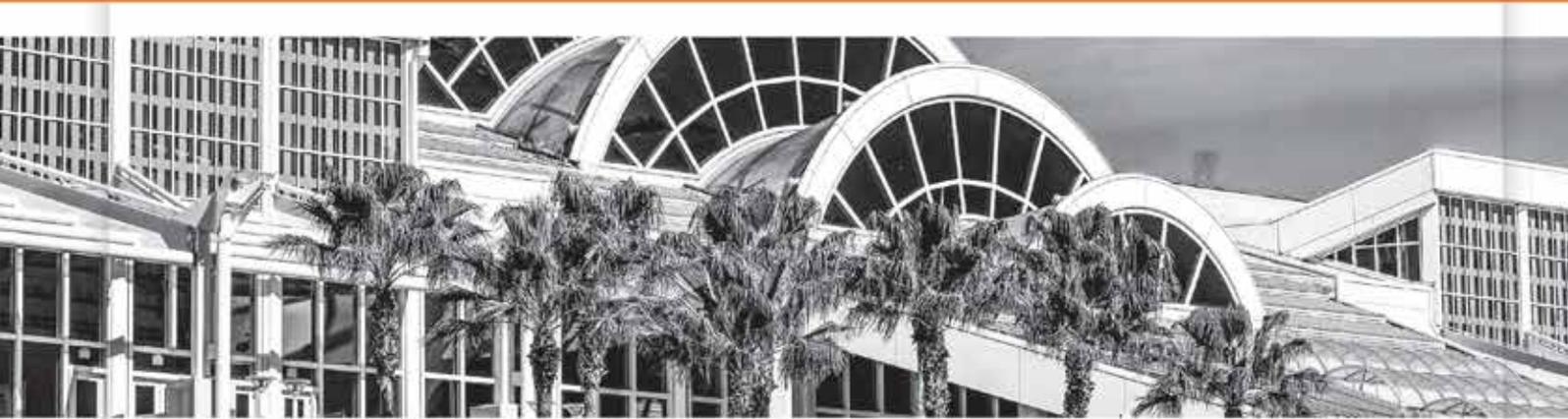
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# Flue Gas Injection And Antiscaling Treatment For Cooling Water Treatment System: Pilot Tests With Merades Installation

Christophe Vanschepdael, Engie Laborelec

## Abstract

The use of CO<sub>2</sub> is a proven antiscalant treatment for cooling water systems and is applied in several plants in Europe. As an alternative to pure commercial CO<sub>2</sub>, we have tested the use of (concentrated) power plant flue gases as a source of CO<sub>2</sub>. The challenge is to determine the minimal CO<sub>2</sub> concentration in the flue gas for an efficient antiscalant treatment knowing that typical flue gas from a thermal power plant contains CO<sub>2</sub> in the range of 4% for gas-fired power plant and 12% for coal-fired power plant.

We used our pilot installation to setup an antiscalant treatment based on the use of power plant flue gases. The pilot installation is a simulation of a semi-open cooling circuit. It contains two parallel and independent circuits allowing the comparison between different treatments under the same conditions. Each circuit is a miniaturized cooling circuit with one simulated heat exchanger and a forced-draft cooling tower. The topic of this presentation is to present the result of the pilot testing.

Pure CO<sub>2</sub> can be used as antiscalant treatment for cooling water circuits. Two power plants in Belgium actually use CO<sub>2</sub> as antiscalant in their cooling water circuit. CO<sub>2</sub> is also generated by power plant through the combustion of natural gas and emitted to the environment through flue gasses. A treatment can be considered to recover CO<sub>2</sub> from the flue gasses and reuse this CO<sub>2</sub> as antiscalant in the cooling water treatment. The goal of the project is to define the minimum CO<sub>2</sub> concentration, after recuperation from the flue gasses, needed in order to be suitable for use in the cooling water treatment.

## Introduction

Last year, during the Annual CTI Conference 2019, we present: "The Use of Carbone Dioxide as Antiscalant for Cooling Water Circuits" (TP19-08). We learned that CO<sub>2</sub> used as antiscaling treatment for recirculating cooling water circuits can be an alternative to traditional treatments. CO<sub>2</sub> treatment has the advantages to be safer and more environmentally friendly. Moreover, this alternative treatment is cheaper in some conditions.

Some cooling towers are already working for many years with CO<sub>2</sub> addition as treatment against scaling. This treatment is replacing acid addition (in most cases sulphuric acid), the most common antiscalant treatment in Europe for large cooling water circuits.

Instead of purchasing commercial pure CO<sub>2</sub>, the use of CO<sub>2</sub> readily available in the flue gas from fuel combustion in power plants makes sense on a technical and economical point of view.

Flue gas composition from a typical thermal gas power plant is 4% CO<sub>2</sub>, 12% O<sub>2</sub> and 74% N<sub>2</sub>. A major question is whether the flue gas can be used as such for injection in the cooling system or a pre-



Christophe Vanschepdael

liminary step for concentrating the CO<sub>2</sub> would be necessary to increase the CO<sub>2</sub> uptake in the cooling system. We carried out pilot trials using their pilot plant to confirm the technical feasibility of using CO<sub>2</sub> from the power plant flue gases and the optimal conditions to do it.

## Description Of Treatments

Sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) treatment is the traditional treatment used in order to avoid the precipitation of calcium carbonate (CaCO<sub>3</sub>). Sulfuric acid transforms the carbonates (CO<sub>3</sub><sup>2-</sup>) present in the water, into bicarbonates (HCO<sub>3</sub><sup>-</sup>). The two reactions below lead

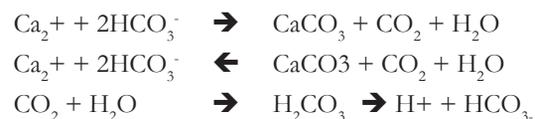
to a decrease of M and P-Alkalinity. Moreover, according to equation (2), some CO<sub>2</sub> is created. Nevertheless, it is partially stripped in the cooling tower.



These reactions show that H<sub>2</sub>SO<sub>4</sub> modifies the water quality. The concentration of bicarbonates (M-Alkalinity) decreases and the concentration of sulphates increases.

Hydrochloric acid is sometimes used as well as antiscalant treatment and works in the same way but the concentration of chlorides increases.

CO<sub>2</sub> treatment works due to the Le Chatelier's Principle. There is an effect on the reaction of CaCO<sub>3</sub> precipitation (3) without modification of the water quality. Calcium carbonate is produced in the water through the reaction (3). A calcium ion reacts with 2 bicarbonate ions in order to form calcium carbonate, which precipitates if its concentration is higher than its solubility. This reaction forms also CO<sub>2</sub> and water. Given the fact that this is a reversible reaction, an addition of CO<sub>2</sub> changes the equilibrium of this reaction to the left and avoids the precipitation of CaCO<sub>3</sub> (4). Moreover, the CO<sub>2</sub> dissolved in the water forms carbonic acid (H<sub>2</sub>CO<sub>3</sub>), which decreases the pH of the water (5).



Flue gas treatment is working in the same way as the CO<sub>2</sub> treatment. CO<sub>2</sub> from flue gas will change the equilibrium of the calcium carbonate formation. The other main components of flue gas (nitrogen and oxygen) do not impact scale formation.

## Pilot Installation Description (MERADES)

MERADES is a mobile installation simulating semi-open cooling circuits. It contains two parallel and independent circuits, allowing comparison between two treatments or two technologies under the same conditions.



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Each circuit is a miniaturized cooling circuit with one simulated tube heat exchanger and a forced-draft cooling tower. Each circuit contains its own circulation pump, blow down pump, makeup water circuit, and an acid injection skid. All the chemical and physical parameters of one circuit can be controlled independently from the other circuit.

### Merades Pilot Plant Comprises:

- One 40-ft-long shelter which contains the simulated heat exchangers equipped, the analyzers, the sampling devices and the control and data acquisition system and working places (office and small lab for manual analysis)
- The pumps, the 2 cooling towers, the acid injection skid and the transformers for heating the heat exchangers are installed outside of the shelter

The pilot plant is fully automated and can be remotely controlled. MERADES pilot plant has been used in R&D projects for testing and evaluating cooling tower fills, antiscalant treatments, biocide treatments (monochloramine, ClO<sub>2</sub>). MERADES has also been deployed on-site in power plants in Belgium to optimize the acid and chlorine injections. The results were representative of the full scale conditions.

### Merades Instrumentation

MERADES pilot station is equipped with several online monitors following physical and chemical parameters. Table 1 summarizes the chemical instrumentation present in the pilot unit. The chemical analysers measure continuously the water quality in the 2 circuits of MERADES.

In Table 2, the physical instrumentation is summarized. Those monitors allow the control of the cooling system process.

Instrument/Measure	MakeUp	Circulation	Blow down
pH	C	C	C
Conductivity	C	C	C
TAC	X		X <sup>1</sup>
THCa	X		X <sup>1</sup>
THT	X		X <sup>1</sup>
SO <sub>4</sub>	X		X <sup>1</sup>
Chlorides	X		X <sup>1</sup>
LPR Corrosion Measurement		X	

Table 1 : Chemical instrumentation on Merades Pilot Plant (with C= cotinuous measurement, X1 = Measurement will be switch from blow down to circulation water if needed and X = Discontinue measurement (1/h)).

Parameter	Make-up	Inlet condenser	Outlet condenser	Blowdown
Flow	C	C	C	C
Temperature	C	C	C	C
Pressure	C	C	C	

Table 2: Physical instrumentation on MERADES plant (C= continuous measurement).

### Test Methodology

The water used as make-up water for MERADES pilot installation is surface water originating from the canal Bruxelles-Charleroi. The water quality is shown in Table 3.

The make-up water will be slightly concentrated (coc = 1.25) in order to be in a good configuration for using the CO<sub>2</sub> originating from the flue gases (as for CO<sub>2</sub> treatment). The water temperature will be increased from 10°C in the condenser to reach a temperature of 37 °C at the outlet of the condenser. The other physical parameters are shown in Table 4.

Parameter	Canal water
Conductivity	750-800 µS/cm
pH	7.8
M-Alkalinity	220 mg/l CaCO <sub>3</sub>
Calcium Hardness	215 mg/l CaCO <sub>3</sub>
Total Hardness	240 mg/l CaCO <sub>3</sub>
Chlorides	150 mg/l Cl <sup>-</sup>

Table 3: Water quality of Canal Bruxelles - Charleroi.

Parameters	MERADES condition
Make-up Water	Canal Bruxelles – Charleroi
Temperature at the outlet of condenser(°C)	37 (98.6°F)
Temperature delta in the condenser (°C)	10 (50°F)
Concentration factor	1.25
Water spread in condenser pipes (m/s)	1.46 (3.26 mph)
Circulation flow rate (m <sup>3</sup> /h)	1.9 (501 gal/h)
System water volume (m <sup>3</sup> )	0.5 (132 gal)
Blowdown flowrate (m <sup>3</sup> /h)	0.08 (21 gal)
Packing spraying flow rate (m <sup>3</sup> /m <sup>2</sup> .h)	8 (196.304 gal/ft <sup>2</sup> )
Hydraulic halftime (min)	15.5

Table 4: MERADES physical parameters during the trial for both circuits.

The trial lasted 2 weeks. In the first week, we tested pure CO<sub>2</sub> in one circuit and synthetic flue gas with a concentration of 20% CO<sub>2</sub> in the second circuit. The second week a synthetic flue gas with a concentration of 4% CO<sub>2</sub>. The different compositions are summarized in Table 5. The occurrence of scaling will be determined using specific electrode to measure calcium ions concentration factor in the cooling water and to compare it with the concentration factor of more soluble ions (like chlorides).

Week	Circuit 1	Circuit 2
1	Pure CO <sub>2</sub>	20% CO <sub>2</sub> ; 10% O <sub>2</sub> ; 70% N <sub>2</sub>
2	/	4% CO <sub>2</sub> ; 12% O <sub>2</sub> ; 84% N <sub>2</sub>

Table 5: Test program. Different CO<sub>2</sub> concentrations are tested.

For this trial, the main goal was to prove that it is possible to use CO<sub>2</sub> originating from the flue gas to treat cooling water circuit against scaling. We didn't study the effect of the flue gas injection on the cooling water composition and their impact on the corrosion, the fouling or on the biocide treatment. Only scaling data's were evaluated.

### Results

Figure 1 illustrates the case study with a 20% CO<sub>2</sub> concentration in the synthetic flue gas and the test methodology adopted:

- In the first period, the target cycle of concentration is reached with acid.
- Then acid injection is stopped and the injection is replaced by gas injection (synthetic flue gas or CO<sub>2</sub>).
- Then the gas injection is step by step reduced with a close monitoring of the chemistry until scaling occurred giving the limit of operation, i.e. the needed amount of flue gas to avoid scaling

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The first step of the test is illustrated in Figure 2. We started the test at low pH with acid injection at the inlet of the condenser until we have stable condition in the cooling water circuit. Stable condition is noticed by a stable and identical cycle of concentration of the analysed parameters (chlorides, calcium and conductivity). M-Alkalinity concentration, as explain in equation 1 & 2, is lower due to the acid injection. The acid injection is then replaced by synthetic flue gas injection when stable operation of the cooling circuit is confirmed. Flue gas is injected also at the inlet of the condenser and the flue gas flow is regulated in order to keep a stable pH at the inlet of the condenser. We started the flue gas injection in order to work with an identical pH than with acid. The consequence of the antiscalant treatment change is visible on the M-Alkalinity concentration (blue curve). The M-Alkalinity concentration increases slowly to reach the same cycle of concentration than the other chemical parameters. If all the chemical parameters concentration are equal, it means that there is no precipitation of calcium carbonate and prove that flue gas composed with 20% CO<sub>2</sub> can be use as antiscalant treatment.

The Figure 3 shows the second step of the test. The flue gas injection flow is reduced step by step in order to decrease CO<sub>2</sub> concentration in the water. Decrease of CO<sub>2</sub> in water will increase cooling water pH. A pH increase causes a higher risk of scaling. In Figure 3, we observe no scaling, the cycles of concentration of all chemical parameters are stable. We were able to increase pH inlet condenser until 7.95.

In Figure 4, the cycle of concentration of M-Alkalinity, calcium and conductivity decrease similarly. In the same time, chloride concentration stay stable which confirms that scaling occurs. This phenomena is observed at pH 8.05. At this 'scaling' point, we can determine the associated Ryznar Index (=6.18) and Langelier Index (=0.73) and notify how much gas flow is needed to avoid scaling with flue gas with 20% CO<sub>2</sub>.

Using the methodology previously described and illustrated, we are able to define Ryznar and Langelier Index limits and compare the gas flow required to avoid scaling (Table 6) for the different gas compositions.

The comparison of the result (Table 6) shows that the CO<sub>2</sub> need is proportionally higher when the concentration of CO<sub>2</sub> is lower in the gas. This phenomenon can be explained by the need to add more gases to compensate the stripping of CO<sub>2</sub> and/or the poorer dissolution of CO<sub>2</sub> in the water.

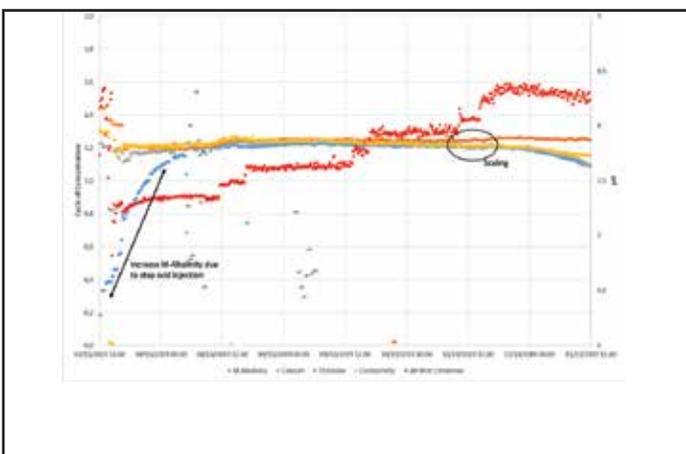


Figure 1: Overview of the testing methodology with 20% CO<sub>2</sub> in the synthetic flue gas composition: In first instance, cycle of concentration of M-Alkalinity increases to reach the same cycle of concentration than the other parameters. From that pH reducing gas injection. Scaling occurs at pH 7.87 inlet condenser.

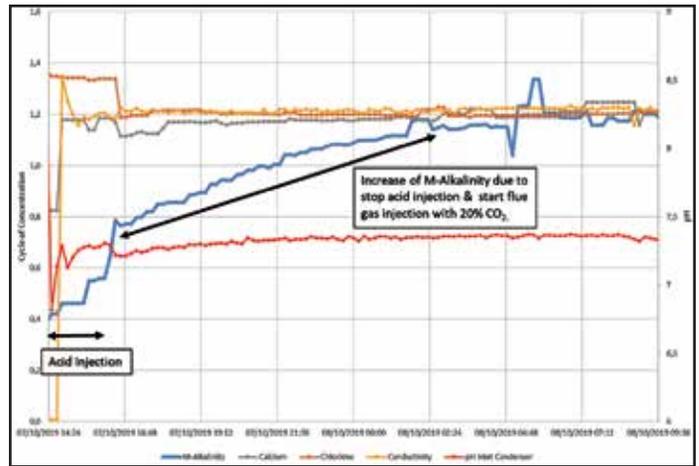


Figure 2: As first stage, we reach the cycle of concentration around 1.2 - 1.25 with acid injection. When the situation is stable, we changed acid injection by flue gas injection in order to keep an identical pH at the inlet of the condenser (red curve) as consequence an increase of the M-Alkalinity concentration (blue curve).

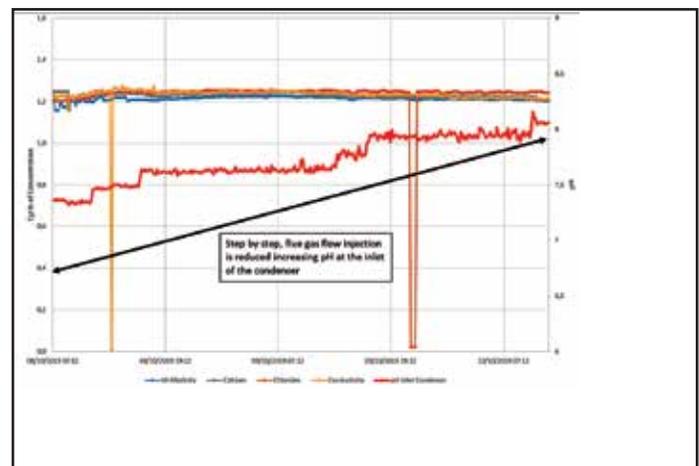


Figure 3: As second stage, flue gas injection flow is reduced to increase pH at the inlet of the condenser. This step, is done until we observe a difference between cycle of concentration of calcium, M-Alkalinity and the cycle of concentration of chlorides.

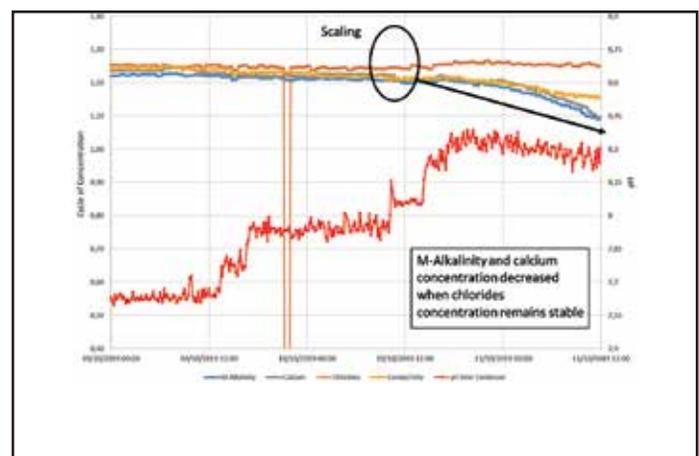


Figure 4: When scaling occurs, we observe a decrease of calcium and M-Alkalinity cycle of concentration. In the same time, chlorides cycle of concentration remains stable confirming that only calcium carbonate is precipitating.

	100% CO <sub>2</sub>	20% CO <sub>2</sub>	4% CO <sub>2</sub>
pH Inlet condenser	8.2	8.05	8.06
pH Cooling Tower	8.37	8.44	8.46
Ryznar Stability Index (outlet condenser (37°C/98.6°F))	5.74	6.18	6.35
Langelier Saturation Index (outlet condenser (37°C/98.6°F))	1.18	0.73	0.54
Amount of gas (Nm <sup>3</sup> /h)	3.6	30.3	255.5
Amount of CO <sub>2</sub> injected (g/h)	7.06	9.9	15.87
Added CO <sub>2</sub> concentration in water (mg/l)	3.71	5.22	8.36

Table 6: Comparison of the different tests and calculation of the different index. The CO<sub>2</sub> need is proportionally higher when the CO<sub>2</sub> concentration is lower in the synthetic flue gas composition. This stripping and/or poorer CO<sub>2</sub> dissolution in the water.

## Conclusions and Perspective

The test has shown that it is possible to use a gas with low CO<sub>2</sub> concentration to reduce pH of cooling water. The CO<sub>2</sub> need is proportionally higher when the CO<sub>2</sub> concentration is lower in the synthetic flue gas composition. This phenomena can be explained by the need to compensate CO<sub>2</sub> stripping and/or poorer CO<sub>2</sub> dissolution in the water. Table 7 compares the amount of CO<sub>2</sub> and the amount of gas needed to treat a cooling water circuit with a recirculation flow of 20.000 m<sup>3</sup>/h which is typical for power plant. The amount of gas is weak in comparison with the flue gas flow of a thermal power plant (about more than one million Nm<sup>3</sup>/h).

<sup>1</sup> Ashrae Position Document On Legionellosis 7 (Ashrae 1998) (2012)

	100% CO <sub>2</sub>	20% CO <sub>2</sub>	4% CO <sub>2</sub>
Amount of CO <sub>2</sub> to treat cooling circuit (20.000 m <sup>3</sup> /h) (kg/h)	74	104	167
Amount of gas to treat cooling circuit (20.000 m <sup>3</sup> /h) (Nm <sup>3</sup> /h)	38	319	2689

Table 7: Comparison of the gas need to treat cooling water circuit with a recirculation flow of 20.000m<sup>3</sup>/h (extrapolation for real scale thermal power plant).

We have shown that it is possible to use flue gas to decrease pH of cooling water circuit and avoid scaling it the circuit. The way to control the flue gas injection remains pH measurement. But as for CO<sub>2</sub> injection, a problem with flue gas injection will cause quickly an increase of pH and precipitation of calcium carbonate. It is needed to have a 'backup' injection in case of injection issue.

The test done in 2019 are 'proof of concept' test and next steps are needed before implementing on site injection of flue gas. We foresee in 2020 new test on our pilot station in order to measure the impact of cooling water temperature on the CO<sub>2</sub> stripping. We need to know the flue gas consumption for higher temperature in order to know the process limit of flue gas injection. In a near future we need also to study the following aspects:

- Different water compositions
- The impact of flue gas injection on corrosion
- What happens with incondensable gases
- Different injection location to determine the best solution (we tested only at the inlet of the condenser after recirculation pump)
- The legislation and the environmental impact of flue gas injection
- The other possible issues like the transport of flue gas from the chimney to the cooling water circuit

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

# 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 cooling tower is a factor in the surrounding environment and limits on those sound levels, and quality, are frequently specified and dictated in project specifications. The project specifications are expected to conform to local building codes or safety standards. Consequently, it may be in the best 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 Sound Testing Agencies

**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 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) West

**McHale Performance**  
4700 Coster Rd  
Knoxville, TN 37912  
865.588.2654  
Fax 865.934.4779  
www.mchaleperformance.com  
ctitesting@mchaleperformance.com  
Contact: Gabriel Ramos

# 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 claimed by the Manufacturer.

CTI Certification under STD-201 is limited to thermal operating conditions with entering wet bulb temperatures between 12.8°C and 32.2°C (55°F to 90°F), a maximum process fluid temperature of 51.7°C (125°F), a cooling range of 2.2°C (4°F) or greater, and a cooling approach of 2.8°C (5°F) or greater. The manufacturer may set more restrictive limits if desired or publish less restrictive limits if the CTI limits are clearly defined and noted in the publication.

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
<b>Clean Air Engineering</b> 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
<b>Cooling Tower Test Associates, Inc.</b> 15325 Melrose Dr. Stanley, KS 66221	Thomas E. (Tom) West www.cttai.com cttakc@aol.com	913.681.0027 (F) 913.681.0039
<b>Cooling Tower Technologies Pte Ltd</b> 17 Mandai Estate #06-02B, Hwa Yew Industrial Building S729934 Singapore	Ronald Rayner coolingtwrtech@bigpond.com Johnny Ong johnny@coolingtwrtech.com	+61.2.9789.5900 (F) +61.2.9789.5922 +65.98251247
<b>DMT GmbH &amp; Co. KG</b> Am Technologiepark 1 45307 Essen, Germany	Dr. Ing. Meinolf Gringel meinolf.gringel@dm-group.com	+49.201.172.1164
<b>McHale Performance</b> 4700 Coster Rd Knoxville, TN 37912	Gabriel Ramos www.mchaleperformance.com ctitesting@mchaleperformance.com	865.588.2654 (F) 865.934.4779



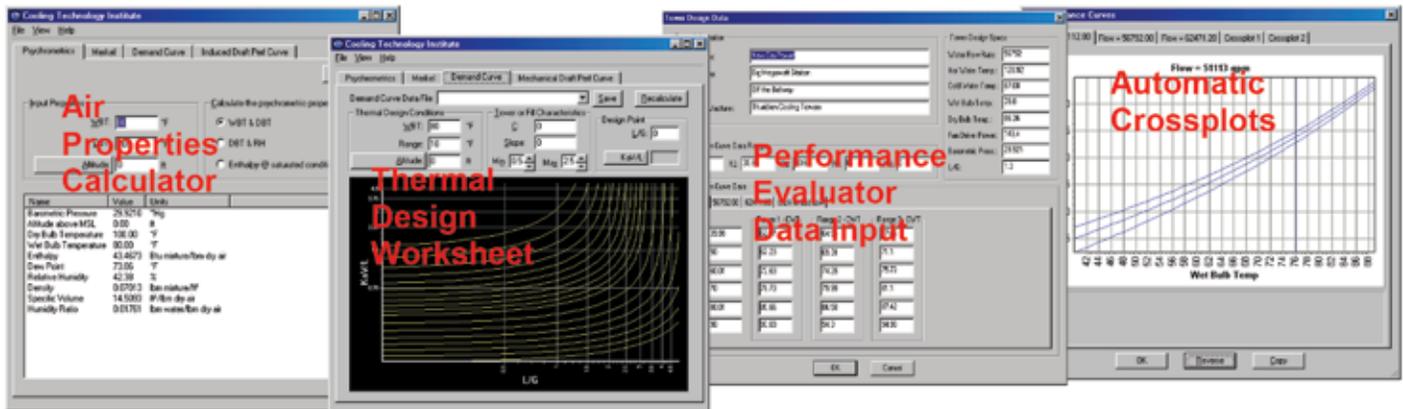
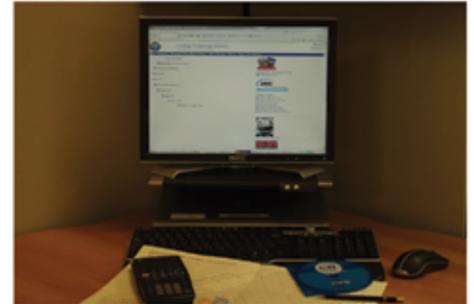


# CTI Toolkit Version 3.2

...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](http://www.cti.org)**

8/8/08



**Order Today**  
**Call 281-583-4087**

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

**Bill to:** \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**Phone:** \_\_\_\_\_ **Fax:** \_\_\_\_\_

**Email Address:** \_\_\_\_\_

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**Charges can be made to Visa, MasterCard or American Express**

Card No.: \_\_\_\_\_ Expiration Date: \_\_\_\_\_  
 Signature: \_\_\_\_\_ CVV; CVC; CID Code: \_\_\_\_\_

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): <i>Priority mail \$6; 2<sup>nd</sup> Day Air \$18; Overnight Domestic \$28; / International (DHL) TBA</i>			
<b>Multi-user site licenses and educational institution pricing available on request</b>			

**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 78 cooling tower manufacturers are currently active in the program. In addition, 18 of the manufacturers also market products as private brands through other companies.

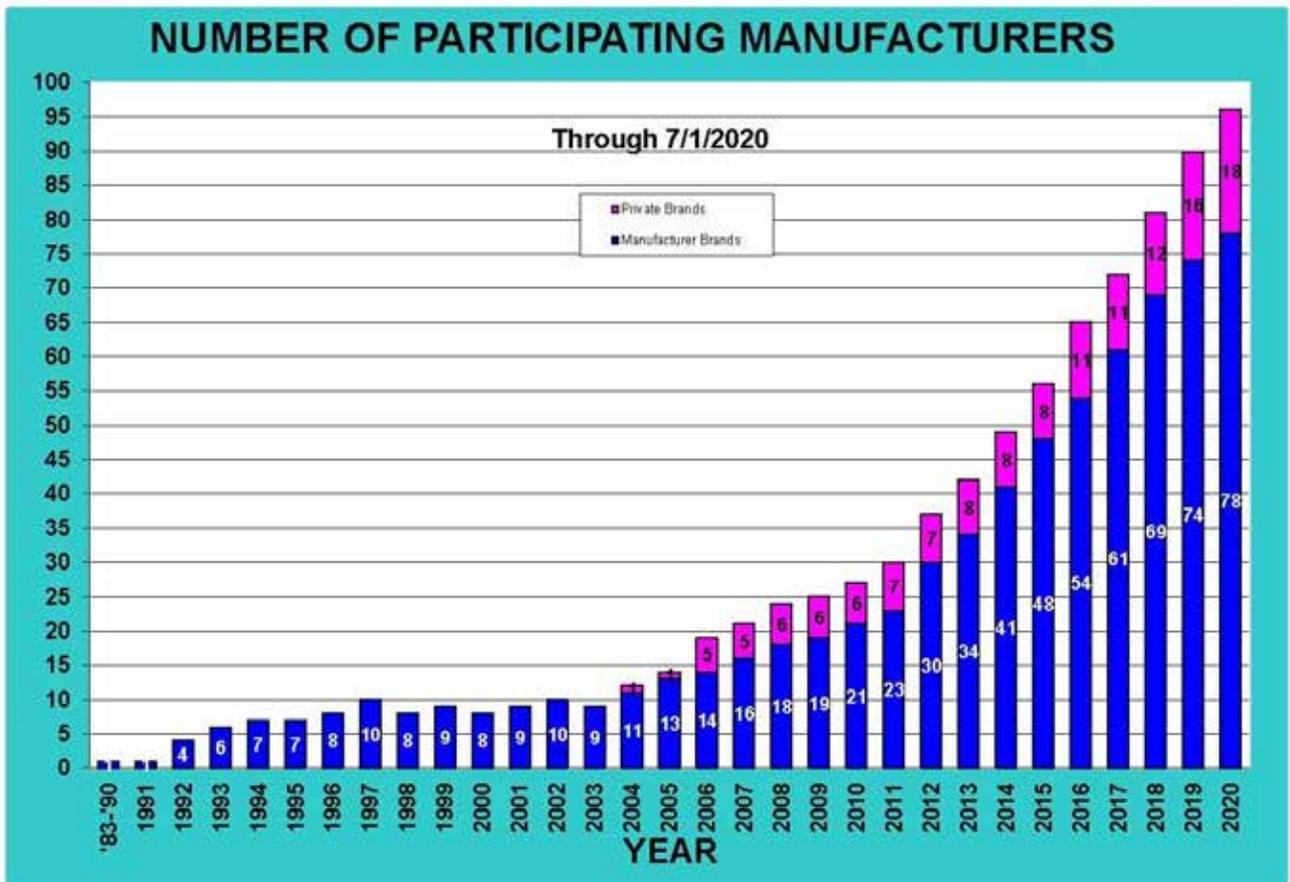
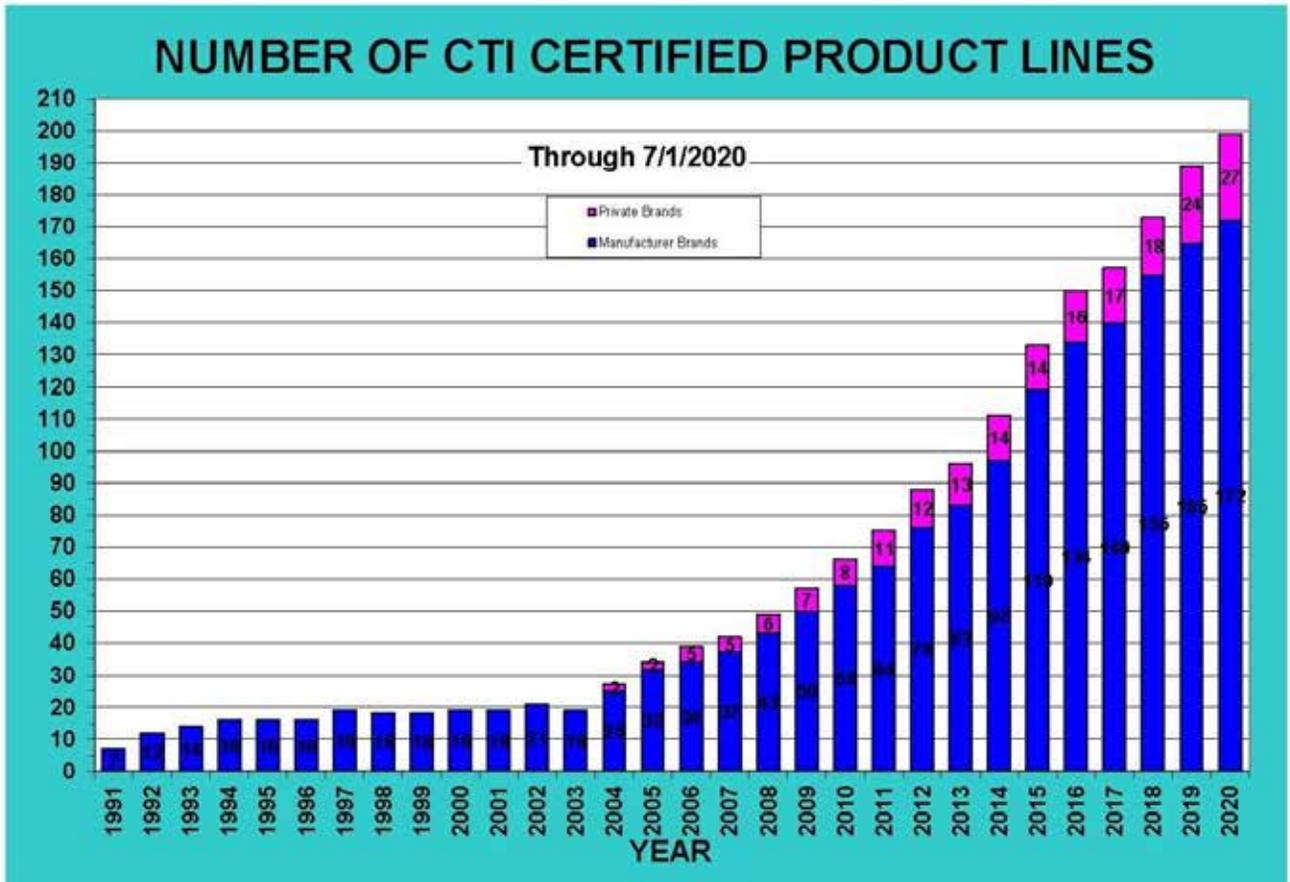
While in competition with each other, these manufacturers benefit from knowing that they each achieve their published performance capability and distinguish themselves by providing the Owner/Operator's required thermal performance. The participating manufacturers currently have 172 certified product lines plus 27 product lines marketed as private brands which result in approximately 50,000 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:

<https://www.coolingtechnology.org/certified-towers>

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](mailto:vmanser@cti.org) for more details.

# Thermal Certification Program Participation



# Current Program Participants

(as of July 1, 2020)

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:

<https://www.coolingtechnology.org/certified-towers>

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

<p><b>A</b></p> <p><b>Advance GRP Cooling Towers, Pvt.,Ltd.</b> Advance 2020 Series A Validation No. C31A-07R03 NTM Line Validation No. C31B-19R00</p> <p><b>Aggreko Cooling Tower Services</b> AG Line Validation No. C34A-08R02</p> <p><b>Amcot Cooling Tower Corp.</b> AST Validation No. C106A-19R00 Series R-LC Validation No. C11E-11R02</p> <p><b>American Cooling Tower, Inc.</b> ACF Series Validation No. C38D-18R00 ACX Series Validation No. C38C-18R00</p> <p><b>AONE E&amp;C Corporation, Ltd.</b> ACT-C Line Validation No. C28B-09R01 ACT-R/ACT-RU Line Validation No. C28A-05R05</p> <p><b>Approach Engineering Co., Ltd</b> NSA Line Validation No. C76B-20R00</p> <p><b>Axima (China) Energy Technology Co., Ltd.</b> EWX Line Validation No. C72A-15R03</p> <p><b>B</b></p> <p><b>Baltimore Aircoil Company, Inc.</b> FXT Line Validation No. C11A-92R02 FXV Line Validation No. C11J-98R10 NXF Line Validation No. C11Q-18R01 PF Series Validation No. C11P-12R02 PT2, PTE &amp; PCT Series Validation No. C11L-07R05 Series V Closed Validation No. C11K-00R02 Series V Open Validation No. C11B-92R06 Series S1500 Validation No. C11H-94R09 Series 3000A,C,D,E, Compass &amp; Smart Validation No. C11F-92R18</p> <p><b>Bell Cooling Tower Pvt, Ltd</b> BCTI Line Validation No. C43A-12R02</p> <p><b>C</b></p> <p><b>Cenk Endüstri Tesisleri Imalat Ve Taahüt A.Ş.</b> LEON Line Validation No. C89A-17R01 LISA Line Validation No. C89B-17R01 ISTANBUL Line Validation No. C89C-19R00</p>	<p><b>Changzhou Hanf Cooling Equipment Co., Ltd</b> GTC Series Validation No. C101B-19R01 GTN Series Validation No. C101A-18R01 GTS Series Validation No. C101C-20R00</p> <p><b>Chengdu Xingli Refrigeration Equipment Co., Ltd</b> HBL-HS Series Validation No. C115A-19R00</p> <p><b>Chongqing Yinengfu Technology Co., Ltd</b> YNF Series Validation No. C103A-18R00</p> <p><b>Composite Cooling Solutions Inc.</b> PhoenixPL Validation No. C79B-20R00</p> <p><b>Cool Water Technologies</b> RTAi Line Validation No. C52A-13R03 RTi Line Validation No. C52A-13R02</p> <p><b>D</b></p> <p><b>Dalian Spindle Environmental Facilities Co., Ltd</b> DC Series Validation No. C112A-19R00 DF Series Validation No. C112B-19R01 DX Series Validation No. C112C-19R01</p> <p><b>Decsa</b> TMA-EU Series Validation No. C42C-17R00</p> <p><b>Delta Cooling Tower, Inc.</b> TM Series Validation No. 02-24-01</p> <p><b>Delta (India) Cooling Tower Pvt, Ltd</b> DFC-60UX Line Validation No. C85A-18R00</p> <p><b>Dezhou Beitai Refrigeration Equipment Co. Ltd.</b> DBHZ<sub>2</sub> Validation No. C104A-19R00</p> <p><b>Dongguan Ryoden Cooling Equipment Co., Ltd</b> RT-L&amp;U Series Validation No. C71A-15R03 RTM-L Series Validation No. C71B-15R00</p> <p><b>Dunham-Bush (China) Co., Ltd</b> BHC Series Validation No. C107A-19R00</p> <p><b>E</b></p> <p><b>Elendoo Technology (Beijing) Co., Ltd.</b> EL Line Validation No. C50C-15R04 ELOP Line Validation No. C50B-14R04</p>
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## **Ebara Refrigeration Equipment & Systems Co.**

CDW Line *Validation No. C53A-13R04*

CNW Line *Validation No. C53C-18R00*

CXW Line *Validation No. C53B-14R02*

## **Evapco, Inc.**

AT Series *Validation No. C13A-99R21*

ATWB Series *Validation No. C13F-09R09*

AXS Line *Validation No. C13K-15R03*

ESWA, ESWB, & ESW4 Series *Validation No. C13E-06R12*

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-16R02*

## **G**

### **Genius Cooling Tower Sdn Bhd**

MK Series *Validation No. C67C-18R01*

MT Series *Validation No. C67A-16R00*

MX Series *Validation No. C67B-16R00*

### **Guangdong EnZen Energy Saving Technology Co., Ltd**

YZC Series *Validation No. C109A-19R00*

### **Guangdong Feiyang Industry Co., Ltd**

LK Series *Validation No. C71A-15R03*

### **Guangdong Green Cooling Equipment Co., Ltd**

GLR-E Series *Validation No. C97B-18R01*

### **Guangdong Zhaorin Industrial Co., Ltd**

SRN Series *Validation No. C95A-17R01*

### **Guangdong Liangken Cooling and Heating Equipment Technology Co., Ltd**

LRT Series *Validation No. C66A-15R02*

LYH Series *Validation No. C66B-20R00*

### **Guangzhou Goaland Energy Conservation Tech Co., Ltd.**

GLH Series *Validation No. C96A-17R01*

### **Guangzhou Laxun Technology Exploit Co., Ltd.**

LC Line *Validation No. C45F-16R01*

LMB Line *Validation No. 12-45-02*

PG Line *Validation No. C45G-17R00*

PL Line *Validation No. C45E-16R03*

### **Guangzhou Single Beam All Steel Cooling Tower Equipment Co., Ltd.**

SLH Line *Validation No. C91E-16R02*

## **H**

### **Hon Ming (Guang Dong) Air Conditioning Equipment Company, Ltd.**

HM Series *Validation No. C66B-20R00*

MK Series *Validation No. C66A-15R02*

## **Hunan Yuanheng Technology Company, Ltd.**

YCH-F Line *Validation No. C40C-16R02*

YCN-F Line *Validation No. C40D-18R00*

YHD Line *Validation No. C40B-15R00*

YHW Line *Validation No. C40E-18R00*

## **HVAC/R International, Inc.**

Therflow Series TFC *Validation No. C28B-09R01*

Therflow Series TFW *Validation No. C28A-05R05*

## **İMAS KLİMA SOĞUTMA MAKİNA SANAYİ TİCARET ve MÜMESSİLLİK A.Ş.**

TA Line *Validation No. C114B-20R00*

TAK Line *Validation No. C114A-20R00*

## **J**

### **Jacir**

DTC ecoTec *Validation No. C46E-18R00*

VAP Line *Validation No. C46C-16R02*

### **Jiangsu Dayang Cooling Tower Co., Ltd.**

HLT Line *Validation No. C94A-14R03*

### **Jiangsu Greenland Heat Transfer Technology Co.**

GBH-TS Line *Validation No. C87A-18R01*

### **Jiangsu i-Tower Cooling Technology Co., Ltd.**

REH Series *Validation No. C75B-16R01*

TMH Series *Validation No. C75A-16R02*

### **Jiangsu Ocean Cooling Equipment Co., Ltd.**

TKS Series *Validation No. C41D-18R00*

### **Jiangxi Ark Fluid Science Technology Co., Ltd.**

FBFJ Line *Validation No. C83B-18R00*

FBNJ Line *Validation No. C78B-20R00*

FKH Line *Validation No. C83A-17R01*

### **Ji'Nan Chin-Tech Thermal Technology Co., Ltd.**

CCOX Line *Validation No. C91F-20R00*

CTHX Line *Validation No. C91E-16R02*

## **K**

### **Kelvion B.V.**

Polacel CF Series *Validation No. C25A-04R02*

### **KIMCO (Kyung In Machinery Company, Ltd.)**

CKL Line *Validation No. C18B-05R04*

Endura Cool Line *Validation No. C18A-93R09*

GX Line *Validation No. C18D-18R01*

### **King Sun Industry Company, Ltd.**

HKD Line *Validation No. C35B-09R06*

KC Line *Validation No. C35C-11R02*

KFT Line *Validation No. C35D-16R01*

### **Korytko Systems, Ltd.**

KDI Line *Validation No. C70A-16R02*

## **KSN Co., Ltd**

KSNC Series *Validation No. C44A-12R03*

KSNX Series *Validation No. 12-44-02*

KSNC-C Series *Validation No. C44C-14R01*

KSNX-C Series *Validation No. C44D-14R01*

## **Kuken Cooling Tower Co.,Ltd.**

GXC Series *Validation No. C81B-16R01*

GXE Series *Validation No. C81A-16R01*

## **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. C20E-11R03*

Series U-LC *Validation No. C20D-10R04*

Series V-LC *Validation No. C20C-10R01*

TLC Line *Validation No. C20G-16R00*

V-LN Line *Validation No. C20K-20R00*

## **M**

## **Marley (SPX Cooling Technologies)**

Aquatower Series *Validation No. 01-14-05*

AV Series *Validation No. C14D-98R03*

DTW Series *Validation No. C14N-16R02*

LW Series *Validation No. C14P-16R01*

MCW Series *Validation No. 06-14-08*

MD and CP Series *Validation No. C14L-08R09*

MHF Series *Validation No. C14G-04R10*

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*

MHD Series *Validation No. C26K-20R00*

MXC Series *Validation No. C26H-12R01*

MXR-KM, MXL, MXH Series *Validation No. C26C-08R09*

## **MITA S.r.l.**

PM Series *Validation No. C56B-16R02*

## **N**

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

HMP-NB Line *Validation No. C55A-14R02*

## **Nihon Spindle Manufacturing Company, Ltd.**

KG Line *Validation No. C33B-12R05*

## **O**

## **Ocean Cooling Tower Sdn Bhd**

OCBSD *Validation No. C86B-19R00*

YC Series *Validation No. C86A-17R00*

## **OTT Company, Ltd.**

OTTC Series *Validation No. C44A-12R03*

OTTX Series *Validation No. 12-44-02*

OTTC-C Series *Validation No. C44C-14R01*

OTTX-C Series *Validation No. C44D-14R01*

## **P**

## **Paharpur Cooling Tower, Ltd.**

CF3 Series *Validation No. C51A-13R03*

OXF-30K Series *Validation No. C51B-14R00*

Series RXF *Validation No. C51C-19R00*

## **Protec Cooling Towers, Inc.**

FRS Series *Validation No. 05-27-03*

FWS Series *Validation No. C27A-04R06*

## **Q**

## **Qinyang Zhonghe Zhi Da Technology Co., Ltd.**

HLO Series *Validation No. C99B-20R00*

HL-SC Series *Validation No. C99A-18R00*

## **R**

## **Reymasa Cooling Towers, Inc. (Fabrica Mexicana de Torres, SA de CV)**

HFC Line *Validation No. C22F-10R06*

RT & RTM Series *Validation No. C22G-13R07*

## **Rosemex, Inc.**

RC (RCS/D) Series *Validation No. C54A-13R04*

RO (ROS/D) Series *Validation No. C94A-14R03*

## **RSD Cooling Towers**

RSS Series *Validation No. C32A-08R01*

## **Ryowo (Holding) Company, Ltd.**

FDC Series *Validation No. C27E-11R00*

FRS Series *Validation No. 05-27-03*

FVS Series *Validation No. 12-27-06*

FWS and FCS Series *Validation No. C27A-04R06*

FXS Series *Validation No. C27B-20R00*

## **S**

## **Shangdong Grad Group Co., Ltd.**

GAT Series *Validation No. C88A-17R00*

## **Shanghai ACE Cooling Refrigeration Technology Col, Ltd.**

AC Line *Validation No. C80A-17R01*

## **Shanghai Baofeng Machinery Manufacturing Co., Ltd.**

BTC Line *Validation No. C49A-12R01*

## **Shanghai Liang Chi Cooling Equipment Co., Ltd.**

LCP Line *Validation No. C62D-18R00*

LNCM Line *Validation No. C62B-16R00*

LRS Line *Validation No. C62C-16R00*

LRCM-DD Line *Validation No. C62E-19R00*

**Shanghai Tyacht Cooling System Co.,Ltd.**

TMC Line *Validation No. C93C-18R00*

**Shanghai Wanxiang Cooling Equipment Co., Ltd.**

FBH/HL Line *Validation No. C54A-13R04*  
FKH/FKHL Series *Validation No. C94A-14R03*

**Shanghai Zendia Cooling Equipment Co., Ltd.**

ZHF-7000 Series *Validation No. C111A-19R00*

**Sinro Air-Conditioning (Fogang) Company, Ltd.**

CEF Line *Validation No. C37D-20R00*  
CEF-A Line *Validation No. C37B-11R03*  
SC-B Series *Validation No. C37C-11R02*  
SC-H Series *Validation No. C37A-10R03*

**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. C32A-08R01*

**The Cooling Tower Company, L.C**

TCIA Series *Validation No. C29C-19R01*

**Thermal-Cell sdn bhd**

THW Line *Validation No. C40E-18R00*

**Thermax Cooling Solutions Limited**

Enerflow (CM) Line *Validation No. C117A-20R00*

**Tower Tech, a div. of CPK Manufacturing, LLC**

TTXL Line *Validation No. C17F-08R05*  
TTXR Line *Validation No. C17F-15R00*

**Truwater Cooling Towers Sdn Bhd**

EC-S Series *Validation No. C41A-12R04*  
EX-S Series *Validation No. C41B-12R06*  
TKS Series *Validation No. C41D-18R00*  
VXS Series *Validation No. C41C-13R02*

**W**

**Wuxi Ark Fluid Science Technology Co., Ltd.**

FBF Series *Validation C83B-18R00*  
FBN Series *Validation C78B-20R00*

**Wuxi Fangzhou Water Cooling Equipment Co., Ltd.**

FFB Line *Validation C64D-20R00*

**Wuxi Zhishui Environmental Co., Ltd.**

ZSBN Series *Validation C113A-20R00*

**Y**

**YM Tech Co., Ltd.**

YFO Line *Validation No. C108A-19R00*  
Xsta Line *Validation No. C108B-19R00*

**York (By Johnson Controls)**

AT Series *Validation No. C13A-99R21*  
LSTE Line *Validation No. C13G-09R03*

**Z**

**Zhejiang Dongjie Cooling Tower Co., Ltd.**

DHC Line *Validation No. C63B-15R00*

**Zhejiang Haicold Cooling Technology Co., Ltd**

SFN Line *Validation No. C76B-20R00*

**Zhejiang Jinling Refrigeration Engineering Co.,Ltd.**

JFT Series *Validation No. C28C-16R02*  
JNC Series *Validation No. C28B-09R01*  
JNT Series *Validation No. C28A-05R05*

**Zhejiang Ryoden Cooling Equipment Co., Ltd.**

RT/SB Series *Validation No. C102A-18R00*

**Zhejiang Shangfeng Cooling Tower Co., Ltd.**

SFB Line *Validation No. C73A-15R01*  
SFCFG Line *Validation No. C73B-20R00*

**Zhejiang Wanxiang Science and Technology Company, Ltd.**

WBH Line *Validation No. C96A-17R01*

**Always Look For the CTI Certified Label with Validation Number on Your Equipment**



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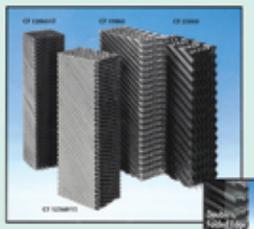
### New Cooling Towers:

- Counterflow • Crossflow
- Wood • FRP



### Professional Services Include:

- Cooling Tower Evaluations
- Bid Preparations • Wood Analysis
- Thermal Engineering



### Field Services Include:

- Repair & Overhaul
- Scheduled Maintenance
- Inspection & Evaluations
- Emergency Service



## Nationwide Service

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Toll Free: (800) 631-1196  
 NJ: (973) 966-1116  
 NY: (212) 355-0746  
 Fax: (973) 966-5122

E-Mail: [stefanguetzov@towerperformance.com](mailto:stefanguetzov@towerperformance.com)

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 E-Mail: [ctowers@tpila.com](mailto:ctowers@tpila.com)

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Berkshire Hathaway  
Company



# Marley Cooling Tower Modularized Construction

*Shorter Schedule with Safety & Quality*

## Schedule Benefits

- Factory pre-assembled components – including structural members, fill packs, water distribution system and power train – are staged to arrive when needed.
- The structure, fill packs and distribution system are hoisted directly from the truck to the tower substructure.
- Assembly averages up to eight modules per day.

## Safety Benefits

- Fewer workers on site for shorter duration.
- Limited work in confined spaces and at elevation.
- Less handling and laydown area required – component assemblies are hoisted directly from the trucks.

## Quality Benefits

- Components are manufactured in a quality-controlled factory environment.
- Assembly kits are inspected and tested prior to shipment.
- Smaller onsite crews are more qualified, experienced erectors.

## Modular Solutions Designed to Your Requirements

- Counterflow – F400 to MD Everest®
- Crossflow – F600 to NC Everest®

**Contact Us:** [spxcooling.com/process-cooling](http://spxcooling.com/process-cooling)  
**Marley Parts & Service Houston:** 1-800-4-Marley  
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