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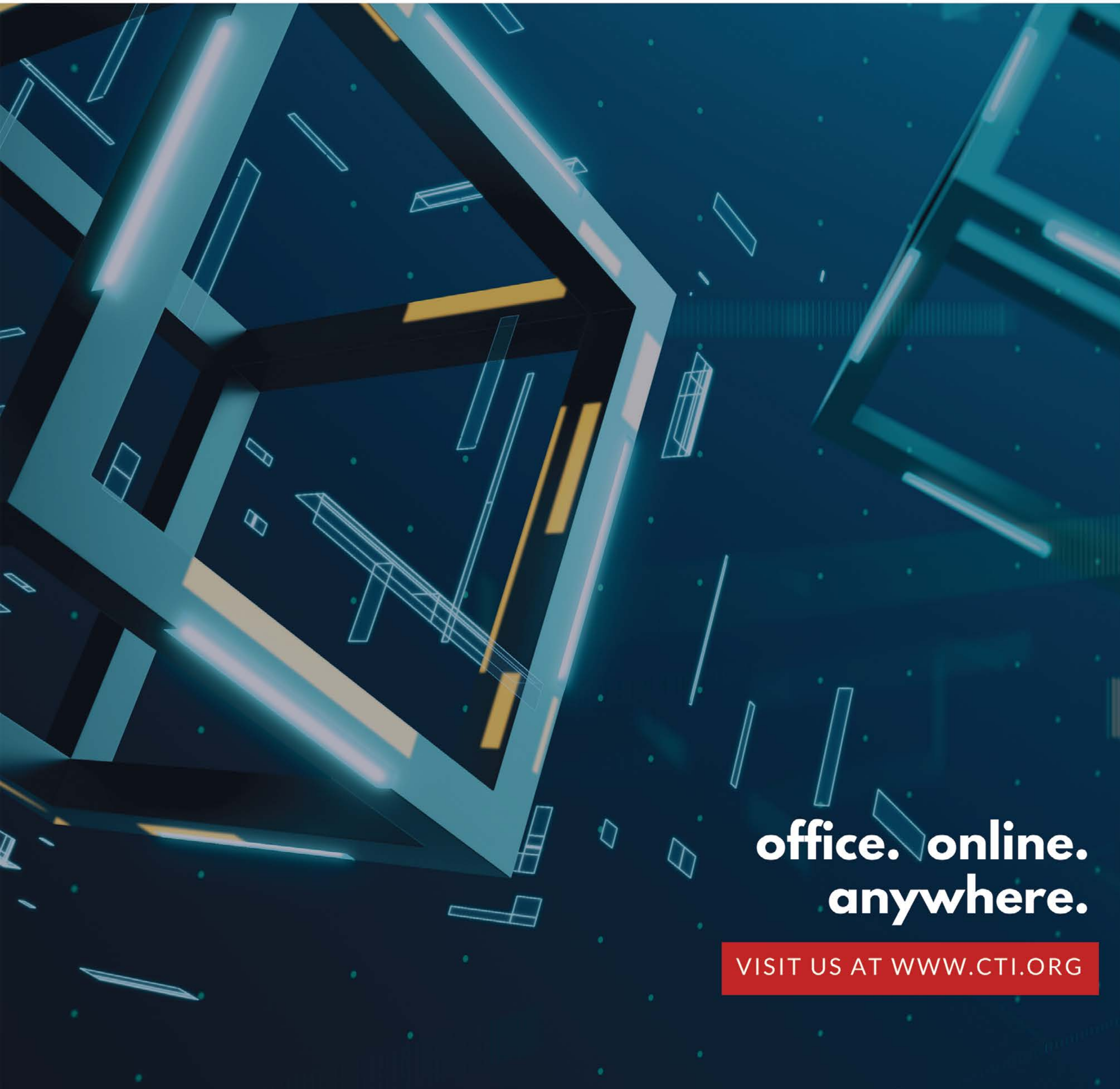
A Publication for the Cooling Technology Industry

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MISSION STATEMENT

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

LETTERS/MANUSCRIPTS

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

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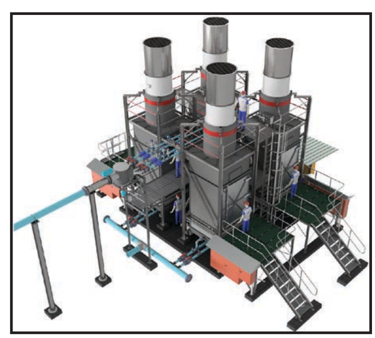
Contents

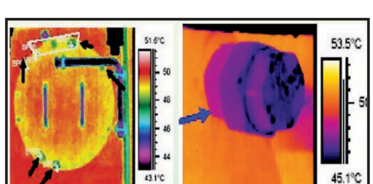
Feature Articles

Special Sections

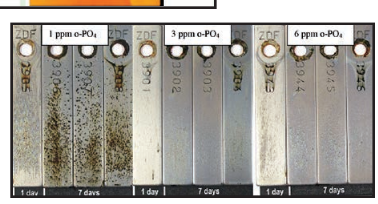
Departments



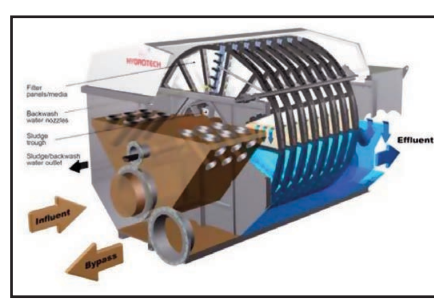
See Page....12



See Page...23



See Page...42



See Page....54

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Address all communications to:

Virginia A. Manser, CTI Administrator
Cooling Technology Institute
PO Box #681807
Houston, Texas 77268
281.583.4087
281.537.1721 (Fax)

Internet Address: http://www.cti.org
E-mail: vmanser@cti.org

For Immediate Release

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

11-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, 2022, at the CTI address listed.

Future Meeting Dates

Committee Workshop	Annual Conference
July 10-13, 2022 The Steamboat Grand Steamboat Springs, CO	February 6-10, 2022 The Westin Galleria Houston, TX
July, 2023 TBD	February 5-9, 2023 The Peabody Hotel Memphis, TN

View From The Tower

"Lately it occurs to me what a long, strange trip it's been."

Chris Lazenby

After the last sixteen months, filled with all variety of new experiences and firsts for us, it seemed appropriate to start with the first ever quotation of the Grateful Dead in a CTI publication. (NOTE: This statement has not been verified by the CTI Office, but really, do you think it's happened before?) I was never a humongous fan of the group, but I couldn't think of a better description for the COVID era. Finally, though, over 500 days later…

We're back!

The CTI's first face to face meeting since February of 2020 took place last week in Santa Fe. In any other year, I'd be writing about all the great work that got done on our Codes & Standards, the progress of our Certification program, the new CTI web site set to be unveiled in a matter of weeks, or a number of other things that happened during the week. This year, though, the big news was just that these things were worked on by real people, sitting (properly spaced) in actual meeting rooms, talking - and occasionally even disagreeing - with each other. It was great!

I know that many of you did not make it out to Santa Fe for a variety of reasons. As I was reminded by more than one person during the meeting, we are blessed in the United States that our health care infrastructure and the widespread availability of vaccines seem to have allowed us to turn a corner with COVID (although even over the last few days, it seems like variants may be casting doubt on that in some areas). Many other places in the world, though, are still not quite there. In fact, many of our members come from countries where virus rates are still high and COVID restrictions are still in place. And even for many here in America, corporate restrictions or personal choice kept you away. You were all missed, but as we've said from the beginning, nothing is more important than your safety and there is no such thing as being too cautious where that is concerned.

Some of you that could not attend physically were still able to participate virtually. To me, you deserve a special thank you for sitting through hours of Zoom meetings. After a year and a half of Zoom fatigue, that is real dedication! It also raises a point that we as the CTI need to think about moving forward:

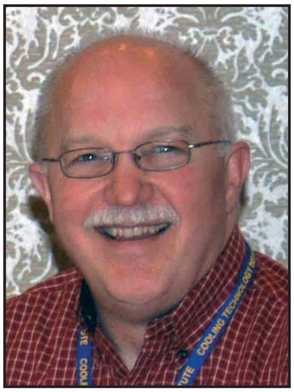
Like most, we as an organization had to learn how to do some things differently in the COVID era out of necessity. For us, that meant incorporating technology into the way we operated and the way we met. As things (hopefully) continue to open and we can return more and more to gathering in person, are there ways that we can incorporate some of what we've learned and used to make our organization and our events even better in the future? This idea was discussed multiple times during our meetings in Santa Fe. There were several good ideas and suggestions of things we might consider, and I would welcome any feedback in that area moving forward.

Whatever we decide to do, I am confident that we will be able to execute it successfully due to the efforts of the CTI Staff. After doing an outstanding job navigating through a couple of purely virtual meetings, this was our first attempt at a "hybrid" meeting. And while there were a couple of hiccups along the way both in the virtual and in-person portions of the meeting, Andrew, Angie, Kelli, and Vicky rose to the challenge and made it all work (and even upgraded the registration process along the way!). As always, thank you very much for your hard work and flexibility.

I also cannot mention the CTI staff without noting that one of our staff members had a rather significant anniversary this year. I won't get into too much detail now other than 1) I won't mention what I was doing forty years ago, and 2) this subject may come up again in a few months in Houston.

And on that note, go ahead and mark your calendars for our 2022 Annual Conference at the Westin Galleria next February. It is my hope that things continue to improve globally to that point that anyone that wishes can be in Houston to attend in person. If that is the case, we may very well break the attendance record we set at the 2020 Annual Conference! If things end up turning in another direction between now and then, it will certainly be a major disappointment, but if the last sixteen months have taught me anything, it's that the CTI will just keep truckin' on. As always, thank you for being the CTI, and please continue to stay safe!

Editor's Corner



Paul Lindahl

As this is being written in July, 2021, the impacts of Covid-19 have begun to wind down, and barring issues with the emerging variants things should continue to open up. CTI had its hybrid meeting in Santa Fe, NM, July 11-14, with some members attending in-person and others virtually. A number of meetings in the fall for other organizations are already being planned for this mode. FYI, ASHRAE is planning on a face-to-face meeting and show in Las Vegas (aka Lost Wages) in January, 2022. Over 68,000 people attended in LV in 2017. Here's hoping 2022 continues this trend!

CTI continues to be active in working to influence governmental and other organization standards that impact our members; note that activity has slowed somewhat. A brief overview:

California Title 24 – We believe that they will push for increased energy efficiency for evaporative heat rejection equipment 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 still not yet seen language to confirm that.

US DOE Fan Rule – A notice has been posted asking for feedback on an AMCA test method for fans using a Fan Energy Index (FEI). Multiple organizations have commented on this, and have supported CTI's request for exemption of embedded fans per the ASRAC agreement within the DOE process some years ago. DOE is becoming more active in energy related issues with the new administration. No response from DOE yet.

ASME Boiler & Pressure Vessel Code – The scope task force is still 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. It was not in the current revision, but it still on the agendas for the BPVC scope task force.

Legionnaires' – CTI has published GDL-159 for evaporative heat rejection equipment (cooling towers, open and closed loop, and evaporative condensers). The Guideline 159 committee is meeting in Santa Fe in July to consider possible improvements to the existing Legionnaires' document for cooling towers, open and closed, and evaporative condensers. ASHRAE Guideline 12-2020 has been released and is in continuous maintenance. ASHRAE Standard 188 will be republished with multiple addenda included in 2021 and is also in continuous maintenance. ASHRAE Standard 514P is in development to cover other building water system hazards, and CTI has official organization representatives, Helen Cerra and Frank Morrison. An advisory public review was successful in gaining a number of comments, which are being considered in 2021.

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

Our goal is to introduce a new CTI regulatory update newsletter this year on the CTI website for CTI members only. Watch for notice of availability as CTI members by email.

Hope to talk with many of you in-person when we meet in February if not sooner.

A Fouling And Thermal Performance Test Rig For Cooling Tower Fill Selection

Johannes P Kotze TF Design
Ockert Augustyn Eskom Soc Ltd

Abstract

Eskom's coal-fired power stations mostly have natural draft wet cooling towers, where excessive fouling results in maintenance and performance issues. Eskom is planning to replace the asbestos fill in selected cooling towers, and needs to evaluate potential replacement fills. A set of four test rigs have been built that simulate conditions within a natural draft wet cooling tower. Water tapped from a cooling tower is used in the test. Both the fouling and thermal performance of the fills are measured as fouling occurs over time. This paper presents the overall design of the test rig and initial results.

Johannes P Kotze

Introduction

Eleven of Eskom's fleet of fifteen coal-fired power stations are cooled by natural draft wet cooling towers. These were built with asbestos cement cooling tower fill and water distribution manifolds. Eskom has committed to the phasing out of asbestos products in its power stations within the next 15 years. Most of these power stations draw water out of surrounding freshwater dams or the Usutu-Vaal system, which has some water quality challenges that result in scaling and fouling build-up. The fouling poses major operational and maintenance issues and over a period of many years resulted in under-performance of the cooling towers, which in turn cause significant vacuum load losses.

In the light of these issues and the requirement to phase out asbestos, the question arises as to what fill is the most suitable as a replacement in these power stations to ensure long-term performance of the cooling towers. Eskom proposed that various fill types be tested for thermal performance (du Plessis, et al., 2018); and fouling along with the thermal performance of fouled fill. A three-phase evaluation program has been set out by Eskom, where an independent contractor, TF Design, performs tests on cooling tower fills to determine fouling characteristics and the effect of thermal performance of fouled cooling tower fills. The first phase would be to construct the test rig and gain significant operational experience on fouling testing, where the second is to formally test a selection of fills based on the knowledge gained during the first phase. The facility is installed next to a large cooling tower (Figure 1), using hot water from distribution piping in the tower.

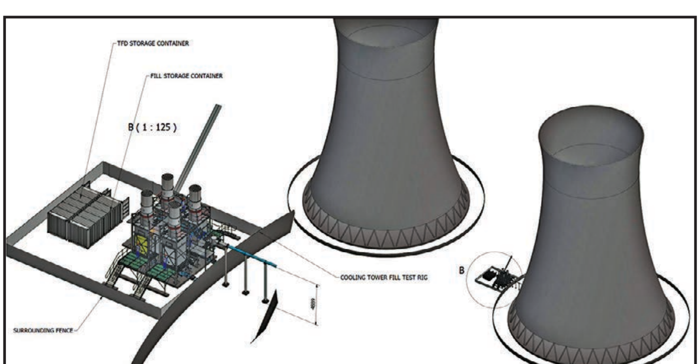


Figure 1- Location of test rig next to the cooling tower

This paper is the first of a series of three papers that will document the testing program and is intended to introduce the overall testing program and test rig to the wider CTI community. The intention is to gain early input from interested parties such as utilities and manufacturers to shape ideas around the testing methodology. Preliminary data is presented to demonstrate the functionality of the test rig prior to the first phase of testing.

Testing Program

The test program falls under Eskom's broader fill replacement strategy outlined in Figure 2. Testing is currently planned in two phases. The first phase will last one year with the intention to gain operational experience with the test rig. The results obtained during this first phase will be used to establish a standardized test protocol for the second phase, also lasting one year, where fills will be evaluated in a side by side comparison.

In each of these phases, four fill materials will be selected. Out of courtesy to the manufacturers, the identity of the various fill materials will only be disclosed to TF Design and Eskom, and all data displayed will be only identified by a number. An attempt will be made to present useful data and conclusions to the wider CTI community without disclosing the identity of the supplier.

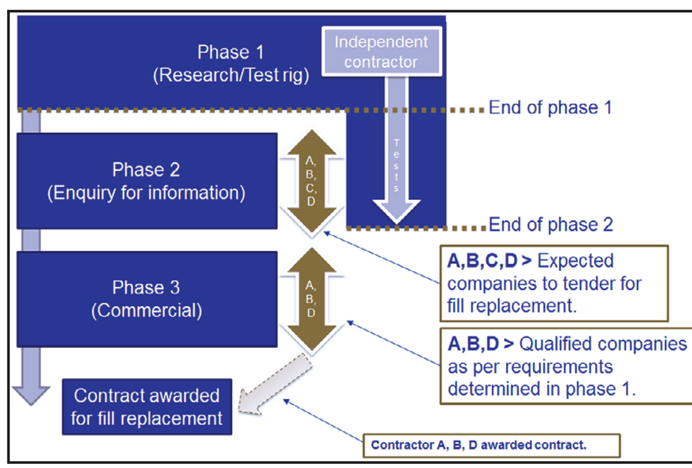


Figure 2: Summary of Eskom's cooling tower fill replacement strategy

Literature Review

Generally, the main objective for all fill fouling testing is to observe and compare the level and rate of fouling occurring in the tower with the aim of linking the cause of fouling to some parameter, whether it is the quality of water or the design of the fill. Fill fouling testing is currently done in one of five methods:

- Laboratory methods (Mortensen & Michell, 2013) (Zaorski & Miller, 2017)
- Online or In situ cooling tower baskets and load cells (Monjoie, 2009) (Troncin, 2012) (EPRI, 2015)

- Field method of removal and weighing (Mortensen & Michell, 2013)
- Probing (Mortensen & Michell, 2013)
- Load cell in an operating cooling tower (Mortensen & Michell, 2013)

Morstensen & Michell (2013) summarized these methods very neatly in their paper, outlining the merits and pitfalls of each of these testing methods.

In laboratory testing, the general setup consists of a single or multiple bays where fills are sprayed with water of which the mineral and nutrient composition of the water is carefully controlled. Some of these setups are shown in Figure 3, Figure 4 and Figure 5. The advantage is that these setups are relatively compact and easy to control in a laboratory environment. It enables researchers to do a side by side comparison of various fills in a controlled environment. The results gained in these chambers is normally limited to biological fouling, but to draw conclusions to real-world application is tricky since there is no air cycling through the fills. The water composition is also bound to be industrially irrelevant, as water composition needs to be controlled in some manner. Accuracy of water composition control is only subject to the ability to measure all aspects of water composition. With full composition analysis being too costly for repeated testing at short intervals, the water composition will always remain artificial. The advantage of these tests is that tests can be artificially accelerated.

In tests done by Zaorski & Miller (2017), shown in Figure 5, the fill was subsequently removed and tested in a counterflow cooling tower test cell to compare the performance difference between the fouled fill and unfouled fill. It could be argued that the lack of air flow through the fill during the fouling process will yield results not representative of conditions inside an actual cooling tower. The fact that the fill is handled between the fouling test chamber and thermal test chamber also affects the results. It has been shown that fouling increases pressure drop through the fills, but not the thermal performance. These are reasonable conclusions, but the real world application of fouling rates and mechanisms is brought into question. This is especially true in natural draft cooling towers, where the air flow through the fill cannot be increased by increasing fan power as in forced draft cooling towers, and pressure drop directly leads to deterioration in thermal performance.

Figure 3 - Laboratory fill testing chamber (Mortensen & Michell, 2013)

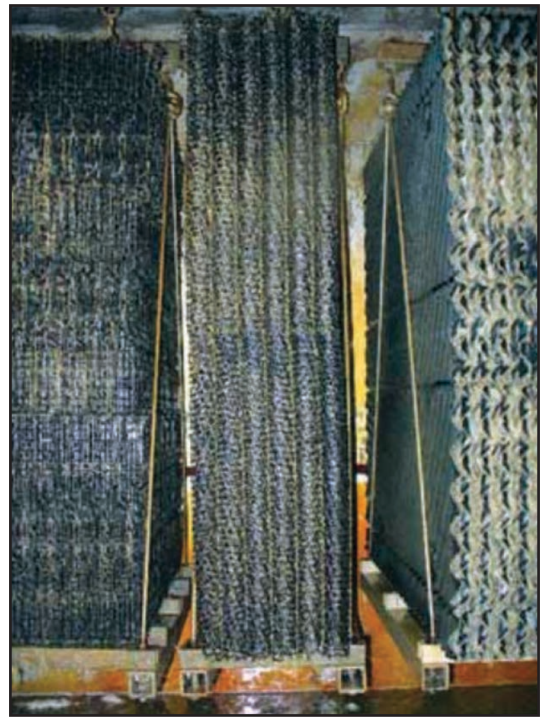


Figure 4 - Fill installed into a laboratory fill fouling test chamber (Mortensen & Michell, 2013)

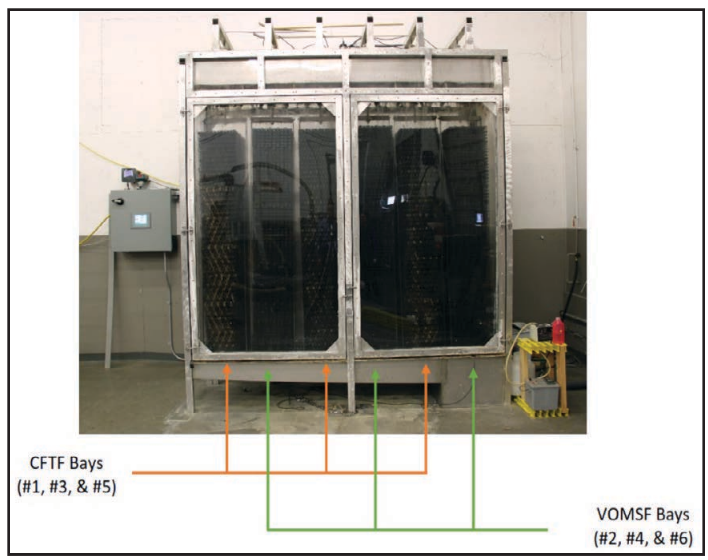


Figure 5 - A laboratory fill testing chamber (Zaorski & Miller, 2017)

In online testing, Troncin (2012) reports the installation of a weighing basket in a natural draft cooling tower as shown in Figure 6. While this solves the problem of industrially significant testing, it lacks detail monitoring of conditions and repeatability. This makes this technique very difficult for side by side comparison of fill fouling performance. Similarly, fills could be weighed by removing them, as shown in Figure 7, reported by EPRI (2015). Whilst this method has similar advantage of being industrially relevant testing, it adds to the measurement uncertainty by handling the fill before measurement.

Figure 6 - Installation of a weighing basket in a cooling tower (Troncin, 2012)

Figure 7 - Fill removal and weighing (EPRI, 2015)

Other methods of testing include probing of fills, but lacks the ability to quantify fouling conditions of a whole block of fill. Placing cooling tower fill in a loose basket, suspended on load cells has also been reported by Mortensen & Michell (2013). This method seems to be one step in the right direction for testing, although the retrofit of an existing cooling tower lacks instrumentation to be able to evaluate thermal performance and possible changes in air side pressure drops.

Table 1 presents a summary of the various testing methods reported in literature. Table 1 indicate that there is a clear need for fill fouling tests that are:

- Industrially relevant
- Sufficiently controlled to perform comparative studies
- Minimizing measurement error
- Tests a large enough section of fill to negate edge effects
- Can evaluate pressure drop and thermal performance of fills

	Focus on Inorganic scaling, or Biological fouling	Industrial representative environment (air flow and water flux)	Free from measurement error due to handling	Controlled environment	Complete measurement and logging of conditions with comparative results	Representative sized testing basket to avoid edge effects
Lab test	Biological fouling	No	Yes	Yes	Yes	No
Online testing	Both	Yes	Yes	No	No	Yes
Field measurement	Both	Yes	No	No	No	Yes
Probing	Both	Yes	Yes	No	No	Yes
Load cell in the cooling tower	Both	Yes	Not Clear	No	Not clear	Yes

Table 1 - Summary of various testing methods reported in literature

Test Facility Requirements

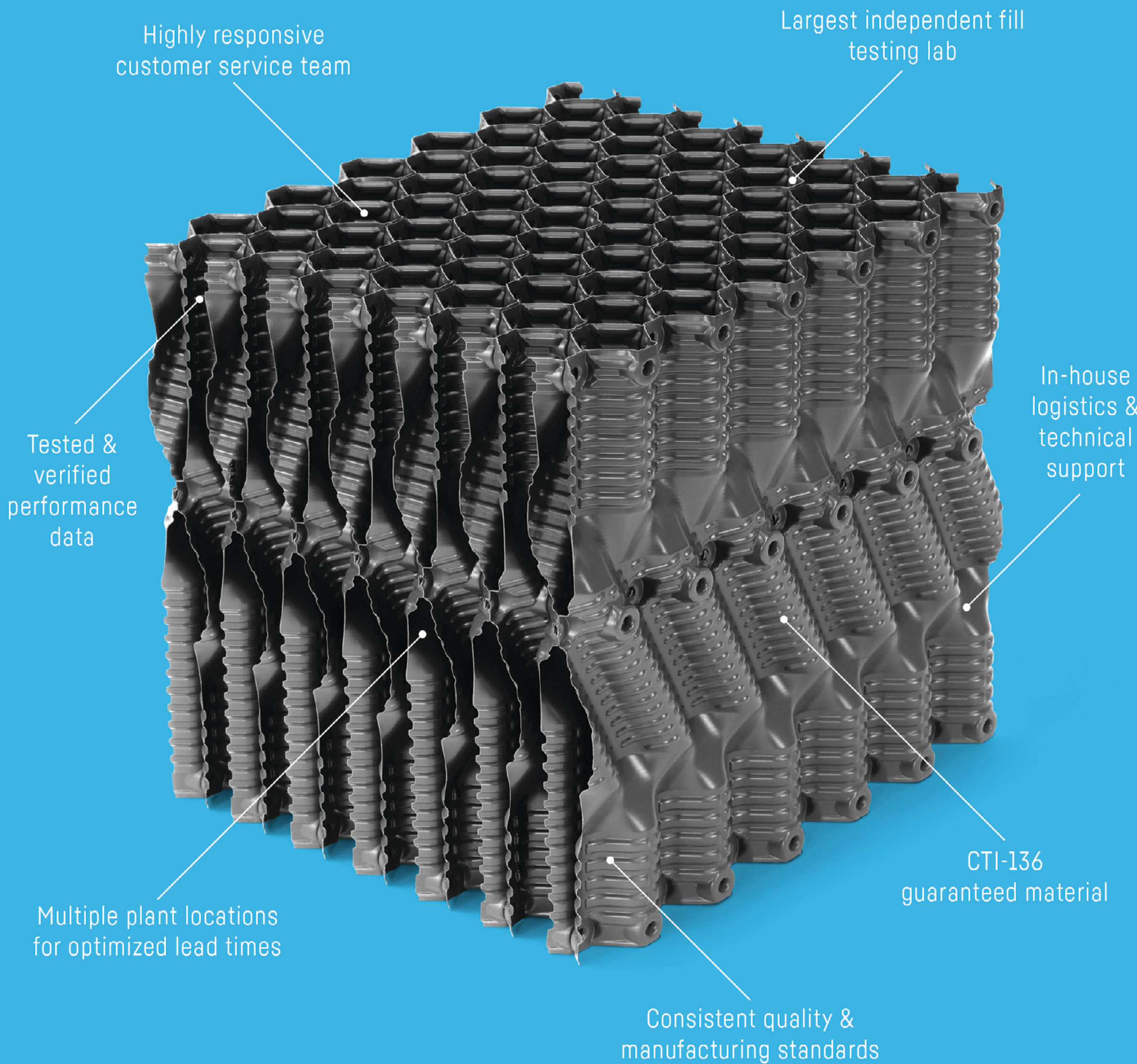
The key design requirements of the test facility have been developed with the focus to make the tests as repeatable as possible, yet keeping them as industrially relevant. The high-level specifications can be summarized as:

- Water supply must be connected to an actual cooling tower struggling with water quality issues and fouling. For this specific project, the water will be piped off from the hot water distribution headers in the cooling towers to the test rig.
- Test rig must be able to deal with debris, scale, flakes etc.
- Mass of the fill must be continually measured and monitored as key metric for fouling, and therefore the fill basket needs to be suspended on load cells.
- Water flux through the fill (Gw) will have to be equivalent to the actual cooling tower at 2.6 kg/m2s.
- Water that bypasses the fill along the walls needs to be accounted for and measured separately
- Air velocity (Va) through the fill must be adjustable between 1.5 m/s and 2.5 m/s
- Thermal performance of the fill should be continually calculated as per Merkel's theory and presented as a normalized Merkel number (KaV/L or MK.1) on a continuous basis as per Kröger (1998).
- Pressure drop over the fill should be continually measured and presented as a normalized pressure drop coefficient (Kfdm1) as per Kröger (1998)
- Frontal area of the fill should be 1.5m x1.5m, and the basket must be 2m deep.
- Because the facility is far from both the TF Design Headquarters and Eskom head offices, all logged data will be stored on cloud storage and periodically backed up at TF Design throughout the test progress.
- Four test cells will operate simultaneously for comparative studies.
- Water quality data will be obtained from power station's water treatment department and will be held as a reference for test conditions.
- System needs to be designed in a manner to minimize the external effect that wind may have on the performance and measuring techniques.

The facility design started with a mathematical evaluation of what is needed for the continuous calculation of the Merkel number and pressure drop loss coefficients. The Merkel number is defined as:

$$\frac{KaV}{L} = \int_{T_{wo}}^{T_{wi}} \frac{c_{pw} \cdot dT_w}{(i_{masw} - i_{ma})} \approx \frac{c_{pwm}(T_{wi} - T_{wo})}{4}\left[\frac{1}{\Delta i(1)} + \frac{1}{\Delta i(2)} + \frac{1}{\Delta i(3)} + \frac{1}{\Delta i(4)}\right] \quad (3.1)$$

VALUE.



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The integral is evaluated through Chebyshev integration in real time as per Kröger (1998) example 4.3.1. The outlet enthalpy of the outlet air is calculated on an energy balance, rather than being measured, as localized conditions in the outlet air after the fill may affect readings. It is measured in practice for verification. The specific heat capacity of water (cpwm) is evaluated at the arithmetic mean of the inlet and outlet water temperatures (Twi and Two respectively). $\Delta i(1)$ through $\Delta i(4)$ is the enthalpy of the water evaluated at the intermediate temperatures according to the Chebyshev intervals.

In evaluating the pressure loss coefficient, it is taken to be defined in terms of the mean air-vapor flow rate and its average density through the fill.

Cooling Tower Fill Fouling Facility Design

The cooling tower fill fouling testing facility is presented in Figure 8. It consists out of a set of four fouling test rigs mounted in steel frames on a concrete plinth. It is 8.4m high and has three levels at which operators can easily access the instrumentation of all four test rigs.

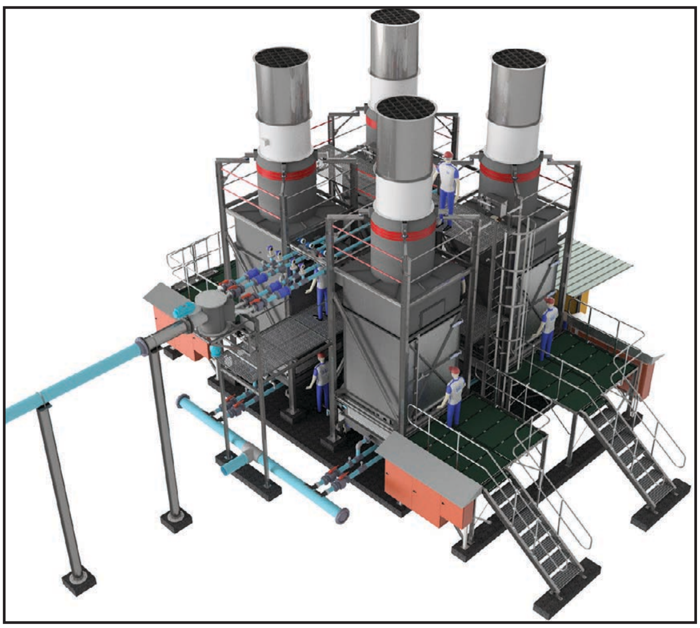

Figure 8 - Eskom cooling tower fill fouling testing facility - isometric view

Each of the test cells consists out of:

- Sump
- Louvre section
- Fill housing with load cells and fill basket
- Sprayer and drift eliminator section
- Airflow measuring section
- Fan section along with adaptor cone and top-hat

As the facility will be running remotely, the emphasis has been placed on robust design along with remote control and monitoring capabilities.

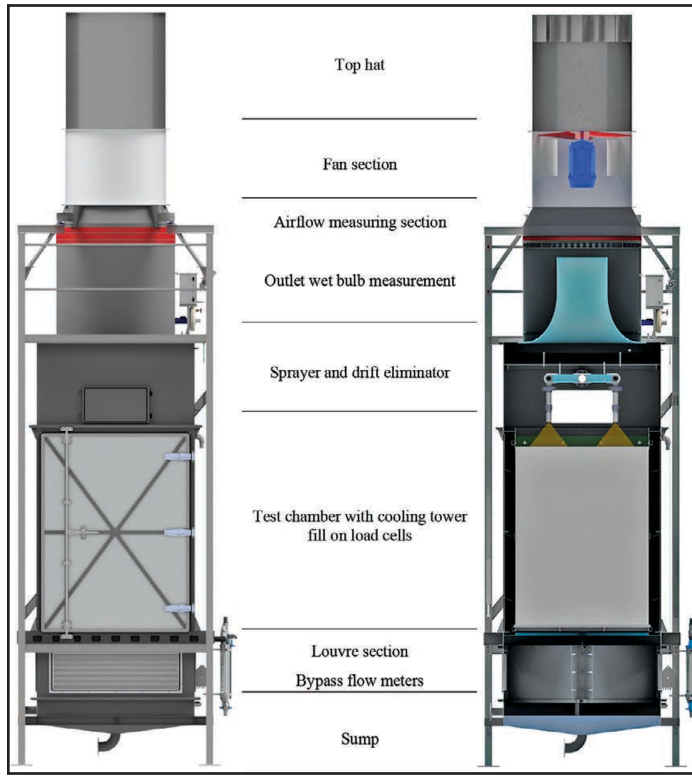

Figure 9 – Cross section of fill fouling test rig

The facility design has been done based on a P&ID diagram that outlines all hardware needed for testing. The P&ID of a single test cell is presented in Figure 10. The following subsections are dedicated to outlining some of the key design considerations in the test facility:

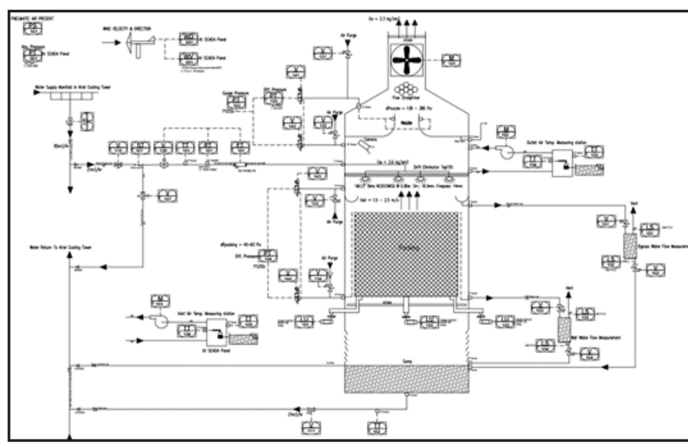

Figure 10 - Fouling test rig P&ID (Details in Appendix A)

Fill mass

The fill is suspended on three load cells (Figure 11), each rated at 500kg, with an accuracy of 0.02%. Each load cell is hermetically sealed and will be fitted with a rain cover. The basket can be jacked up by using a removable hydraulic jack installed just above the load cell as shown in Figure 12.

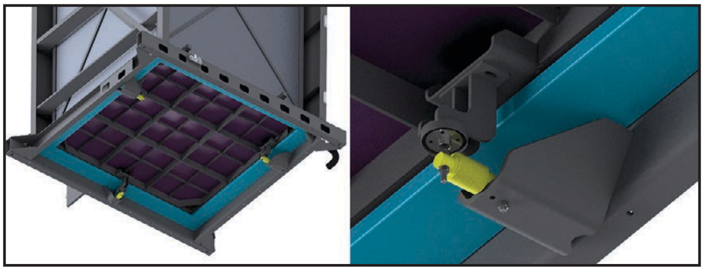

Figure 11 - Load cell placement and load cell mounting

Figure 12 - Test section showing fill basket and bottle jacks

Airflow measurement

Airflow is measured using an ASME 550mm diameter long radius low β nozzle with a discharge coefficient of 0.98, as shown in Figure 13. It is located after the drift eliminator and has honeycomb installed (Figure 14) above it to prevent the fan's vortex from affecting the measurement. All the pressure taps are connected with a blowout system allows it to be cleaned out using compressed air. The pressure measurement is done using an E&H PMD75 differential pressure transducer. The inlet air density is calculated using an E&H PMP51 absolute pressure gauge that acts as a barometer, and an E&H PMD75 to measure the differential between ambient and the pressure inside the tower just before the nozzle inlet. The air temperature and humidity ratio are measured with a wet bulb station just before the nozzle.

The air flux through the fill will be controlled using a VSD on the fan, and it can either be used to control pressure drop constant or velocity through the fill, depending on the experiment.

Figure 13 - 550mm ASME low beta nozzle

Figure 14 - Nozzle housing with honeycomb on the outlet


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Pressure drop over the fill

The pressure drop over the fill is measured using an E&H PMD 75. The pressure before the fill is measured in the sump based on 12 pressure taps located in the center baffle as shown in Figure 15. The outlet is measured in the sprayer section just above the fill. Similar to the pressure drop, it has been fitted with a blowout system that blows the pressure taps clear at intervals in case they get clogged. A cross in the middle of the louver section is designed to prevent external wind to cause flow maldistribution that will affect pressure drop performance.

Figure 15 - Centre cross in the louver section with pressure taps

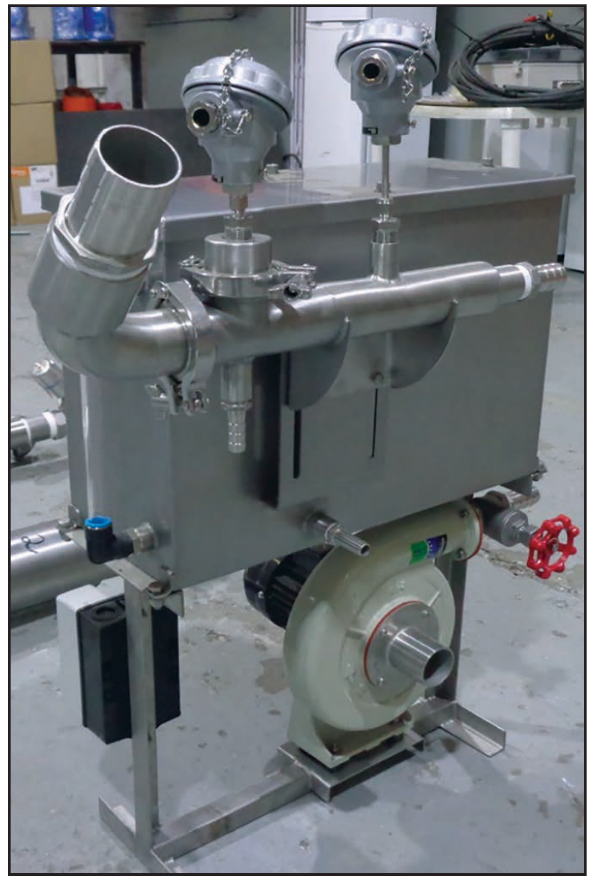

Figure 16 - Wet bulb station

Air temperature measurements

Air temperature and wet bulb temperature is measured using a custom wet bulb station shown in Figure 16. The wet bulb station is fitted with a small three phase blower that sucks air over the two E&H PT100 probes, one with a wick. The whole system has been developed with serviceability, robust operation and remote fine-tuning in mind. The ideal wet bulb measurement requires an airflow of about 2m/s, and this can be remotely adjusted using a VSD. If dry out should occur, the fan speed can be scaled down remotely.

There are two of this type of wet bulb stations on each tower. One on the inlet, and one just after the drift eliminator located above the sprayer manifold. The inlet wet bulb station is absolutely critical to measurements, and the second one is to evaluate air temperature for the flow measurement and to be used as an indicator of thermal performance.

Sprayer system and side wall flow meters

In order to minimize the amount of water running down the walls of the test section of the test rig, nozzles have been chosen with a square spray pattern. Standard cooling tower sprayers, even those rated for evenly distributed square spray patterns, do not throw a spray pattern in a square footprint on a 1.5m x 1.5m area. For this reason, a special spray nozzle has been sourced with perfectly square spray pattern as shown in Figure 17. These sprayers have a similar droplet size as regular cooling tower nozzles and can handle particle sizes of up to 14mm. These nozzles will minimize the by-pass flow. A CCTV camera is installed on the inside of each cooling tower to monitor the spray pattern and check for potential blockages. The spray manifold is shown in Figure 18 along with the CCTV camera.

Figure 17 - Nozzle square spray pattern and distribution being measured and evaluated

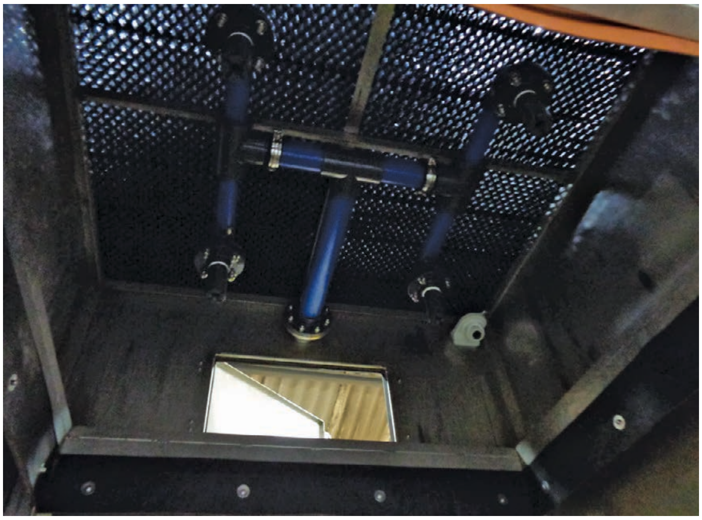

Figure 18 - Sprayer manifold with IP camera in the back corner

Bypass water flow is measured by a custom built volumetric flow meter. The one unit measures the flow of water that collects in the gutter just above the bundle, and another unit collects the water that ends up in the gutter around the bottom of the fill support basket. The bypass flow meters have been calibrated over the full range of operational flow rates expected and has an accuracy of 0.5%. The bypass flow meters consists of a cylinder used as a measuring volume using a set of level switches at the top and the bottom of a cylinder to indicate the full and empty positions. A set of angle seat valves are switched to empty the flow meter's measuring chamber when it is full, and water flow rate is calculated based on the intervals between being emptied. The bypass flow meters are shown in Figure 19.

Figure 19 - Side channel flow meters

Water flow control

To ensure that the water flux is correct, the flow rate into each sprayer manifold is measured by an E&H 10D80 flow meter, and controlled using a variable pressure control valve and a pinch valve. Blockages can be monitored through the water inlet pressure transducer, a PMC51. Each nozzle has a characteristic discharge coefficient, and if the flow is not attained at a higher pressure, then a blockage has occurred.

Water inlet and outlet measurements

Water inlet and outlet measurements are done using a PT100 in the inlet manifold and at the sump outlet. The effect of the rain zone will be evaluated with a small sampling station (Figure 20) that can travel along with the cross braces. The difference between the measurement at the sampling station and the water flowing in the sump return will be compared for various fills.

Figure 20 - Temperature sampling station

Accommodation for wind effects

A cross plate in the louver section (Figure 15), prevents the wind from smothering the inlet of the tower, and similarly, a crisscrossed top-hat section (Figure 8) prevents wind from smothering the fan. An ultrasonic wind sensor will log the wind conditions throughout testing to determine if there are any weather anomalies present.

Control system and connectivity

The control system is a Siemens PLC along with:

- SCADA running on a panel mount industrial display
- Remote login through an industrial GSM modem
- Netbiter web-based storage for additional backup connectivity capabilities and ability to present data live to all interested parties

The system will be monitored daily for operational issues, and data will be analyzed on a weekly basis.

Initial Results

The four test rigs are operational, and rig 1 is running in a pre-commissioning trial to establish an optimal operational method and long term testing methodology. The rig is shown in Figure 21.

Figure 21 – Test rig installation

Remote connection through a custom SCADA enables remote monitoring and operation of the test rig by all interested parties. A screenshot of the SCADA is shown in Figure 22.

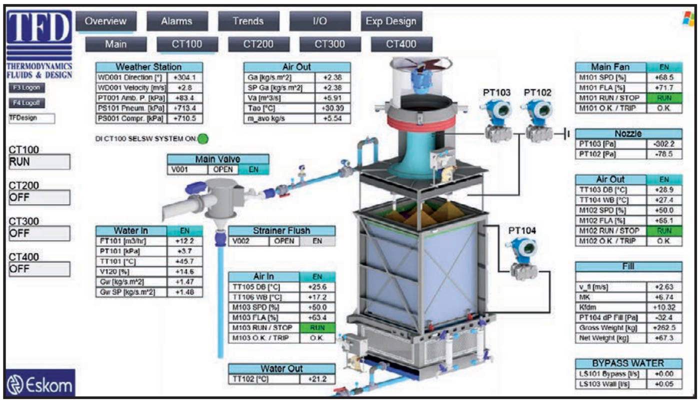

Figure 22 - Remote access SCADA

To obtain initial data and to validate the experiment, a high performance, high fouling dummy fill with known characteristics has been installed into rig 1. The rig has been programmed to run a range of tests to evaluate the ability of the system to control and hold set points for testing. The long term test program consists out of:

- Daily mass measurement at 7 pm after a 10min drip-dry
- A strainer flush at 7 am every morning
- Weekly Merkel number and loss coefficient measurements at 2 am every Friday morning
- Continuous running at a set point. At this stage Ga=2.0 kg/m2.s and Gw=2.6 kg/m2.s

The dummy fill was loaded and a test was run through the summer break from 14 December 2018 through to the 23rd of January 2019 to uncover any issues that may hinder long term testing. During this time, some issues were discovered that had to be resolved before long term testing can commence.

Fouling and mass increase

During this testing period, an unforeseen scheduling and measuring interval issue with the PLC caused the daily drip dry not to be recorded, as such, only data between the 10th and the 19th of January 2019 was available. On the 19th of January, there were alterations made to the load cell covers, skewing the data again, but the bit of data that can be presented is shown in Figure 23. An average mass increase of 179g per day was recorded. Figure 24 shows how biological fouling is attaching to the fill, and it can be seen how ridges act as nucleation points for bacterial growth.

Thermal performance and pressure drop

Measuring thermal performance of fill is typically done in laboratory conditions where ambient conditions and inlet water conditions are carefully controlled. The challenge with online measurement in a real-world rig is that ambient conditions and water inlet conditions vary as shown in Figure 25. Thermal performance data of the rig over a matter of 5 days is shown in Figure 26. It can be seen that the Merkel number fluctuates on a daily cycle with some noise. Tests showed that is due to solar radiation incident on the rig itself and a control issue on the water inlet valves. This will be rectified by installing radiation shields and new control valves. The fluctuation also shows that the daily Merkel number evaluation should only occur in the early morning where there are less ambient disturbances.

Range testing will be done, but only at very long intervals, as it is extremely time-consuming and subject to

An energy balance between the inlet and outlet streams is presented in Figure 27, showing satisfactory levels of measurement performance, as it fluctuates around 3%, with more energy leaving the air stream.

Pressure drop through the fill is fairly constant and is within the expected bounds.

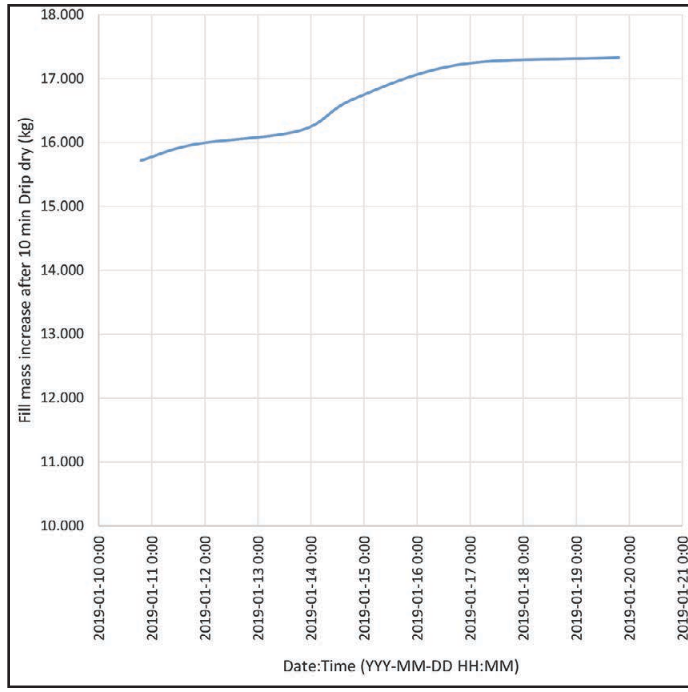

Figure 23 - Fouling data captured.

Figure 24 - Biological fouling starting to grow on the fill

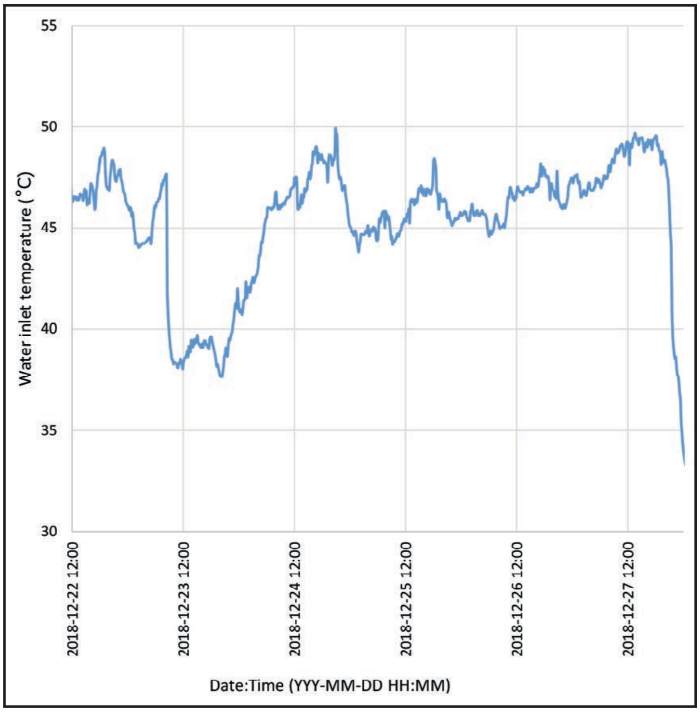

Figure 25 Water inlet temperature

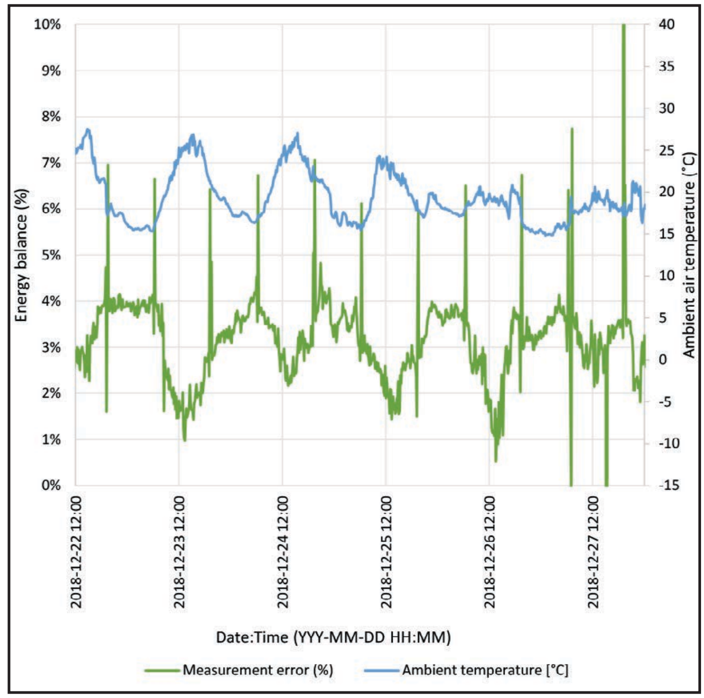

Figure 27 - Energy balance

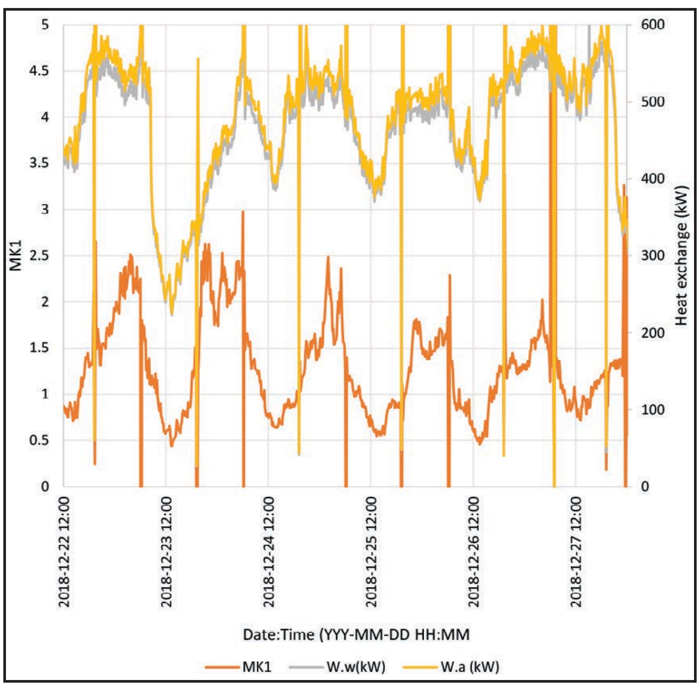

Figure 26 - Heat transfer and normalised Merkel number

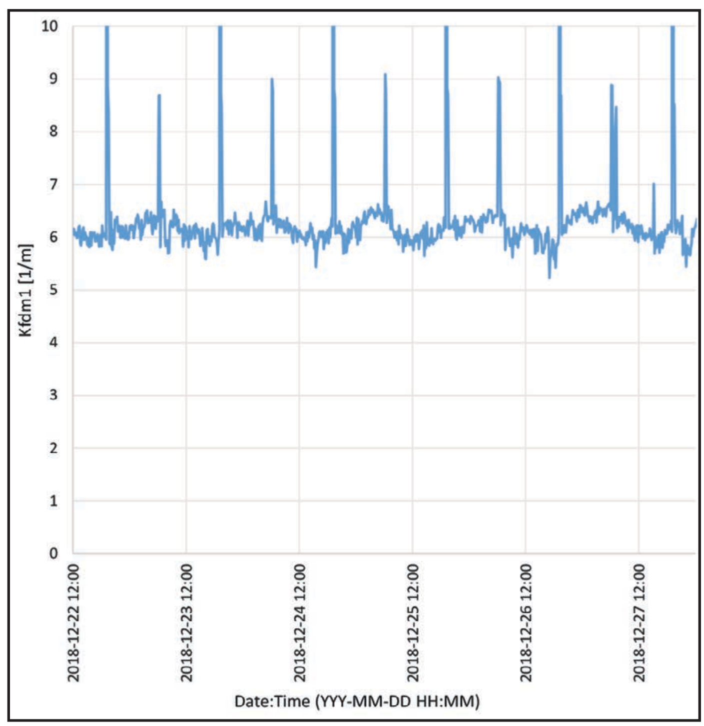

Figure 28 -Dimensionless pressure drop coefficient

Conclusion

Eskom needs to replace a significant portion of its fleet's cooling tower fill over the next two decades. With fill performance and fouling performance in question, Eskom has embarked on a three-stage program to evaluate various fills in an industrially relevant test setup, using water from a cooling tower with known fouling issues.

The past testing methodologies are not sufficient for fouling and performance testing in a comparative study in an industrial setting, and a new test rig had to be devised. This paper is the first of a series of three papers that outlines the testing program and aims to familiarize the broader CTI community with the proposed testing methodology and the hardware developed for these tests, with the hope that feedback from the broader community might be beneficial to the program as a whole.

Initial testing of rig 1 uncovered any unforeseen issues regarding the rig design and helped to form a testing methodology to ensure successful testing for a year. Riggs 2, 3 and 4 are finished, and parallel testing of four significantly different fills will start in the second week of February 2019. The first year of testing is designed to evaluate the testing methodology itself, which will be used to evaluate four fills side by side in phase 2 (2020)

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ATC-105 And Cold End System Performance

Upendranath Bhupal
Spectrum Consultants Pvt Ltd

Upendranath Bhupa

Presently, the ATC-105 publication of CTI is the most popular Acceptance Test Code adopted in India for the verification of guarantee parameters. This code is comprehensive and easy to use. However, Performance Guarantee (PG) testing of cooling towers by CTI licensed testing agencies is limited to a couple of public sector companies in the power sector in India.

It is only because of the entry of CTI licensed testing agencies in India that certain anomalies concerning the evaluation method prevailing in the industry have come to light. Apart from this, certain other factors related to the condition and operation of the cold end system that contribute to a deviation in the expected CWT have also been brought to light during the course of PG testing in several projects recently. This paper is being presented with an objective to promote the correct interpretation of ATC-105 and its use for the purpose of verification of guarantee parameters of Cooling Towers and also to help understand and eliminate other contributing causes to the deviation in expected CWT. The intent is also to help improve the overall performance of the cold end system.

The above topics are covered under two distinct sections.

Section I

Interpretation of ATC-105

The basis of evaluation of the thermal performance of IDCTs specified in India is the Performance Curve method, which is also recommended by CTI. However, the PG test is at ambient WBT instead of the inlet WBT, as it is considered that the onus of accurate estimation of the recirculation allowance is on the tower manufacturer.

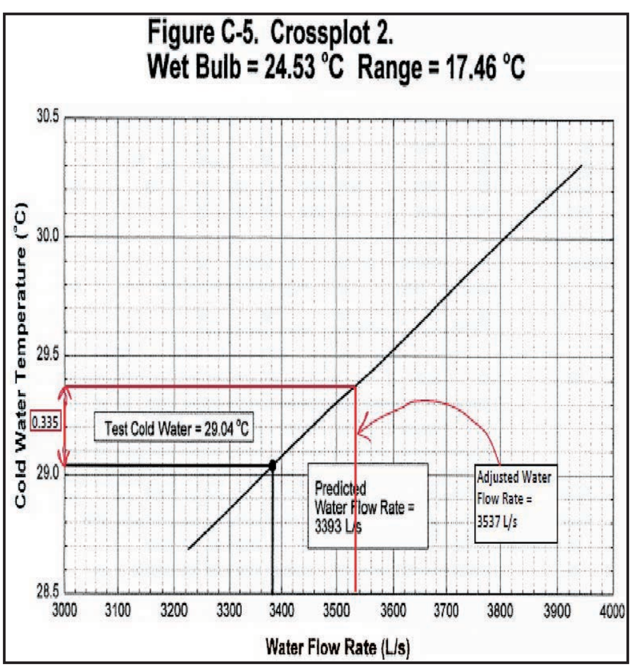

Fig.1 [Crossplot] [1]

TC-105 requires that the tower capability be determined first and then this capability is used to establish the deviation from the guaranteed design CWT as per the procedure laid down in Appendix-M.

Step 4 of the performance curve method in ATC-105 for IDCTs clearly explains that the test CWT should be entered horizontally to intersect the curve on the second cross plot to read the predicted circulating water flow rate vertically below the intersection point. This predicted water flow rate is then used for determining the capability of the IDCT using the adjusted water flow rate, the calculation of which is given in Step 5 of the procedure.

However, it has been found during the CTI tests that the Purchasers generally insist on the opposite of Step 4, i.e. enter the adjusted water flow rate (from Step 5) on the second cross plot to read the predicted test CWT at the intersection point as shown in Fig.1. The Purchaser then compares this predicted test CWT from the cross plot with the CWT measured during the test. The difference between the two values is considered as the deviation in guaranteed performance.

This method has several flaws associated with it as under:

1. It is not valid as the guarantees apply to design CWT and not the test CWT. This is a fact in all contracts globally as only one design point can be guaranteed. All off-design performance ratings depend on test conditions.
2. The adjusted water flow rate formula considers only the fan power variation for correcting the measured test water flow. Since the correction in water flow due to a change in fan power (within the limits specified in ATC-105) is small, the predicted CWT at test conditions using the adjusted water flow in the second cross plot will also be low. This is because this formula assumes that the water flow rate is directly proportional to the air flow rate, which in turn varies as the cube root of the fan power. Whereas the opposite is true for the ATC-105 method because any increase in measured test CWT will result in an increased predicted water flow rate thus, reducing tower capability.
3. This predicted CWT instead of the predicted water flow rate (as per ATC-105) does not indicate the reduction in thermal capability of the IDCT.
4. The thermal capability of the IDCT remains fairly constant, whereas the predicted CWT (as per the deviant method) will vary with test conditions. Hence, establishing the true deviation of the CWT (either design or test) is not possible by doing the opposite of Step 4.
5. In case the test CWT is higher than expected, the remedial measures for improving the performance can only be envisioned in terms of thermal capability and not CWT.
6. Step 4 of ATC-105 and the opposite of Step 4 produce conflicting results, especially when the cooling tower or the cold end system as a whole is in less than desirable condition. For example, an 85% capability established for

a badly maintained IDCT per Step 4 returns a test CWT deviation of about 4.5oC by doing the opposite of Step 4. This is not possible because an 85% thermal capability cannot result in a 4.5oC CWT deviation. Appendix M of ATC-105 results in a 2.5oC CWT deviation, which is expected at about 85% thermal capability. Hence, doing the opposite of Step 4 is incorrect.

7. Step 4 cannot be used for determining both the thermal capability and the predicted CWT from the second cross plot.

In view of the above contradictions, the evaluation method prescribed in ATC-105 must be made mandatory, at least wherever PG testing by CTI licensed agencies is involved and/or wherever ATC-105 is specified to be followed as a guideline for performance evaluation.

In other contracts where CTI licensed test agencies are not involved but ATC-105 is specified, it is a question of enforcing the procedures of the code and hence the manufacturers/contractors must insist on the same to avoid disastrous consequences as above.

Section II

Inter-dependence of Cooling Tower and Condenser Performances

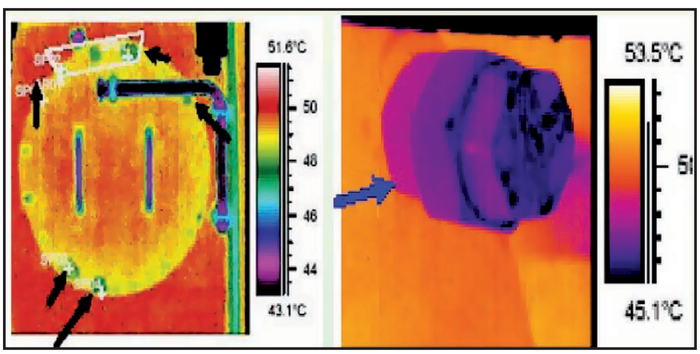

Fig.2 loose bolts of hot well [5]

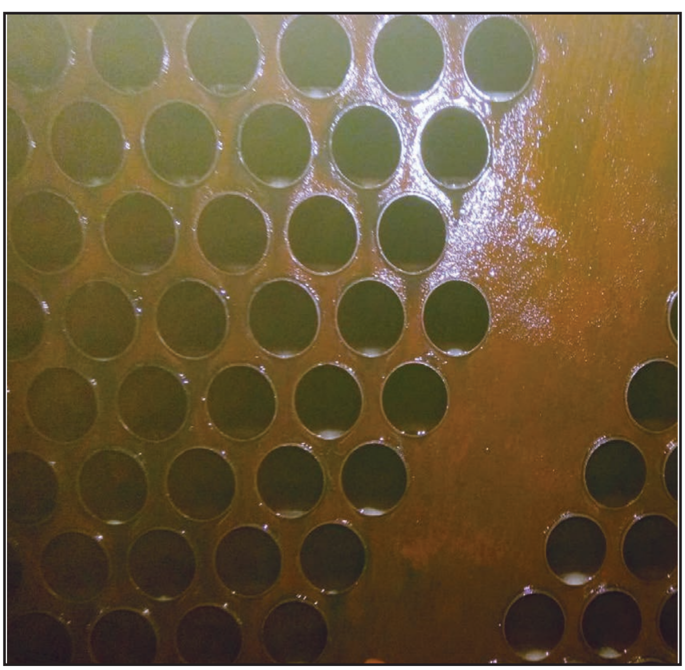

Fig. 3 Scaled condenser tubing in a 500 mw thermal power plant

It is known that the Condenser and the Cooling Tower together constitute the cold end system in a power plant [2]. The performance of these two units is interdependent. Any less than desired performance of the cooling tower due to design issues or condition issues like fouling/scaling, etc. of internals will result in a higher CWT that affects the condenser pressure. Similarly, any performance or condition issues with the condenser (like scaled tubing (Fig.3), air leakages and vacuum pump side issues) will affect the return water temperature to the cooling tower that in turn raises the CWT delivered by the cooling tower.

Even though cooling towers can be tested independently of the Condenser, the true performance will be known only when all the contributing factors for the deterioration in performance are addressed before the PG test.

Fig.4 Scaled pp splash grid fill in the same thermal power plant

Fig.5 [5]

Most of the power plants in India have a configuration where two cooling towers serve a single condenser that is fed from a common pump sump as shown in Fig.6, i.e. the cold water from both the cooling towers mix in the sump before being pumped into the condenser. In some of the recent tests it so happened that the power plant was running at 60% load due to reduced demand from the grid. The range was 60% of design, which means that the PG test could not be conducted. However, a decision was taken to switch off all the fans of the second IDCT (not under PG test) but retain hot water circulation in both the towers so that the range/heat load of the first IDCT (under PG test) increases. In this particular case the expected heat load on the IDCTs based on the performance curves was as under (based on plant operating load):

Tower under PG Test (all fans running):

Water flow rate	: 30,000 m3/hr	
HWT:	39.24°C	
CWT	29.24°C	at a particular test WBT on the day of the PG test)

Tower not under PG Test (all fans switched off):

Water flow rate	: 30,000 m3/hr	
HWT	: 39.24°C	
CWT	: 39.24°C	(assuming no natural draught for simplicity)

Since the cold water from both the IDCTs mix in the channel leading to the pump sump, the final CWT in the sump will be,

$$3 \times 10^7 \text{ kg/hr} \times 1 \text{ kCal/kg/}^\circ\text{C} \times (39.24 - T_f) = 3 \times 10^7 \text{ kg/hr} \times 1 \text{ kCal/kg/}^\circ\text{C} \times (T_f - 29.24)$$

Therefore, T_f = 34.24°C, which means that the condenser is supplied with cold water at 34.24°C instead of the expected 29.24°C at 10°C range and test WBT with fixed design water flow rate. This will result in a HWT of 44.24°C to the IDCTs instead of 39.24°C. This will stabilize over a period of time and the cooling tower under PG test will deliver a CWT that will not match with the expected CWT at test conditions from the manufacturer supplied performance curves. This will have an additional effect on the condenser in terms of increased pressure and saturation temperature of steam as the CWT it receives under the above conditions will not be what it expects at 60% plant load.

Further, the performance of both the cooling towers will be very different when they share the heat load equally. Also, the condenser will expect the lowest CWT that is possible at the plant load when both the towers are fully functional. But as the CWT from a single cooling tower (with no heat load on the second tower) will be higher than when both the towers are functioning, the back pressure in the condenser will rise (Fig.7) resulting in a higher saturation temperature of steam that alters the TTD. This is apart from the increase in CWT because of mixing of return waters from both IDCTs (one returning lower CWT and the other returning more or less the hot water temperature as its fans are turned off).

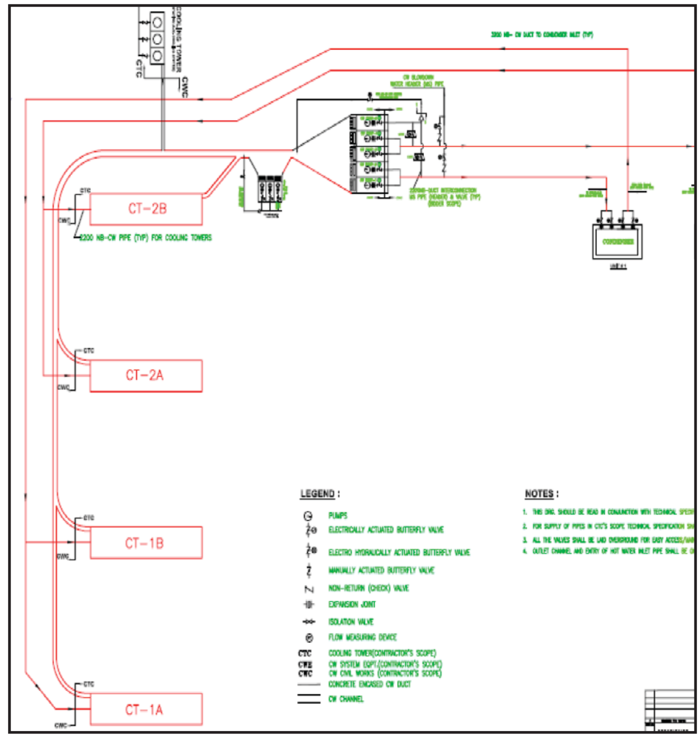

Fig. 6 A typical Layout of the CW System with common HW Header and CW Channel (taken from Purchaser Specifications)

The situation can be even more complex when there are two plant units having 4 IDCTs (2 per unit) with a common outlet channel and pump house. The performance of the cooling tower to be PG tested gets affected because of the non-performance of the other three towers as the cold waters from each of these mix in the common pump sump. The return water temperature will have an impact on the condenser back pressure, saturation temperature of steam and TTD. This configuration aspect of the cooling towers must be addressed suitably in ATC-105 so that true performance of the cooling tower under evaluation is known.

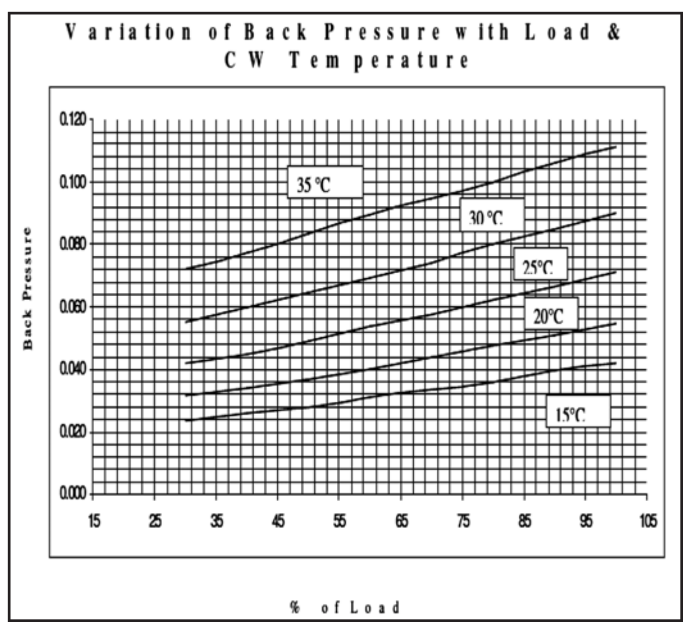

Fig. 7 [3]

Further, any choking/fouling/scaling of fill or distribution system in the cooling tower is an indication of a similar occurrence in the condenser tubing as well. Both systems must be cleaned at the same time to ensure that performance of one end does not deteriorate because of neglect of the other. There must be a mention of conditions like air leakage/ingress, scaling and vacuum pump side issues in ATC-105 that affect condenser vacuum and raise the saturation steam temperature resulting in altered TTD and enhanced CWT from the cooling tower. Test personnel from the Purchaser's and manufacturer's side will focus and address the above issues only when it becomes part of the test code. These measures alone can ensure that the true performance of the cooling towers is evaluated.

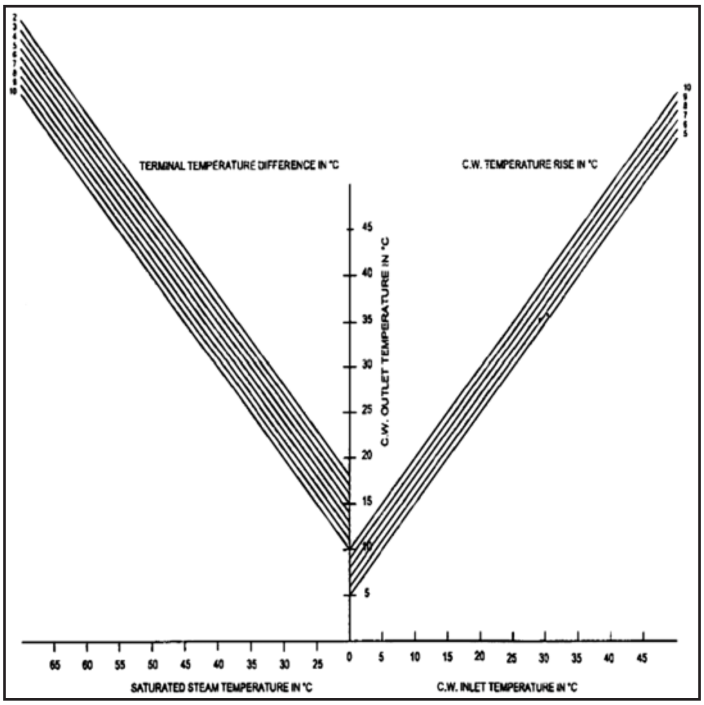

Fig. 8 Condenser Conditioning Graph [3]

Most often the cooling tower performance is evaluated assuming that all is well with the Condenser. However, it should be the responsibility of the power plant operator also to investigate contributing causes in the power plant as above. In addition the operator should also investigate the condenser itself for the following:

1. Vacuum pump side performance
2. Air ingress into the condenser (parting plane bolting, strainer bolting, all flange connections bolting, glands, etc., etc. complete)
3. Condenser tube fouling/scaling

Without investigating and correcting the above parameters, insisting on cooling tower performance ignoring the dependent parameters/conditions will not help the cause of the power plant. Adequate care must be taken by plant operators to ensure that all the above and other dependent parameters are taken care of to achieve desired performance of the cooling towers.

A true demonstration of cooling tower performance will only be possible with necessary support from the power plant operator as above. Hence, there must be a suitable clause in ATC-105 that addresses the condenser side issues in general so that the Purchaser does his bit in ensuring desirable conditions. In addition it must be stated in ATC-105 that in case more than one cooling tower services a condenser all the towers must be inspected for condition assessment and the heat load must be shared equally by the towers at the time of PG testing.

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Fluidized Bed Cooling Towers Come Of Age

Howard Davis ,Fluid Technologies (Env) Ltd
David Missions, Osprey Corporation Ltd

Howard Davis

In this paper we examine the reasons why three phase fluidized bed contactors did not transition from their use in scrubbing applications, started in the USA in the 1960s, to cooling tower applications and why the previous limitations, as discussed, have finally been overcome to offer designers improvements in the scale, performance and safety of liquid cooling towers.

Recognising the Challenges in Classic Cooling Tower Design

Firstly any overview of the various classical systems, including random packed, structured packed and sieve plates or trays would show that all of these cooling tower designs suffer from a variety of well-known operational disadvantages;

1. For a start classical systems tend to be bulky, which causes them to occupy otherwise valuable space.
2. Classical systems all suffer limitations in the approach temperature or 'Approach' (i.e. the temperature difference between cooled outlet liquid and cooler inlet gas).
3. Typically the Approach of a cooling tower varies inversely with its size, meaning that the Approach cannot be decreased beyond a certain point without the tower becoming uneconomically and unaesthetically large. Ultimately, approach temperatures below 7ºF (4°C) are seldom guaranteed in the cooling tower industry.
4. Classic tower designs are also prone to fouling which can greatly reduce their over-time efficiency and in the very worst & many infamous cases where bio-fouling occurs they can turn into dangerous sources of Legionella.
5. Last, but not least, packed towers (both random dumped & structured) and trays both have a serious design limitation known as "Flooding" which requires that high operating air to water or gas to liquid (A/W or G/L) or low L/G ratios are required to avoid the early onset of Flooding (the Loading point) thus leading to increased fan sizes and air flow costs. In fact trays, although not popular as cooling towers, suffer from a far wider range of design limitations including Weeping and Aeration or Foaming.

Flooding of Structured Packings is explored in great detail by Lockett, Victor & Billingham1 in their where, for example, they quote a Pressure Gradient figure of 8 mBar/m as the Flooding point for Sulzer's Mellapak 250Y. They also refer to Verschoof, Olujic & Fair's 1999 paper2 in which they note Loading typically occurs at Pressure Gradients between 1-2m Bar/m.

Sulzer's own published data for Mellapak 250Y (Figure 1) shows that the superficial gas velocity range to avoid such an undesirable, if not inoperable, Loading condition is upper limited to about 2.2m/s (7.2ft/s) with water head or spray pressure at 960mBarG.

The data (L/G ratios not shown) also shows that HETPs increase asymptotically from about 2.5m/s thus limiting the maximum window of operability to about 0.9-2.5 m/s even delivery water pressure is reduced below 400mBarG.

So classical tray and packed cooling tower designers have, for decades, generally had to try to keep their A/W ratios high to avoid such

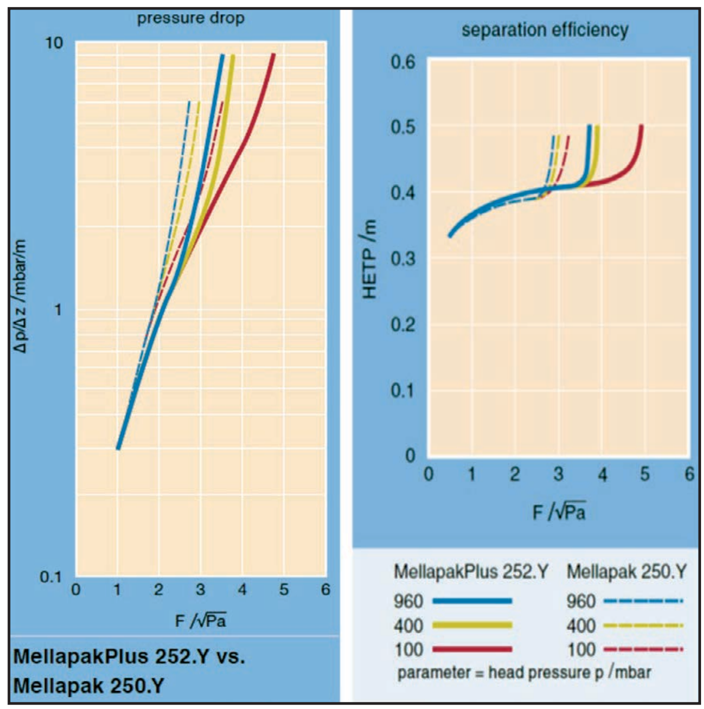


Figure 1: Sulzer Chemtech's Mellapak® 250Y & 252Y Pressure Drop & HETP Profiles

Loading/Flooding scenarios or alternatively to back off on gas or air velocity to allow for higher L/G ratios which in turn leads to ever larger diameter or bulkier columns.

Despite the knowledge of these longstanding and well documented design limitations the basic systematic issues leading to these problems remain and appear to be a problem awaiting a solution.

Fluidized Beds a Solution in Waiting?

Now let's turn our attention to Fluidized bed cooling towers and why they have not, so far, risen to the challenge or fulfilled the early promise shown in absorbers and scrubber systems.

In a nut-shell their main problem is that they have virtually always employed spherical balls as the contact medium.

Mobile beds of spheres were originally proposed as a way of overcoming fouling issues and despite quite a lot of, usually lab or pilot scale, academic research showing additional mass transfer and particulate removal benefits they have never really gained traction, even in the scrubbing business where they are a niche product, in the marketplace.

Although spherical balls will fluidize in uniformly distributed upwardly flowing gas streams with counter-current downward flowing liquid their pattern of fluidization is limited to an up & down pulsing type motion.

If however there is significant gas, or even liquid, maldistribution this almost always leads to an uncontrolled swirling or side stacking of the ball bell.

It is generally true that the bed will not foul such that biomass or other fouling build up concerns are overcome, which is an important benefit, but the mal-distribution issue impinges directly & negatively on performance.

Even when designers tried paying great attention to gas and liquid distribution spherical balls by their very nature are so prone to channelling that unless the distribution was near perfect the beds would frequently shift to one side of the column with the majority of the gas passing through the path of least resistance.

Further-more even if mal-distribution were not such an issue the combined mass & heat transfer using spheres advantage over random dumped packings is fairly in-significant such that any transfer coefficient gain is off-set or even out-weighed by the extra height required to accommodate the bed's expansion.

The result has been the need for even bulkier columns than packed towers. This when coupled with the relatively high pressure drops required to move the spherical ball bed inevitably led to a rapid loss of attraction of their use to cooling tower designers.

However there was still an appeal in the nature of fluidized beds particularly in academic circles and investigatory work on enhancing performance continued.

Back in 1988 a pioneer of thinking in fluidized beds K.N.Seetharamu and his co-author K.V.S. Varier published a paper[3]. The paper reported on work undertaken testing four shapes from the usual sphere to a half spherical cup, a V shape and an S shape in a cooling tower apparatus in Madras, India.

The work showed that spherical balls were generally the least efficient of all the shapes and, with the exception of the spheres, that as the Richardson-Zaki[4] shape factor increased the water temperature for equivalent conditions decreased.

The work showed that the sphere is an inefficient shape for mass & heat transfer but, although pioneering, did not venture any further in explaining the relationship between shape, and other factors, and how fluidized bed cooling tower efficiency improvements could be achieved.

More or less simultaneously to the work being undertaken in India the present authors were heavily involved in researching and developing a series of eccentric tumbling hollow elements starting with an ellipsoidal or oblate spheroidal shape marketed as TurboFill®. At the time this work was aimed squarely at gas scrubbing and absorption or desorption systems.

By tumbling sideways and spinning randomly rather than being dragged up & down in the counter current up-passing gas & downward flowing liquid streams, like spheres, elipsoidal shapes were able to create much higher mass and heat transfer rates. Such were the increases that the normally high bed heights associated with spherical balls, also trialled & used in gas scrubbers at the time, could be reduced by a factor of around three. Not only did this have the effect of reducing the gas scrubber tower heights but it also greatly reduced pressure losses.

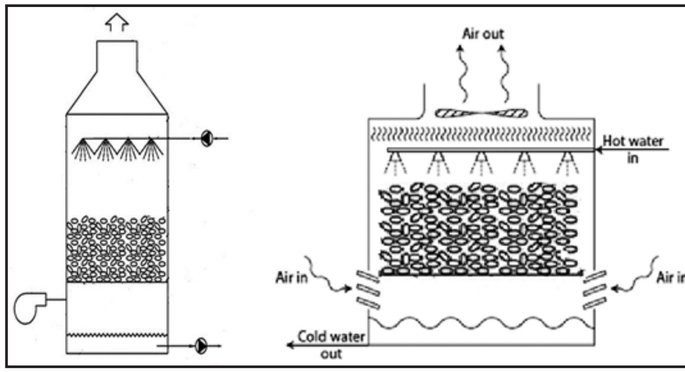


Figure 2: Fluid Bed Towers with Ellipsoids

The fluidized bed was also shown to overcome many if not all of the problems of gas channelling in all but the most aggravated of poor-design induced maldistribution. This was because the ellipsoidal shapes possessing more degrees of freedom than spheres, themselves limited to up & down motion, continuously fell back & forth into the path of both gas & liquid streams thereby staying 'connected'.

The long research & development showed the great importance of placing the centre of gravity (COG) outside the centre of symmetry (COS) to create a 'COG/COS offset' in a non-symmetrical or eccentric shaped element. The tumbling itself constantly generating multiple collisions between elements, diverting & changing gas flow lines instantly and, above all, creating very fast surface renewal rates & huge interfacial surface area to enhance the mass transfer. This coupled with high gas and liquid turbulence in the narrow but constantly thrashing voids created the opportunity for a huge advance in mass transfer technology.

Shapes other than the oblate spheroid were developed at FTL/Osprey by a mathematical modelling approach in defining the three-phase fluid bed system. This drew on earlier work from P.V Danckwerts of Cambridge University on surface renewal[5] (explained in his book) and including a key relationship developed by the authors linking pressure gradient and heat and mass transfer.

By dint of the painstaking mathematical modelling undertaken in tandem with long pilot and site trials it was found that optimal sizes, shapes and COG/COS offset could be predicted for high heat and mass transfer with low energy consumption.

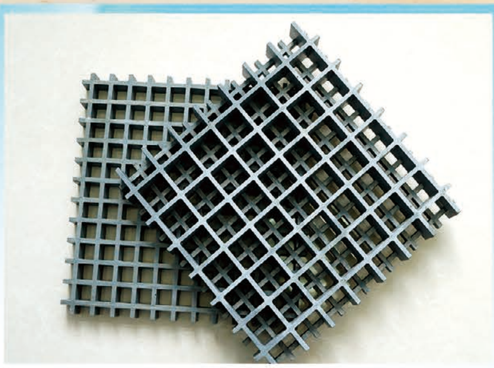
The work led rapidly to a series of improvements with the introduction of ovoidal, hybrid & indented shapes (known respectively as Turboid® & TurboPak®) each one increasing tumbling, turbulence and surface renewal to extraordinary effect so that today the technology offers bed height reductions in excess of ten times to those available in random dumped packed bed columns.

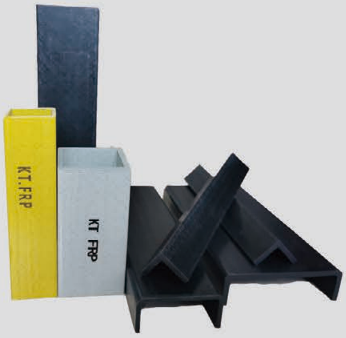
Fast forwarding to 2016 and the eccentric shaped fluidized bed technology, marketed to process companies for many years under the brand name TurboScrubber®, was adapted, effectively reverse

NAN JING KANG TE

ABOUT US

FRP Kangte Co. LTD. was established in Nanjing in 2005.
The registered capital is 50 Million (approx. 8 Million USD) ,The total investment is over 60 million.
Kangte has 14700M² workshop, production facilities including 34 production lines with dual molds and 8 production lines for different sizes of gratings.
From 2011, Kangte started to deliver our products to International markets including Australia, Taiwan, South Korea, Egypt, Thailand, Europe, USA to support our clients for their projects.
Our QA/QC department is a group of specialist who focus on international projects and contains a Laboratory to do strength tests and LOI tests for every batch of products.





CERTIFICATE

The Certification Body
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Post Code: 211124

has established and applies
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Development, Manufacture and Sales of Composite Materials (FRP) and Related Products (Pultruded fiber reinforced polymer composites structural profiles and Glass fiber reinforced thermosetting resin grating for supporting loads)

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Proof has been furnished that the requirements
according to

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engineered, trialled and proven to overcome the problems afflicting the classical cooling tower systems. The system is known as the TurbEx® cooling tower.

The principal benefits of the technology have been;

1. In overcoming the huge challenge of reducing the size of cooling towers,
2. In boosting performance so much to achieve Approach temperatures of well below 2.0°C (3.6°F),
3. In guaranteeing non-fouling operation even using slurries,
4. In allowing the operation of very low A/W ratios without flooding.

The first TurbEx® unit installed and trialled that year by Huhtamaki at their Waterville Maine pulp mill using indented ovoidal elements (TurboPak®) had a design heat load of 2.2MW in cooling $105 m^3/hr$ of sticky white water from 53.3°C to 29°C and was to have Approach temperatures of less than 1.67°C although this itself is also a function of air humidity which varies throughout the year. The overall column height was kept to 7.25m with a diameter of 1.83m for a pressure loss of around 1500Pa (6" W.G.).

The work undertaken at Waterville allowed for a direct comparison with data published by Parekh[6]. It also allowed for a comparison with data and correlations for Structured Packings assembled and published by Kong, Zhao et al in their paper[7]

To understand Parekh's and Kong et al's results and allow comparison with the TurbPak® data comparative use is made of a variant of the Height of Diffusion Unit, HDU called the Volume of Diffusion Unit or VDU.

VDU, derived below, is a direct function of the packing or cooling tower internals is a useful measure for comparing different systems such as fluid beds to random packed and structural fixed beds because it takes intoaccount the column's cross-sectional area which differs widely between systems.

Table 1 shows comparisons between a selection of different classical dumped packings, Sulzer's structural packing MellaPak® 250Y and TurboPak® which is a 38mm x 32mm indented eccentric hollow 'egg' type shaped fluidized bed packing.

The trial of TurboPak® packings in the Huhtamaki TurbEx® unit was undertaken using upwards of 67.5m3/hr (300 USgpm), of white water at 44.7ºC (112.5°F) with ambient air at 93ºF (33.9ºC), with a RH above 64%.

Deriving VDU from HDU as follows;

$$HDU = L/(Kxa)$$

Where,

Kxa = Combined Mass/Heat-Transfer Coefficient – $kg/m^3.s$ or $lb/ft^3.s$ and

L = liquid flow-rate - $kg/m^2.s$ or $lb/ft^2.s$

As the HDU increases, so the height of the cooling tower increases for a given or expected performance (characterised as the system NDU) because;

$$Z \text{ (packing height)} = HDU \times NDU$$

Where,

NDU is the Number of Diffusion units, which rises logarithmically or asymptotically as the tower is designed to get closer to 'pinch' by reducing the approach temperature, ΔT, and approach water vapour pressure ΔP.

To economically compare different systems designed to achieve the same cooling or heating efficiency, i.e. the same NDU value, this equation can be modified as follows;

$$Z = V/A = HDU \times NDU$$

Where V = tower contact zone or packing volume, and where

A = tower cross sectional area

Re-arranging, $V = A \times HDU \times NDU$

So different systems' contact volumes may be compared as follows:

$$V2/V1 = A2 \times HDU2/A1 \times HDU1$$

And rewriting the term A x HDU = VDU or Volumetric Diffusion Unit this then becomes

$$V2/V1 = VDU2/VDU1$$

Table 1 & Figure 3 compare fixed packing data against the TurbEx® fluid bed results for TurboPak® indented hollow packing elements whereas Figure 4 compares the TurboPak bed to structured packings as examined by Gharagheizi et al in their paper[8] and Figure 6 shows Pressure Drops for Structured Packings[9].

In Figure 5 the Approach Temperature reduction for the trialled TurbEx® cooling tower versus L/G ratio is characterised.

1 Fixed Pack ~ 0.9m/s 2 Structured ~ 1.8m/s 3 Fluid Bed ~ 3.6m/s	Volumetric Diffusion Unit (m^3)				
L/G in litres/m^3 => Packing	L/G = 2 1 L=6.5m/hr 2 L=13m/hr 3 L=26m/hr	L/G = 6 1 L=19.5m/hr 2 L= 39m/hr 3 L= 78 m/hr	L/G = 12 1 L= 39m/hr 2 N/A 3 L= 156 m/hr	L/G = 20 1 L= 65m/hr 2 N/A 3 L= 260 m/hr	L/G = 28 1 L= 91m/hr 2 N/A 3 L= 364 m/hr
1" Raschig Ring	0.67	0.98	1.44 Flooding!	N/A	N/A
1.5" Raschig Ring	0.73	1.24	2.05 Loading!	N/A	N/A
2" Raschig Ring	0.80	1.52	2.60	N/A	N/A
0.5" Berl Saddle	0.48	0.98	1.54 Flooding!	N/A	N/A
1" Berl Saddle	0.62	0.99	1.61 Loading!	N/A	N/A
1.5" Berl Saddle	0.76	1.50	2.39	N/A	N/A
TurboPak® * *Expanded Bed Basis	7.89	0.59	0.12	0.04	0.01
MellaPak® 250Y	0.3 Loading! > 2mBar/m	0.45 Flooding!	N/A	N/A	N/A

Table 1 VDU (m3) v L/G (litres/m3) for different Systems & Packings

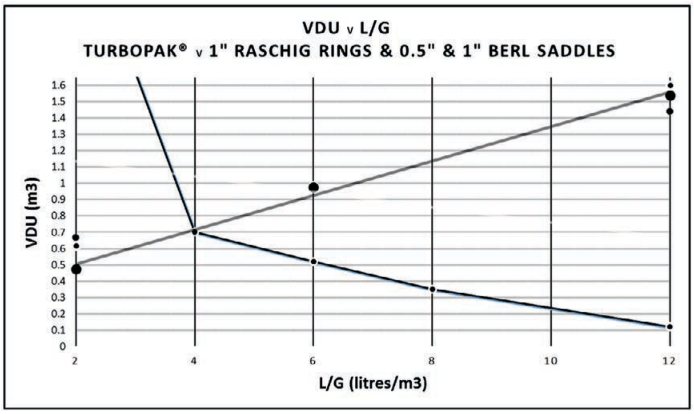

Figure 3: VDU values v L/G for small Raschig Rings & TurboPak®

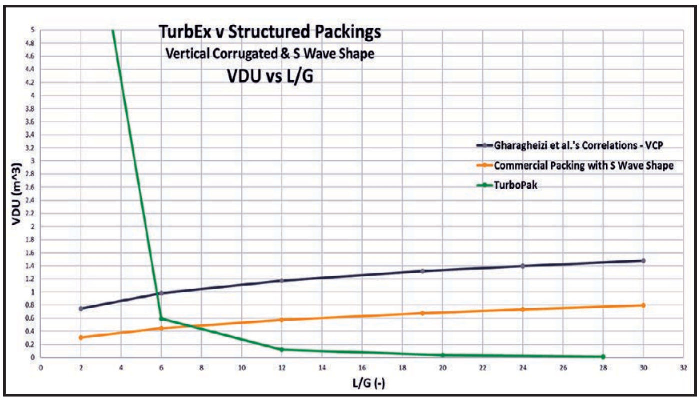

Figure 4: VDU values v L/G for Structured Packings & TurboPak®

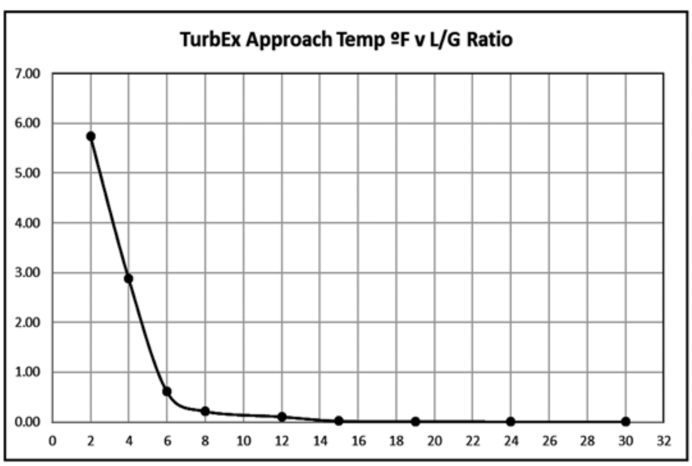

Figure 5: Approach Temperature v L/G for TurboPak®

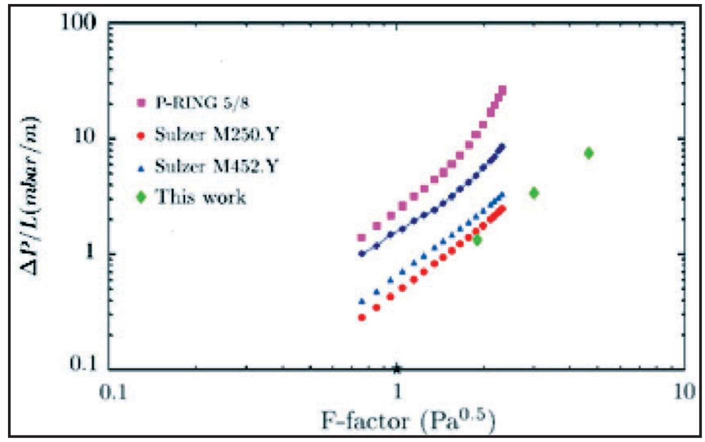

Fig. 6. Illustration of wet pressure drop between the cross-flow elememtary cell (Mellpak 500.Y at a liquid load of 1.3m^3/m^2 /h) and different packings: P_RING 5/8 Sulzer M250.Y at a liquid load of 7 m^3/m^2/h

The values shown in Table 1 and Figures 3, 4 and 5 demonstrate the capacity of the TurbEx® fluidized bed system to substantially reduce both VDUs and Approach significantly. Due to the noticeably different operating curves and characteristics of a fluidized bed system as opposed to fixed beds the benefits grow more and more significant as L/G values increase above about 5 litres/m^3, an area where packed columns might struggle to operate due to Loading and Flooding concerns, thereby giving highly significant reductions in both the tower volume and the air flow volume in favour of the TurbEx® system.

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Metal And Organic Solutions For Reduced Phosphorous Applications

Paul R. Frail & Claudia P. Pierce
Suez Water Technologies & Solutions

Paul R. Frail

Abstract

Customers are facing a trending reduction in the allowable phosphorus they can expect from open recirculatory cooling systems in direct discharge applications, requiring significant modification of traditional treatment programs. Other customers have had to circumvent fouling associated with the use of phosphorus inhibitors, seeking non-fouling options and assurances. This paper will provide a review of metal solutions, as well as, highlight recent advances in the use of aluminum and all organic solutions. Surface analysis was used to identify passivation films and correlate their chemical composition to respective treatment and water conditions, providing the knowledge to manipulate film chemistry for performance.

Introduction

Phosphate has been the hallmark of industrial cooling corrosion control programs since the transition from chromate beginning in the 1970s.[1] When the correct ratio of calcium and phosphate are achieved in an industrial cooling program, a Ca/PO_4 passivation film forms on the surface of iron-based metallurgies.[2-4] This passivation film provides the necessary protection against corrosive factors such as oxygen, chloride, sulfate, and inorganic oxidizers (hypochlorite, bromine, peroxides, ClO_2, etc.). The performance provided by the addition of *o*-PO_4 to industrial cooling system led to decades of development of various calcium phosphate (Ca/P) salt inhibitor and dispersant polymers that feature a wide variety of monomers used in co-, ter-, and quad- polymers, where one monomer features a sulfonic acid group.[5-10,16,17] The advancement of Ca/P dispersant polymers allowed for the use of phosphate throughout the cooling pH continuum, ranging from pH 6.8 to 9.5.[5,8,16,17,18]

Despite many successful applications of phosphate-based corrosion programs over three decades, there are some risks associated with the addition of phosphorus: (i) environmental concerns regarding phosphorus discharge to lakes, rivers, and other water bodies contributing to algae and microbial growth;[11,12,14,15] (ii) fouling due to either deposited calcium phosphate or precipitation of phosphorus containing salt inhibitors.[13,21] Phosphorus, being a necessary micronutrient, can accelerate algae and microbial growth. The main source of elevated environmental phosphorous is due to agricultural runoff. Regardless, regulations target the points of industrial effluent: direct discharge cooling systems and water treatment facilities specifically. Regulations regarding allowable phosphorus discharge date back to the 1980s and remain highly regional in their restrictions.[14] The reduction of phosphate in all industrial cooling corrosion programs has never fully come to fruition due to the small market segment that directly discharges cooling tower blowdown into natural bodies of water.

Hydroxyapatite (HAP), which is the bulk water precipitating species, has a Ksp $\sim 10^{-45}$ and inverse solubility causing it to be one of industrial cooling's most prevalent fouling species.[20-23] Risks associated with HAP have largely been mitigated with the advancement of sulfonated polymer chemistries. The addition of a sulfonated monomer into the polymer backbone allows for cooling programs to handle the stress due to HAP, as well as suspended solids, other scaling salts, and metals.[16] Some stress tolerant polymers have been able to handle PO^4 levels as high as 100 ppm in the bulk water under reuse water applications.[39] Complimenting the advancement of sulfonated polymers has been the use of online monitoring and digital centers that accumulate trending data allowing water treaters to proactively react to system upsets, further minimizing risk associated with fouling.[19] An additional tool to mitigate scaling is the use of saturation equilibrium modeling software to identify conditions where scaling may occur and to anticipate potential fouling conditions during operation variations and upsets.[20,21]

Prior to the ubiquitous use of *o*-PO^4 in industrial cooling program transition metals such as chromium or molybdenum were highly effective and operated in a low or no added phosphorus program.[1,13] Similarly, the use of other cationic metal salts can be used in conjunction with low and/or no added phosphorus programs to meet performance standards. Zinc is one of the best cathodic inhibitors, forming passivation layers as either zinc oxide or phosphate.[24] It is a low-cost inhibitor that is easy to formulate and feed into industrial cooling chemical treatment programs. There is over 40 years' experience with the use of zinc salts as cathodic corrosion inhibitors for low carbon steel. Unfortunately, it was used in conjunction with chromium corrosion programs and is highly regulated; however, even low residual levels can greatly reduce the added phosphate in a corrosion program.[25] More recently the use of alternative metals has grown in popularity in attempt to reduce the added phosphorus in corrosion control programs. Alternative metals include the use of tin, manganese, aluminum, silicate, tungsten, titanium, etc.[26]

Combining the use of surface analytical techniques (XPS, ToF-SIMS, IR, etc), chemical treatments, and knowledge of water characteristics the concept of engineered passivation films has been developed to deliver the desired corrosion performance.[2,27-30] The analytical techniques identify the chemical composition of the various layers within a passivation film. Combined with the knowledge of the water chemistry and applied chemical treatments a desired film composition and thickness can be constructed for a given water environment. This approach has already shown the consequence of removing phosphate from a cooling program and will result in increasing corrosion rates due to the thinning of the calcium phosphate layer.[2, 27] Figure 1 highlights a TEM images taken from coupon samples, previously reported, showing the drastic change in passivation film thickness between a no-P and traditional alkaline corrosion program. Engineered passivation films have led to the development of new yellow metal corrosion inhibitors and the development of low phosphate or no added P cooling programs.[30]

As regional regulations on phosphorus effluent discharge continue to evolve, there is a need for successful corrosion control programs with limited use of added phosphate[31-38] The following document will consider the effects of regulations on why customers may implement a low or no added P program and the assets involved within the cooling system. Utilizing surface analysis, this paper will discuss the ability to engineer surface passivation films that utilize metals (Zn, Sn, and Al) in the chemical treatment, as well as, the use and importance of Carbon-Hydrogen-Oxygen inhibitors (CHO-inhibitors listed in Table 1). Successful low or no added P corrosion programs have been developed and will be explored using laboratory and field examples.

Methods and Materials:

Full experimental details concerning the design and capabilities of testing equipment have been described previously.2[8-30] Corrosion rates were measured by weight loss or calculated using the linear polarization method and reported as mils of penetration per year, mpy.

Beaker Corrosion Testing: Beaker testing methods and materials have been described in detail previously. The method utilizes the standard 3 electrode corrosion cell in synthetic cooling water with treatment doses. Instantaneous corrosion rates are acquired as Rp vs. Time plots for a predetermined time: generally, 18 to 40 hours. The total average of the instantaneous corrosion rates is used to evaluate performance; as well as, evaluating inserted coupons for deposit and density of corrosion cells.

Cooling Recirculating Tests: All coupons, heat exchange surfaces, and corrosion data were acquired using Bench Top Units (BTU) with various water conditions. Specifics regarding the test methodology have been reported previously.

Coupon Preparation: Laboratory coupons were polished with corn cobb media, sonicated, rinsed with distilled water (DI) and isopropanol, and polished with acid/pumice prior to use. Field coupons were used as received in protective sleeves. All coupons are inserted at the start of an experiment or field coupon cycle. At the end of the testing duration the coupons are removed, rinsed with DI water to remove the application water, and air dried prior to shipping. Coupons were stored under dry conditions prior and during shipping to the GE Global Research Center in Niskayuna, NY for surface characterization.

Surface Analysis:

X-Ray Photoelectron Spectroscopy – XPS measurements were performed on a Kratos Axis Ultra DLD instrument (Kratos, Manchester, England) using a monochromatic AlKa X-ray source (1486.6 eV). The analysis area is 700 x 300 mm2. Compositional survey scans were acquired using a pass energy of 160 eV. Three spots on each coupon were analyzed. The compositional data are an everage of the values determined at each spot. Compositions were calculated with CassXPS software.

Time of Flight Secondary Mass Spectroscopy – ToF-SIMS measurements were performed using an ION-TOF.SIMS 5-100 (ION-TOF) GmbH, Munster, Germany). The instrument was equipped with 25 kV and bismuth liquid metal ion gun (LMIG). The analysis Bi3+ beam was rastered over a 100 x 100 mm2 area on the coupon's surface. A low energy electron flood gun was used to stabilize surface charge and the high current bunched mode was used for analysis. Data analysis was performed using a SurfaceLab 6 software from ION-TOF GmbH.

Transmission Electron Microscopy – TEM analysis were conducted using FEI Osiris TEM operating at 200 kV equipped with 4 SDD detectors for faster acquisition of EDS signal. The image was collected in the STEM mode. Due to the presence of organic layers on top of the sample STEM mode was selected to give lower dose to the sample and minimize possible beam damage. TEM samples were prepared with Focused Ion Beam (FIB) lift-out technique to extract cross section specimens. The dual beam FEI NOVA FIB was used to prepare the TEM cross section.

Discussion

Commercial Drivers

There are two distinct market segments that would utilize a low P or no added P corrosion control program: (i) Industrial cooling systems that directly discharge their effluent to bodies of water; (ii) Industrial cooling systems whose effluent is sent to water treatment facilities. A third market segment, outside the scope of this document, are industries who are conscientiously focused on adapting sustainable and environmental initiatives. The commercial drivers are significantly different for the two, as well as, the type of metallurgy and expected performance criteria. Understanding the commercial drivers, metallurgy involved, and associated performance expectations all contribute to developing a successful corrosion control solution. The distinct differences between the two types of customers underscores the need and ability to engineer surface films that provide asset protection by pairing chemical treatments with the water chemistry.

Industrial cooling systems that are directly discharging their effluent to varies types of water ways are those most concerned with meeting or exceeding phosphorus regulations. A large portion of customers are power applications. These systems have transitioned from yellow metal to metals that are corrosion resistant such as stainless or even titanium heat exchangers. Often scale control supersedes corrosion control. Low carbon steel within these systems is often in the form of transfer lines of various diameters with expected performance targets being less than 2-3 mpy. An effective corrosion control program should meet or exceed the expected low carbon steel pipe lifecycle. The engineered passivation films for this application may require a much leaner program versus the necessary robustness for elevated temperatures as seen on heat exchangers.

When industrial cooling water effluent goes to a water treatment facility their commercial drivers for adopting a low P or no added P corrosion program are drastically different. Such customers would weight regulations drivers lower than performance factors such as fouling and corrosion. Fouling concerns may stem from past or current issues associated with the use of phosphate-based programs. In these systems, the metallurgy may be mixed between steel and yellow metal; as well as, having low carbon steel heat exchangers. Due to heat exchangers' elevated temperatures, more robust surface films need to be engineered as part of the corrosion control program. As temperatures increase so does the corrosion potential for a given metal surface. One can implement a cationic metal (Zn, Sn, or Al) or select the correct CHO-inhibitor for a metal free program while being cognitive of the fact that only low levels of *o*-PO^4 need to be targeted unless a no added P program is specified. Lowering phosphate, by any amount, will proportionately lower the fouling potential.

The concern about fouling may be associated with a long history of many organic phosphonates that are not calcium tolerant.[13] For example, HEDP in the presence of Ca can precipitate under alkaline conditions. Similarly, calcium phosphate has a high potential for fouling under alkaline conditions and elevated temperatures.[20-23] When a fouling event occurs, several deleterious results may happen within the cooling system: (i) loss of heat transfer efficiency; (ii) reduce flow due to narrowing of piping; (iii) under deposit corrosion; (iv) increase in biofouling. These risks due to fouling have been largely mitigated through the development of non-P scale inhibitors.[18,31] Low molecular weight polycarboxylic acid polymers have been used in place of organic phosphonates for several decades. Many can rival the performance of organic phosphonates ability to inhibit $CaCO_3$ scale. Often, organic phosphonates are chosen due to their lower cost and long history as successful $CaCO_3$ scale inhibitors. The advancement of sulfonated polymers as Ca/P inhibitors concurrent with polycarboxylic acid scale inhibitors has offered a desirable solution versus organic phosphonates that have scaling tendencies with a phosphate corrosion program.[18] Remote monitoring systems with data trending capabilities will further mitigate any concern associated with fouling.[19]

The initial development of sulfonated polymer chemistry that inhibited calcium phosphate and that could be utilized as a dispersant was the initial development of a low P cooling program. It allowed the migration from neutral pH cooling programs, ~15 ppm *o*-PO^4, to alkaline pH cooling programs, ~6 ppm *o*-PO^4.[8,18] Surface analysis revealed that this shift in pH and phosphate levels resulted in two different passivation film thicknesses, densities, and compositions: neutral pH programs resulted in a thinner and more dense film; alkaline resulted in a thicker and more porous film.[2,27] A recent report highlighted the negative effects of when *o*-PO^4 is decreased from 6 ppm to 1 ppm on the passivation film quality without adjustment of the cooling program.2 Figure 2 displays 7-day coupons taken from recirculatory cooling testing where the only factor within the water matrix that changed was the amount of phosphate. As the phosphate was decreased general and localized corrosion increased significantly. Laboratory and field examples will show the ability to circumvent the reduced robustness of passivation films with 1 ppm *o*-PO^4.

The use of saturation modeling is an invaluable tool when designing recirculating deposit and corrosion control programs.[20-23] Even though low P or no added P programs have an inherent reduced fouling tendency, it is still prudent to evaluate saturation values of all potential salts than just Ca/P species.[21] A prerequisite for many low P and no added P programs is that the pH set point be within the alkaline range: pH greater than [7.8]. Within this pH range there is still the potential for $CaCO_3$ scale. Under standard alkaline conditions (4-6 ppm *o*-PO^4) there is minimal amount of *o*-PO^4 to significantly influence the calculated saturation value of $CaCO_3$. Thus, when a low P or no added P program is designed there is minimal change to the $CaCO_3$ saturation value; however, this decrease in *o*-PO^4 is enough to effect changes in induction time: the time delay before the first crystallization aggregates will form. Some lab conditions tested, thus far, have shown $CaCO_3$ precipitating under conditions where if there was 4-6 ppm *o*-PO^4 no $CaCO_3$ scaling is observed by acid testing metal surfaces. A more detail study is required to fully address potential changes in $CaCO_3$ induction time under low P or no added P conditions. A successful CHO inhibitor must aide in the engineering of surface passivation films and calcite scale inhibition.

Application of Metals

The use of Zn salts as a cathodic corrosion inhibitor is well known and a validated form of corrosion control.[24] Zinc having appreciable solubility and ease of coordination, allows it to be easily formulated and applied to aqueous systems. A good portion of what is applied to the system is not recovered due to constant equilibrium between formation and dissolution from the passivating film. Surface analysis from an ethylene plant revealed how zinc films passivate a surface in the presence of *o*-PO^4. Utilizing depth profiling to construct a relative chemical composition of the passivation film as a function of pH reveals the ZnO and PO signatures co-form at the top interface. Figure 3 shows the depth profiling for a series of passivated low carbon steel samples at various pH's within an ethylene plant. All three share the similar characteristic that the top interface is a co-film of Zn and *o*-PO^4. The neutral pH, 7.0, coupon has a more compact passivation film versus the higher pH samples. The Zn signature drops off at neutral pH and shows a concentrated PO, representing phosphate, at the metal interface. At the higher pH, 7.5 and 8.4, the passivation films are thicker and reveal a more equal distribution of the Zn within the Ca/P layer. However, unlike the neutral pH sample the metal interface is now dominated with Zn.

As the phosphate content decreases in a low or no added P program it is expected that like the Ca/P scenario that the films become thinner. However, given that the Zn under more alkaline conditions is concentrated at the metal interface, sufficient corrosion protection can be obtained despite reduced passivation film thickness. In some cases, discharge permits may limit the use of Zn entirely or simply limit the amount in the effluent due to concerns with aquatic toxicity. Depending on the reason for converting to a low P or no added P corrosion control program, it will be feasible to utilize low levels of zinc, less than 2 ppm of a traditional program, in combination with a CHO to engineer effective passivation layers for corrosion control.[25] The selection of the CHO inhibitor becomes more critical as both the P and Zn content are decreased in a corrosion control program (Table 4). CHO inhibitors aide in targeting the necessary water components to form passivation films when limited amounts of P and metals exist in the water matrix. Efforts are continuing to fully resolve the relationship between the water matrix, CHO inhibitor, and passivation films under low P and Zn conditions utilizing surface analysis techniques.

Tin salts have recently been identified as an acceptable corrosion inhibiting salt versus zinc for industrial cooling applications. The use and discharge of tin and tin complexes and potential long-term toxicity and accumulation are not well understood.[46] Using tin in non-fouling applications may be a misnomer due to the insolubility of stannous and stannic salts throughout the neutral and alkaline pH range: Tin(II) hydroxide Ksp = 5.5×10^{-27}, Tin(IV) hydroxide Ksp = 1×10^{-56}.[45] Thus, the application of tin in this pH range is to disperse these salts until they precipitate on top of the outer most surface layer of a metal. This would be consistent with published surface analysis where the tin(IV) species is found on top via XPS analysis.[40] XPS only measures the top 10 nm of a surface film. A corrosion inhibitor that operates in this manner would only add additional stress to dispersant polymers in addition to $CaCO_3$ and suspended solids. Typically, tin salts are most soluble under acidic conditions in the presence of hydrochloric acid. One can utilize a chelating agent to solubilize tin salts in the formulation or under cooling tower conditions. However, microscopic reversibility due to alkaline pH or oxidation of the metal center may ultimately lead


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to some degree of precipitation of insoluble tin hydroxide or other salt form. Under alkaline conditions the ligand's solubility will increase and readily free up a binding site leading to the release of cationic tin. Tin may also be readily displaced by another cationic metal that has a higher binding strength and release unbound tin into the aqueous medium. Once cationic tin is released into alkaline water the hydroxide species is readily formed and is insoluble. Thus, it may be a best practice to constantly measure the amount of soluble versus total tin present in product drums over time, as well as in the bulk water of industrial cooling systems to ensure protection against fouling on top of maintaining adequate corrosion protection. Additional research is required to fully understand the fate of tin with respect to an ion association model of saturation indices.

Additional concerns around the use of tin are due to the associated electrochemical properties. Tin oxidation states (0, 2+, 4+) participate in galvanic corrosion cells with Zn, Cu, and Fe. The half-cell potentials are also reactive towards oxidizers and may represent an additional demand during their use. Table 2 lists half-cell potentials and the corresponding Gibbs free energy.[41-43] It is clear from the table that tin's lower oxidation states will react with inorganic oxidizers. Tin salts have thermodynamic driving force to cause dezincification of yellow metal alloys, copper plating of soluble copper, and direct galvanic corrosion of iron. This may explain some literature accounts that propose a mechanism where tin salts can remove tubercles: tin enters a galvanic cell and reduces iron (III) to form more water-soluble iron.[44] Such a mechanism would impart more stress onto dispersant polymers leading to fouling caused by solubilized iron or disrupting the stabilization of $CaCO_3$ colloids. More long-term surface analysis studies are required to fully understand the mechanism and potential deleterious effects of tin based corrosion programs with respect to galvanic corrosion.

An attractive alternative to Zn and Sn based salts is the use of Aluminum (Al) as the metal inhibitor. Aluminum is known to form surface films with silicate.[26] The solubility of aluminum and its corresponding salts are well understood and can be modeled for potential fouling. Figure 4 shows the solubility curve for Al^{3+} where there is an appreciable solubility level in the alkaline region.[47] The ability to construct corrosion programs around salt's natural solubility allows for a more robust non-fouling low P or no added P corrosion control program to be designed. The choice of CHO inhibitor is imperative to ensure that the cationic Al^{3+} is soluble and is transported to the metal interface to engineer a passivation film. CHO inhibitors listed in Table 1 that are complementary with Al^{3+} include CHO-1, -2, -6, -8, -10.

An exemplar study was conducted to show how the use of Al can positively improve low P cooling programs. Table 3 lists water characteristics for the test water and based on the solubility curve at pH 8.0, Figure 4, suggests that ~0.25 ppm Al^{3+} would be soluble under these conditions. Low carbon steel heat exchange tubes were pretreated for 12-16 hours with Ca/P. The sump water was quickly transition to the low P water with and without Al^{3+} present. Previous screening has shown CHO-1, -2, -6, -8 and CHO-10 to be ideal inhibitors to aide in the solubility and engineering of passivation films in the presence of Al salts. Figure 5a compares the results of the two tests where coupons and heat exchanger tubes without Al salts exhibit heavy general and localized corrosion. The test with 0.25 ppm Al^{3+} significantly improves the general and localized corrosion. The heat exchanger tube displays some low density of pits for an unoptimized corrosion control program; adjustment of the dosing amount of CHO-2 (or changing to another acceptable CHO inhibitor) or Al^{3+} will ameliorate these imperfections. Figure 5b highlights the ability of the use of Al^{3+} to minimize the imbalance, localized corrosion, throughout the duration of the test compared to just the use of CHO-2. The concentration of CHO-2 between the two tests was equal. Corrosion on the pretreated Ca/P heat exchanger tube reveals the ability of Ca/P passivation films to slowly erode over time and are not bound to the metal surface indefinitely. Surface analysis from this run was not completed prior to submission and is ongoing.

Carbon-Hydrogen-Oxygen (CHO) Inhibitors

In efforts to mitigate fouling associated with organic phosphonate chemistry, polycarboxylic acid salt inhibitors were developed as a no added P chemical treatment for industrial systems.[8, 18, 31] Polycarboxylic acid salt inhibitors are known to have improved Ca tolerance levels and do not add any P to the cooling program.[13] Some polycarboxylic acid salt inhibitors can behave as corrosion inhibitors depending on their concentration and hardness levels. Most polycarboxylic acid inhibitors are included within the CHO nomenclature. Utilizing surface science, a large ensemble of CHO inhibitors has been identified, and is expanding, for low or no added P applications, see Table 1. Performance depends on many factors that include molecular weight, anionic charge, molecular sterics, metal binding constants, and water chemistry (salt concentrations, pH, etc.). Nitrogen containing species could be incorporated in the molecular design. However, these species may contribute to biofilm growth or unnecessary oxidizer demand. Although, the lone pair of electrons on nitrogen are an ideal ligand construct for binding iron surfaces. Several CHO inhibitors have been identified as successful surface engineering species.

There are several roles for CHO inhibitors: (i) they possess the ability to interact with calcium ions or colloids in solution and inhibit crystal growth or precipitation; (ii) aid in the engineering of passivation films by being transporters of colloidal species that become part of the cathodic matrix preventing electron transfer at the metal interface; (iii) act as surface buffering species that alters the rate of the anodic reaction's production of hydroxide anions. The selection of CHO inhibitor will depend on specific water conditions and customer driving forces and assets.

CHO inhibitors are needed in low P and no added P programs that utilize metal salts such as Zn, Sn, and Al. They have the dual role of solubilizing the cationic metal and transporting it to the surface. Not all CHO inhibitors are effective in conjunction with a metal additive. Table 4 highlights beaker studies that show for a low hardness and pH conditions that some CHO inhibitors are effective with the presence of low dosage amounts of Zn and/or silicate. Synthetic cooling water was used to mimic the water characteristics highlighted in Table 5. CHO-4, -5, and -7 experienced elevated corrosion rates versus the other CHO inhibitors under the same test conditions and dose. Thus, it is feasibly to utilize these results with surface chemistry to engineer passivation films for specific customers based on their water conditions. The underperforming salts are believed to be ineffective due to diminished ability to transport water components and metal additives to the metal interface surface.

Field Studies And Scenarios Exploring The Use Of Cho Inhibitors To Engineer Surface Films

An East Coast Power plant that sources make up water from a reservoir and directly discharges their cooling tower effluent required a no added P program. Water analysis of the reservoir revealed little or no presence of available *o*-PO^4 that could be cycled up to achieve optimal corrosion protection. Due to conductivity limits only four cycles of concentration can be targeted for the application. Cycled up water in an evaporating recirculating system achieved an oscillating pH between 7.8-8.0. Table 5 summarizes the water characteristics of the cycled-up water and had *o*-PO^4 levels between 0 and 0.5 ppm. Initial screening of various CHO inhibitors was done in beakers to select the best inhibitor to engineer a passivation film. CHO-2 and CHO-3 were selected based on beaker performance. CHO-9 worked complementary with CHO-2 and CHO-3.

Site water was used as make up water and cycled using an evaporating recirculating cooling test. Each product was dosed at 60 ppm for CHO-2 and CHO-3 with sufficient dispersant to handle suspended solids. Figure 6 compares the two CHO inhibitors and CHO-3 out performs CHO-2 with instantaneous corrosion rates below the key performance indicator, KPI, mark of 3 mpy. CHO-3 achieves a much steadier corrosion rate that oscillates in response to blow down and oxidizer feed increasing the level of noise in the data set. Figure 7 compares the coupons at various days throughout the 30-day testing duration. CHO-2 and CHO-3 are similar in appearance at seven and 14 days. The longer exposure time, 22 days, reveals the inability of CHO-2 to maintain the passivation film under low hardness, phosphate, and pH conditions. CHO-3 has some low pit density on the coupon around the surface edge, otherwise, it is a successful treatment program. Average pit depth was also significantly less for CHO-3 versus CHO-2 under the cycled-up reservoir conditions.

A South American chemical plant's 30-day corrosion coupon was evaluated to understand the use of CHO-1 inhibitor in a low P corrosion program. The chemical plant had switched from a traditional alkaline program to a low P program to meet regulations. The site operates with an upper limit of *o*-$PO^4$of 3 ppm, while the corrosion program targets ~2.5 ppm. Table 6 lists the comparison of the traditional and low P corrosion programs. Corrosion rate targets are less than 1.0 mpy and are consistently met with this low P program using CHO-1. TEM analysis of the coupon, Figure 8, revealed similar features as previously reported low P experiments. The engineered passivation film is roughly 40-50 nm thick for 30-day exposure, which is consistent with previous laboratory studies. Cross-sectional EDS mapping highlights the ability of CHO-1 to properly transport the water components into close interaction with the metal interface to form a passivation matrix consisting of Ca, P, and O. Carbon also contributes a significant amount to the matrix and is often removed from analysis due to the large amount of interstitial contamination. It is even harder to accurately conclude the origins of carbon in surface analysis testing due to $CO3^{2}$- anion and the large amount of -COOH contribution from CHO-1 and/or the dispersant polymer.

Biological contributions of carbon cannot also be ruled out under field conditions.

A customer service study was done to evaluate the use of CHO-2 with and without Al^{3+} in the presence of low P, 1 ppm *o*-PO^4, conditions. The cycled up synthetic water conditions are listed in Table 5. Based on the solubility curve, Figure 4, an effective dose of 0.5 ppm Al^{3+} was selected. Al becomes more soluble at higher pH ranges and pH 8.9 could easily tolerate the elevated Al^{3+} levels from the previous testing. Since Aluminum salts run the risk of fouling it is important to monitor and validate the soluble Al^{3+} remains in solution with the aid of the CHO inhibitor. Figure 9 shows the Al^{3+} remains soluble throughout the duration of the testing the recirculating unit. The target dose was 0.5 ppm and 0.4 ppm were recovered where the remaining 0.1 ppm was actively involved with forming engineered passivation films with the CHO-2 inhibitor. The system had mixed metallurgy (LCS, 90:10 CuNi, and ADM) and used 3 ppm of azole to provide yellow metal corrosion protection. Figure 10 compares the coupon results for experiments with and without Al^{3+} present. The CHO-2 run without Al^{3+} present exhibited low density pitting like previous experiments and slightly elevated average corrosion rate of 2.1 mpy. All yellow metal had satisfactory corrosion rates of 0.06 mpy and 0.23 mpy for CuNi and ADM respectively. The experiment with 0.5 ppm Al^{3+} yielded improved LCS appearance, absence of localized corrosion, and lower corrosion rate of 0.8 mpy. Yellow metal performance was similar between the two runs suggesting that Al salts do not negatively impact azole chemistries ability to protect yellow metals surfac

Conclusions

Engineered passivation films for low P or no added P programs can be achieved utilizing either CHO-inhibitors or CHO-inhibitors with the addition of metal species (Zn, Sn, or Al). Surface analysis continues to prove to be a valuable tool in connecting chemical treatments and water conditions to desired passivation films with predictable surface thickness, chemistry, and robustness. Not all CHO-inhibitors are effective at transporting cations and anions to the metal interface for the construction of surface films. An array of effective CHO-inhibitors has been identified for low and non-P conditions that allows the construction of cooling programs to engineer desired passivation films spanning the cooling pH continuum. The use of aluminum was demonstrated under anticipated field conditions in laboratory recirculating testing validating it successful use under cooling conditions. Advantages of aluminum are the low dose required to impact performance and predictable solubility in industrial water. When soluble Al^{3+} was maintained in these systems it could provide improved corrosion performance as measured by corrosion rates and the reduction or elimination of localized corrosion. Further optimization of CHO inhibitors or with the addition of metal salts over a wide range of conditions will be completed in the future to address corrosion needs when there is commercial pull to reduce the P in recirculating cooling programs due to regulations or fouling conerns.

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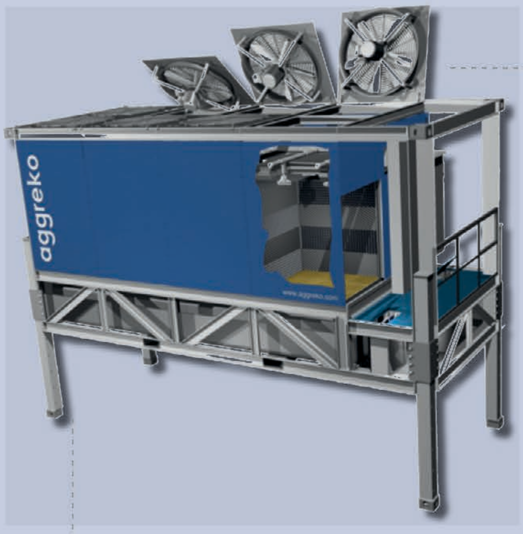

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Tables and Figures

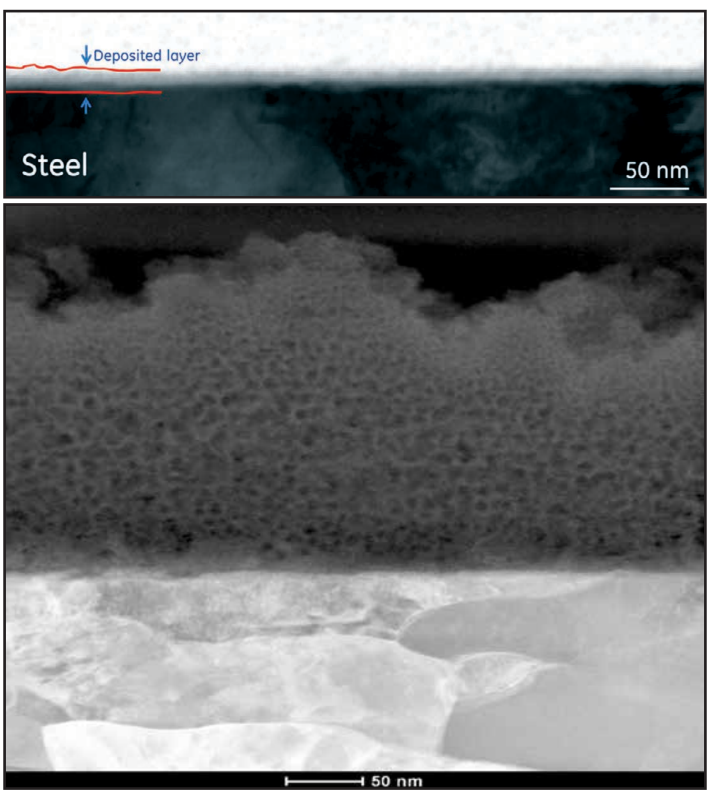

Figure 1 – TEM images of a non-P program (Top image, 20-30 nm thick) and a standard alkaline program (bottom image, 70-100 nm thick). The alkaline sample was taken from a refinery cooling tower operating without pH control, 8.6, and ~4-6 ppm o-PO^4 The non-P TEM (Top image) reveals a very thin passivation film that is uniform with full coverage of the metal surface. The phosphate film (Bottom image) contrasts the non-P film with a much thicker and porous film morphology.

CHO Inhibitors	MW	Description
CHO-1	<1000	Polymer
CHO-2	<1000	Polymer
CHO-3	<8000	Polymer
CHO-4	<8000	Polymer
CHO-5	<8000	Polymer
CHO-6	<5000	Polymer
CHO-7	<10000	Polymer
CHO-8	<500	Molecule
CHO-9	<500	Molecule
CHO-10	<500	Molecule

Table 1 - CHO Inhibitors for low and/or no added P applications.

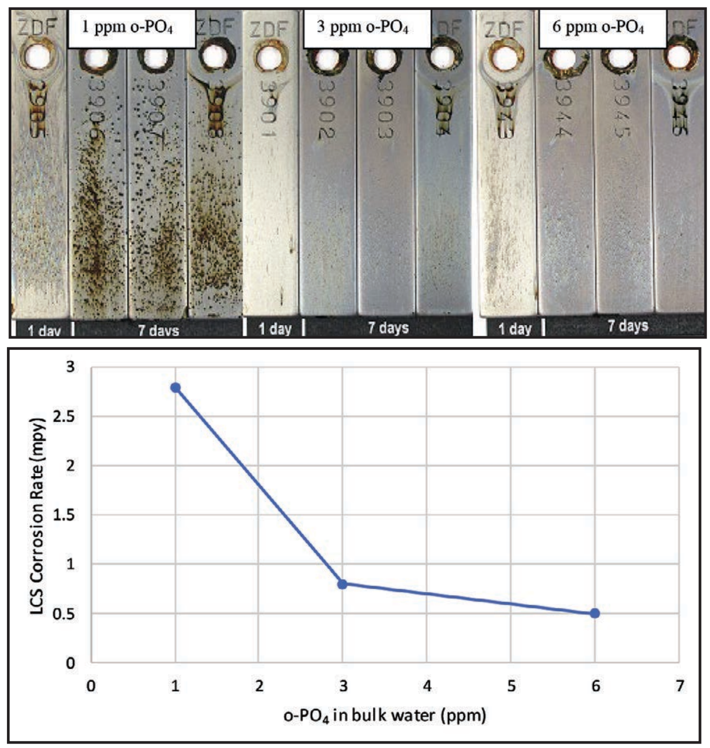

Figure 2 – Corrosion rate (mpy) versus o-PO^4 in the bulk water and corresponding coupons obtained from Cooling recirculating tests: low carbon steel metals, bulk temperature 120 °F.

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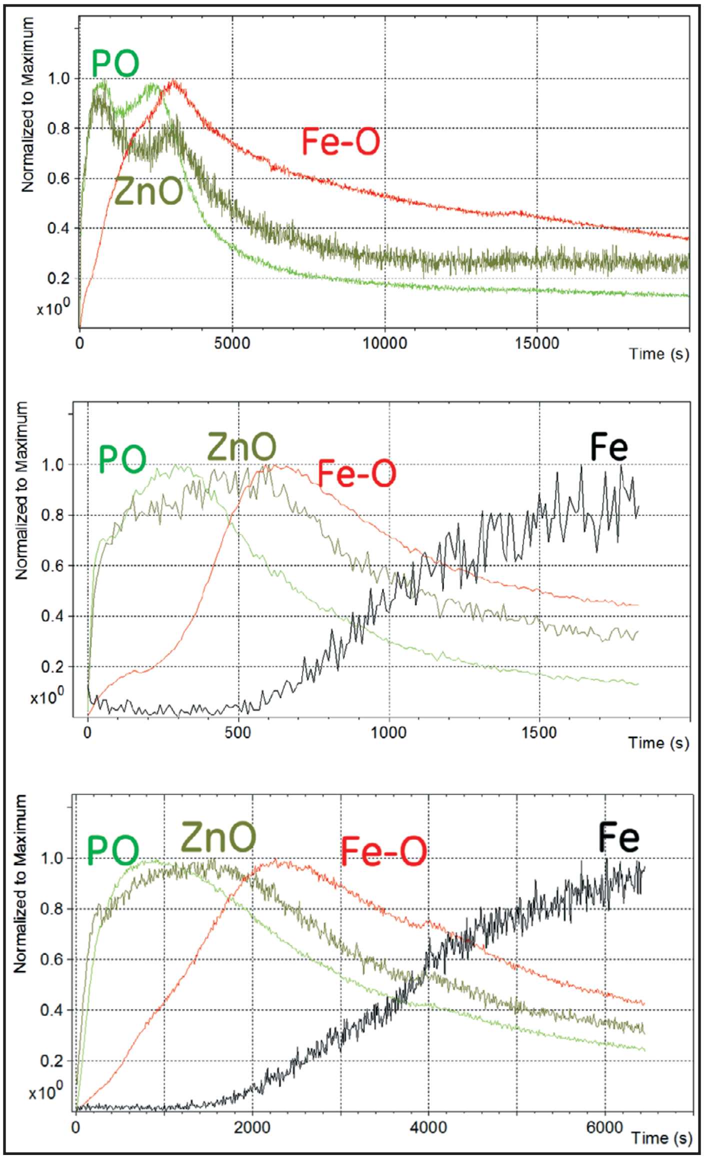


Figure 3 – ToF-SIMS depth profiling of LCS coupons obtained from ethylene plant operating standard Zn (2 ppm) phosphate corrosion program at various pH set points: Top, pH 7.0; Middle, pH 7.5; Bottom, pH 8.4. The 3 samples were acquired from 3 separate cooling towers on the same site.

Half Cell Reactions	E° (V)	ΔG° (KJ)	Expected Result
$Sn^{4+} + 2e^- \rightarrow Sn^{2+}$	0.15		
$Sn^{2+} + 2e^- \rightarrow Sn^0$	-0.14		
$Cu^{2+} + 2e^- \rightarrow Cu^0$	0.34		
$Zn^{2+} + 2e^- \rightarrow Zn^0$	-0.76		
$Fe^{2+} + 2e^- \rightarrow Fe^0$	-0.45		
$HClO + H_2O + 2e^- \rightarrow Cl^- + H_2O$	1.49		
$ClO^- + H_2O + 2e^- \rightarrow Cl^- + OH$	0.89		
Galvanic Reactions	**E° (V)**	**ΔG° (KJ)**	
$Sn^{2+} + Zn^0 \rightarrow Sn^0 + Zn^{2+}$	0.62	-120	Dezinc
$Sn^{4+} + Zn^0 \rightarrow Sn^{2+} + Zn^{2+}$	0.91	-176	Dezinc
$Sn^{2+} + Cu^0 \rightarrow Sn^0 + Cu^{2+}$	-0.48	93	No Reaction
$Sn^{4+} + Cu^0 \rightarrow Sn^{2+} + Cu^{2+}$	-0.19	37	No Reaction
$Cu^{2+} + Sn^0 \rightarrow Cu^0 + Sn^{2+}$	0.48	-93	Cu plating
$Cu^{2+} + Sn^{2+} \rightarrow Cu^0 + Sn^{4+}$	0.19	-37	Cu plating
$Sn^{2+} + Fe^0 \rightarrow Sn^0 + Fe^{2+}$	0.31	-60	Galvanic
$Sn^{4+} + Fe^0 \rightarrow Sn^{2+} + Fe^{2+}$	0.6	-116	Galvanic
$Cu^{2+} + Fe^0 \rightarrow Cu^0 + Fe^{2+}$	0.79	-152	Galvanic
Oxidizer Reactions	**E° (V)**	**DG° (KJ)**	
$HClO + Sn^0 \rightarrow Cl- + H_20 + Sn^{2+}$	1.62	-315	hypochlorite demand
$HClO + Sn^{2+} \rightarrow Cl^- + H_20 + Sn^{4+}$	1.33	-258	Hypochlorite demand
$ClO^- + Sn^0 \rightarrow Cl^- + H_20 + Sn^{2+}$	0.84	-199	Hypochlorite demand
$ClO^- + Sn^{2+} \rightarrow Cl^- + H_20 + Sn^{4+}$	0.84	-143	hypochlorite demand
E°cell = E°red - E°ox			
DG = -(nFE°cell)			
n = number of electrons			
F = 96500 C/mol			
E°cell = V			
V = J / C			

Table 2 - Half-cell reactions and Gibbs free energy of expected electrochemical reactions in cooling applications with respect to the use of tin cations. When Gibbs free energy is negative the reaction is expected to be spontaneous and occur. Thermodynamic values cannot infer kinetic information.

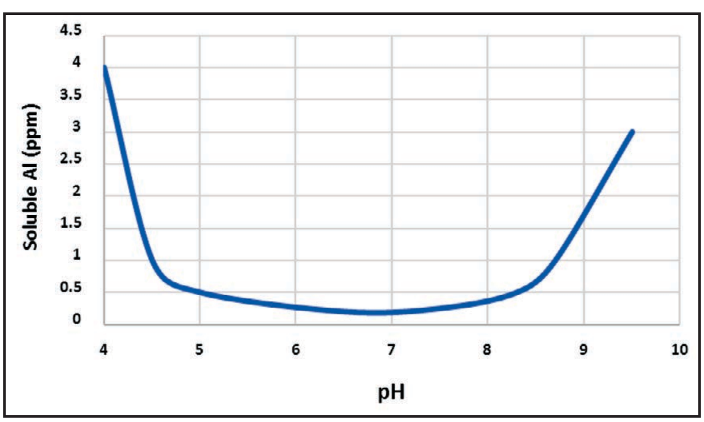
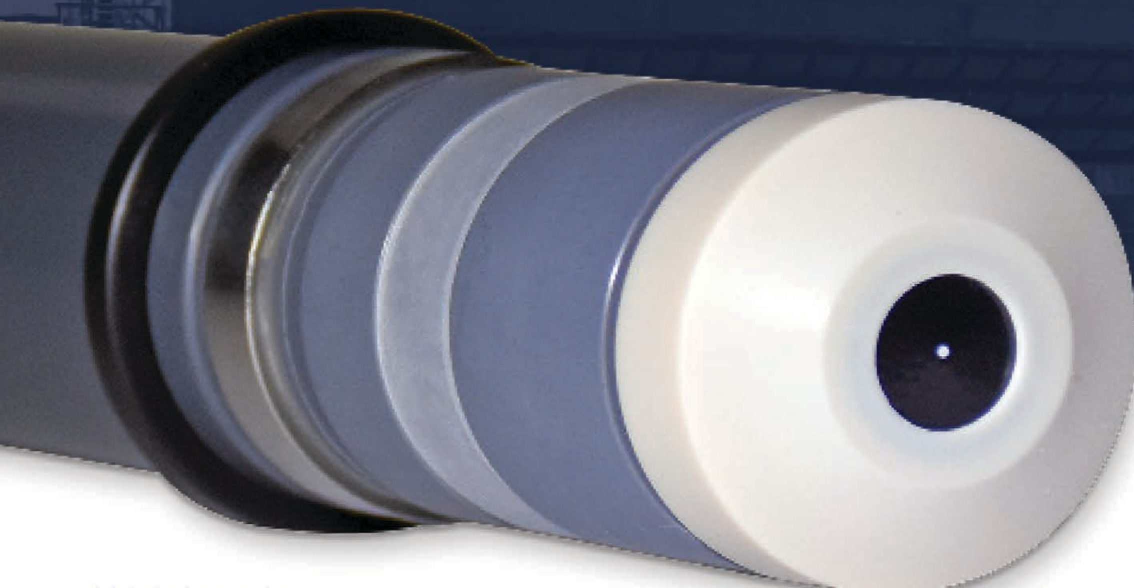


Figure 4 – Solubility curve for Al^{3+} versus pH.

	Target
pH	8.0
M-alkalinity as $CaCO_3$	250
Ca as $CaCO_3$	600
Mg as $CaCO_3$	200
Cl	424
SO_4	240
SiO_2	30
o-PO_4	1
Al	0 – 0.25
hypochlorite - residual	0.3 – 0.5

Table 3 – Water conditions evaluating Al^{3+} potential as a low P or no added P corrosion inhibitor. Two tests were done in the BTU systems with and without the addition of Al^{3+}.



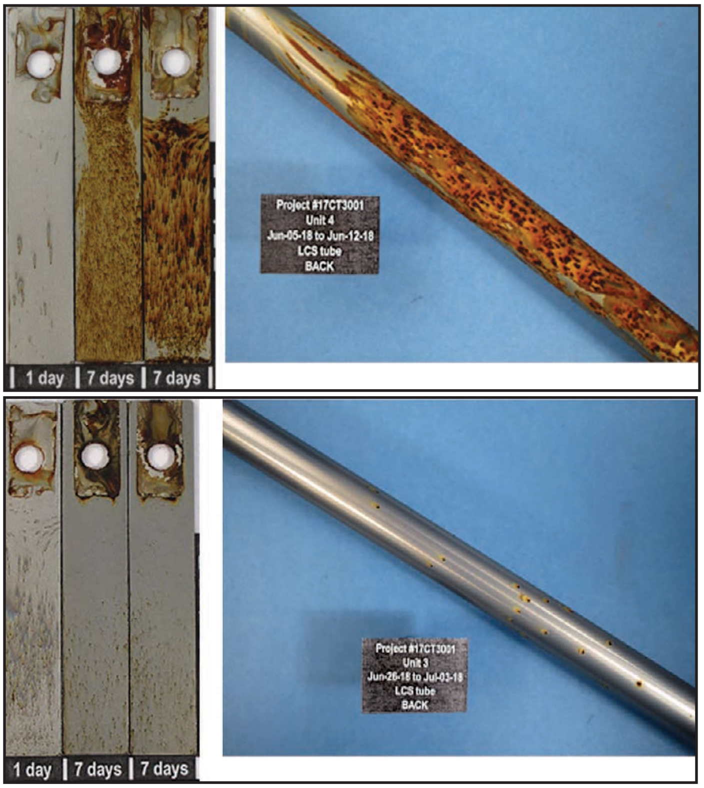


Figure 5a – BTU results comparing the use of CHO-2 with and without the addition of Al^{3+}. HX tubes were pretreated for 24 hours to form an initial passivation film with Ca/P, coupons were not pretreated with Ca/P. Al was fed at 0.25 ppm and was maintained in the bulk water +/- 0.5 ppm of that target throughout testing duration. Average coupon corrosion rate for CHO-2 was 5.6 mpy. Average coupon corrosion rate for CHO-2 with Al^{3+} was 1.93 mpy. A large contribution of the corrosion rate appears to originate at the holder siteas under deposit corrosion.

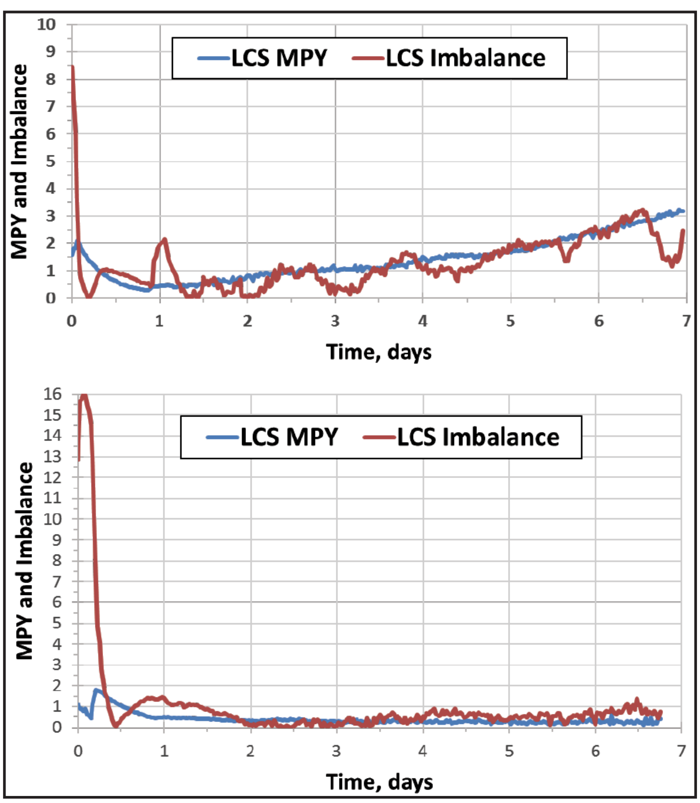


Figure 5b – mpy and imbalance versus time plots for CHO-2 and CHO-2 with Al^{3+}. The use of Al^{3+} greatly lowers the imbalance versus CHO-2 indicating that it is effective in minimizing localized corrosion cells. Hypochlorite feed is started roughly 12-16 hours after the start of the experiment allowing for equilibration.

	Condition 1	Condition 2
CHO-1	1.2	2.8
CHO-2	1.2	4.1
CHO-3	1.8	1.9
CHO-4	3.9	5.1
CHO-5	6.7	26
CHO-6	1.8	2.3
CHO-7	3.6	4.2

Table 4 - Beaker Corrosion results for East Coast Power application, water conditions listed in Table 5

	Target
pH	7.8 – 8.0
M-alkalinity as $CaCO_3$	100
Ca as $CaCO_3$	56
Mg as $CaCO_3$	48
Cl	40
SO_4	46
SiO_2	70 – 125
o-PO_4	0 – 0.5
Zn	0 – 0.5
Hypochlorite - residual	0.3 – 1.0

Table 5 - Water conditions for East Coast Power Facility utilizing reservoir water

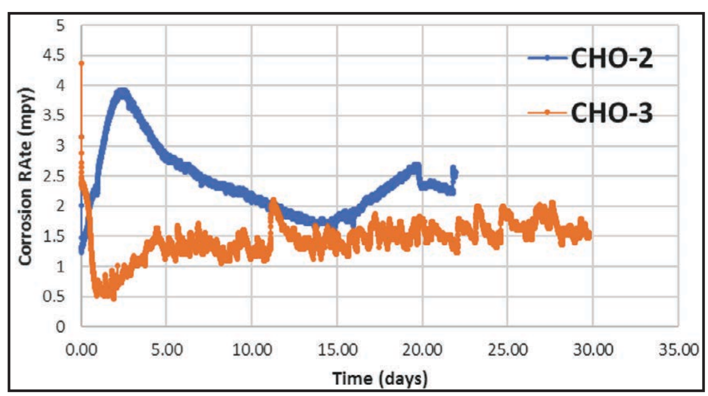


Figure 6 - East Coast Power application cycled up reservoir water comparing CHO-2 to CHO-3.

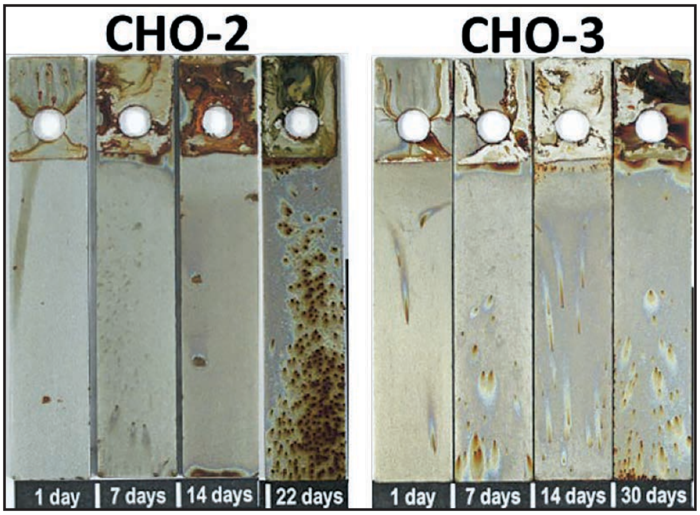


Figure 7 - Coupon results comparing CHO-2 and CHO-3 for East Coast Power Application using cycled up reservoir water. Average corrosion rates for CHO-2 were 2.0 mpy (143 micron, average measurable pit depth); average corrosion rates for CHO-3 were 1.30 mpy (43 micron, average measurable pit depth).

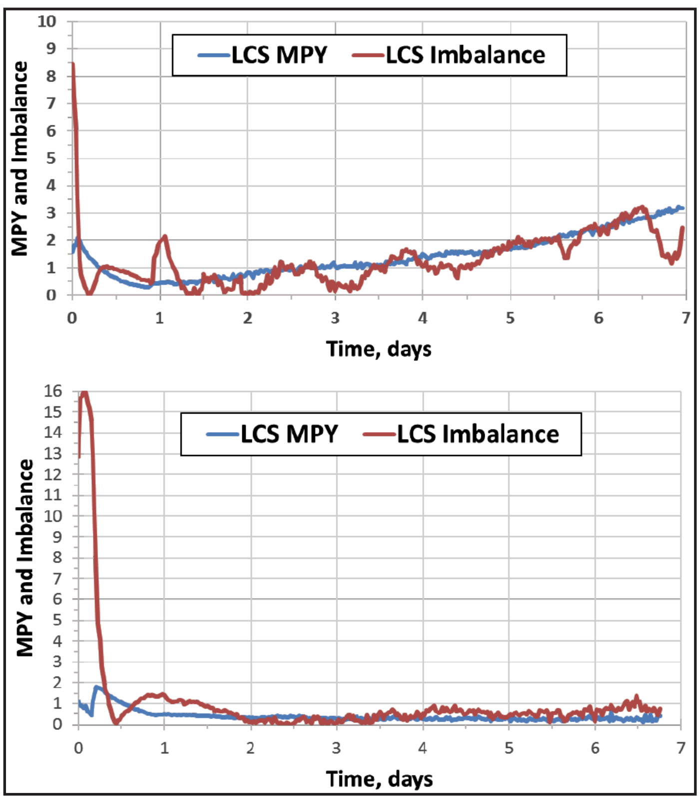


Table 5 – Synthetic cycled up water chemistry of a Midwest refinery.

Parameter	Traditional	Low P
pH range	8.2-8.6	8.2-8.5
o-PO_4	6	2.5
Ca as $CaCO_3$	150-250	200-300
M-alk as $CaCO_3$	200-250	200-250
CHO-1 Inhibitor		10-12

Table 6 – South American Chemical plant's transition from traditional to low P program utilizing CHO-1 to achieve corrosion rates less than 1 mpy.

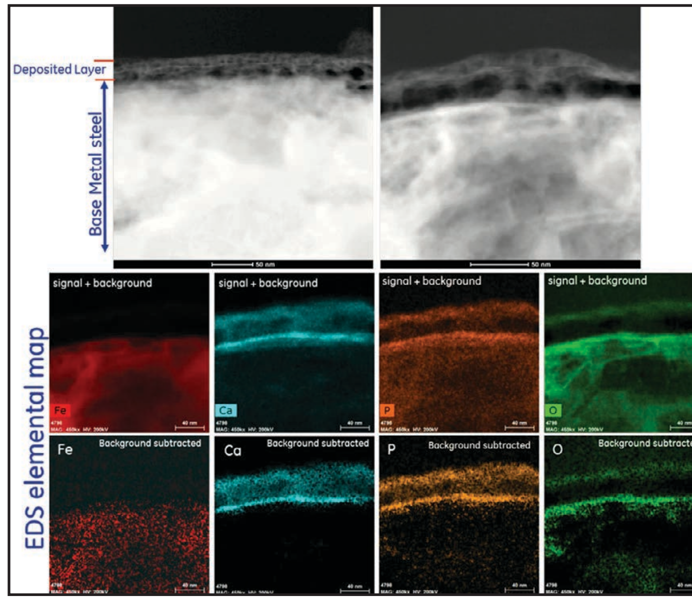


Figure 8 – TEM images of the CHO-1 engineered passivation matrix from a 30 day LCS field coupon. The engineered passivation matrix is roughly 40-50 nm thick and consists of a fully covered surface with significant percentage of Ca, P, and O. Carbon is present and is often not shown due to contamination.

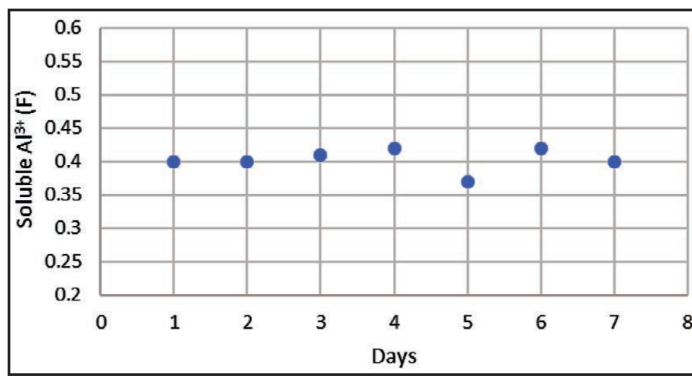


Figure 9 – Measure of soluble Al^{3+} in filtered recirculating water. Maintaining soluble Al^{3+} allows for the engineering of specific passivation salt matrix that reduces localized corrosion and general corrosion rates.

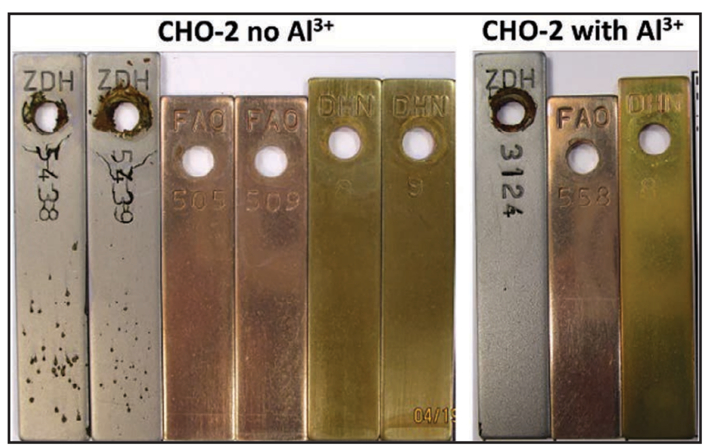


Figure 10 – representative coupon data showing the improvement from using an Al^{3+} and CHO-2 inhibitor program versus just the CHO-2 inhibitor. CHO-2 with no Al^{3+} had measured corrosion rates for LCS, 2.1 mpy, 90:10 CuNi, 0.08 mpy, and ADM, 0.20 mpy. CHO-2 with Al^{3+} had measured corrosion rates for LCS, 0.80 mpy, 90:10 CuNi, 0.06 mpy, and ADM, 0.23 mpy. There was 3 ppm azole present for yellow metal corrosion control.

A New Technology For Ultra-Low Noise And High Efficient Axial Fan For Industrial Application

Riccardo Provasi, Axial Fans Int Srl

Riccardo Provasi

Abstract

In the industrial plants, the regulations concerning the noise emission are prescribing more and more stringent requirements. In the large cooling systems like cooling towers and air-cooled steam condensers, to comply with these regulations, the use of the so called ultra-low noise fans is mandatory. But these fans actually available on the market, despite their optimal acoustic properties, have some negative aspects in terms of efficiency, weight, and size, that determine a huge impact on the cost of the whole unit.

This paper describes an innovative technology solving all the negative aspects that the last generation of the ultra-low noise fans could not solve completely.

Common Methods To Reduce The Noise

In the field of axial flow fans for industrial applications, the methods used today to satisfy the requirements of low noise emissions are the reduction of the rotational speed and the modification of the blade shape. The particularities of the ultra-low noise fan blades are more evident when compared with the characteristics of the normal noise fan blades, as detailed hereinafter.

The normal noise fan blades, used when there are not specific requirements about noise emission, have rather narrow chord and long span which provide them with the highest aspect ratio among all the types of blades. The aspect ratio is the ratio of the blade span to its mean chord and it is equal to the square of the blade span divided by the blade area.

These blades use very efficient aerodynamic profiles, staked along their radial span. They are twisted and tapered from the root section, which is more inclined and larger, to the tip section, which is less inclined and narrower, in order to have a uniform distribution of pressure all along the radial span. They typically operate at the maximum tip speed accepted by the standards, which is about 60m/s, and at these conditions, the fans have their best efficiency and lowest cost.

In a projection on the rotating plane, these blades show a rectangular or trapezoidal shape, or any combination of these two; the leading edge and the trailing edge are almost straight, may be inclined respectively backward and forward with respect to the rotating direction as it becomes clearer looking at the Figures 1 and 2, where two typical blades commonly used today in the large fans are shown: the blade of figure 1 is tapered and twisted, the blade of figure 2 comprises at the trailing edge of the profile an integrated trimmed flap so that the blade finally results twisted and tapered.

The same blades can be used when the noise level must be reduced about 5 dB(A) with respect to the standard emission. This result can be easily reached just operating the fans at a lower speed. In this case, to compensate the loss in the aerodynamic force, the surface of these blades has to be increased enlarging the chord length. In fact, the blades have the same profile, just scaled in size in order to have a more extended chord, with the same shape: in a projection on the rotating plane they are almost rectangular, trapezoidal or any combination of these two; the blades are tapered and twisted; leading and trailing edges remain straight, may be inclined with respect to the rotating direction. In figures 3 and 4 the blades for the normal noise requirements are compared with the blades for the low noise requirements.

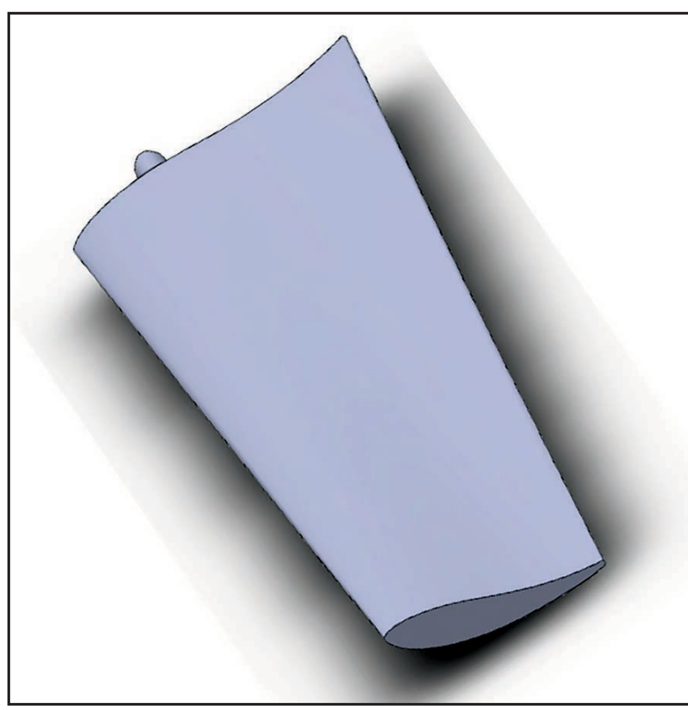


Figure 1 – Tapered and twisted blade for normal noise application

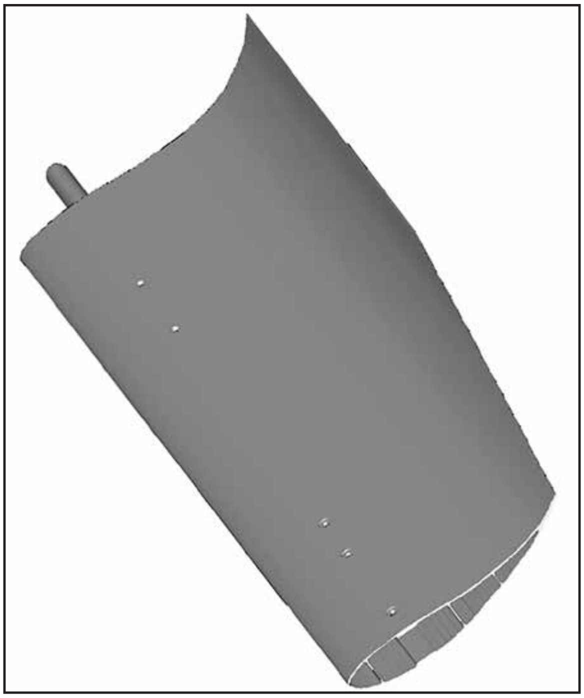


Figure 2 - Blade with trimmed flap for normal noise application

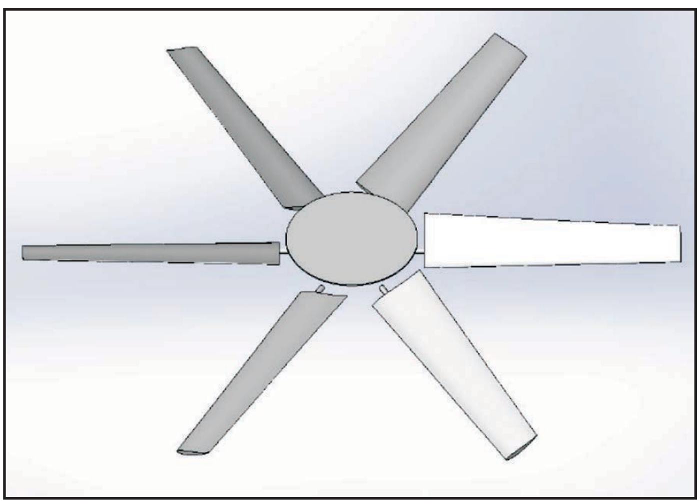


Figure 3 - Blades of normal noise large diameter axial fan

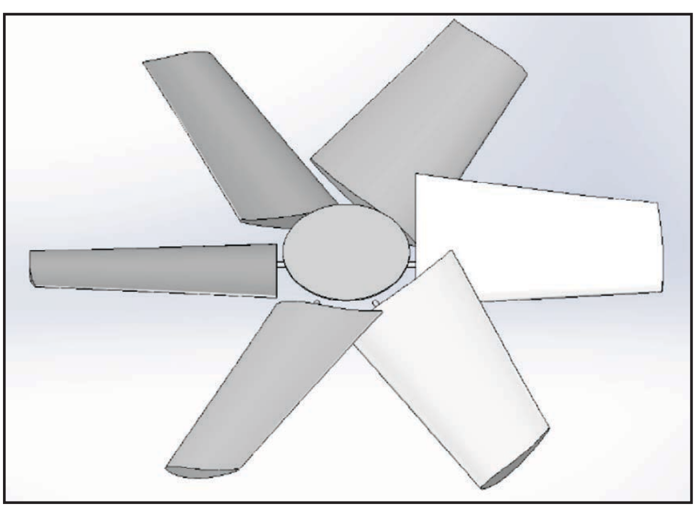


Figure 4 - Blades of low noise large diameter axial fan

As the opposite, the ultra-low noise fan blades, even called super low noise fan blades, are used when an abatement of at least 10 dB(A) in sound emission, with respect to the common fan blades, is required.

In order to obtain this noise abatement a further reduction of the tip speed with a consequent enlargement of the chord length and a radical change in the blade shape are needed. In fact, considering the typical rotational speed for these fans is about 30m/s, that is half of the typical operating speed of standard fan blades, the surface of the ultra-low noise blade has to be at least four times the surface of the normal blade in order to compensate the loss on the aerodynamic forces. Consequently, the ultra-low noise fan blades have an extremely low aspect ratio and their shape in the projection on the rotating plane is completely different with respect to the previous blades.

The leading edge is swept forward or backward; the trailing edge is usually swept accordingly. The sweeping can be according to a curved or a straight line; a combination of these two can be used for leading and trailing edges.

Figure 5 shows the sweeping of both the leading and trailing edges according to curved lines; Figure 6 shows the sweeping of both the leading and trailing edges according to a straight line; Figure 7 shows the sweeping of trailing edge according to a curved line and the sweeping of leading edge according to a straight line.

All these types of blades clearly have a very large chord at the tip, larger than at the root, especially the blade of figure 5 and 7, and all of them, have a very complicated shape.

Figure 5 - Ultra low noise fan blade with leading edge and trailing edge swept according to a curved line

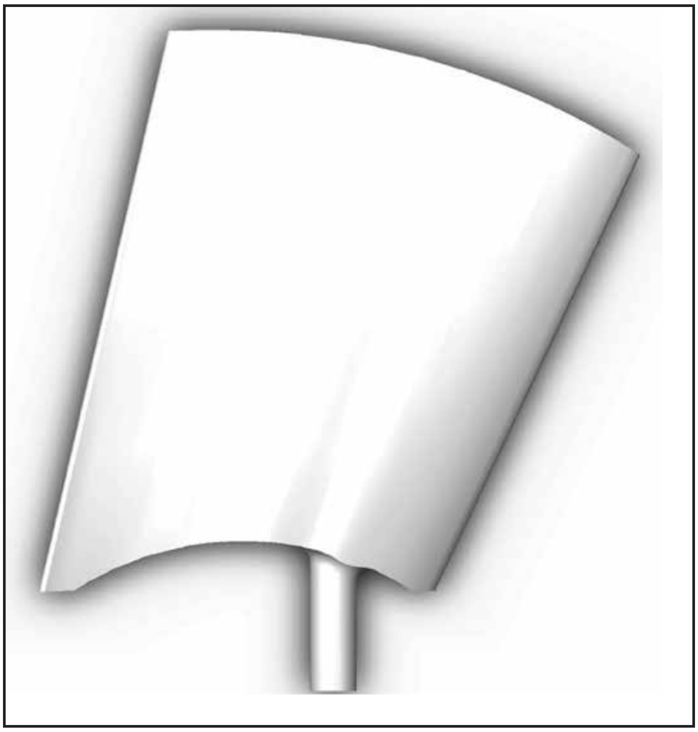


Figure 6 – Ultra low noise fan blade with leading edge and trailing edge swept according to a straight line.

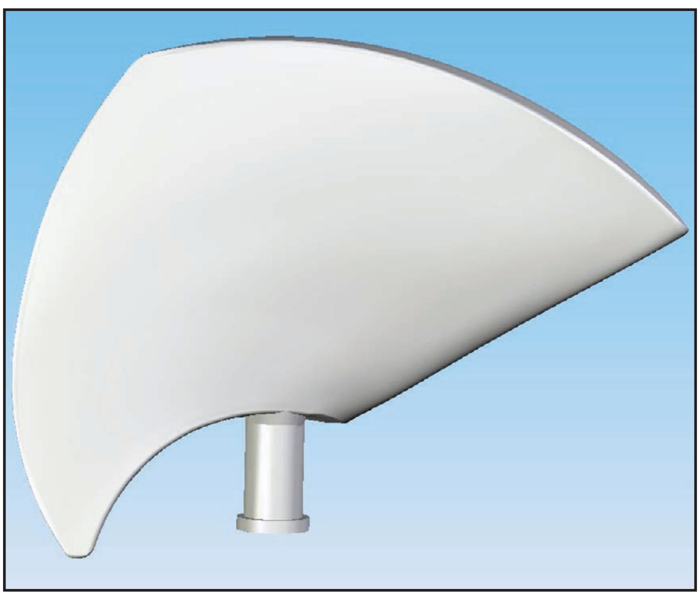


Figure 7 – Ultra low noise fan blade with leading edge swept according to a straight line and trailing edge swept according to a curved line

Despite their optimal effects in terms of acoustic emission, these characteristics have several negative effects on efficiency, costs, installation and operation.

First, the decrease in the aspect ratio reduces the aerodynamic efficiency as well-known from technicians skilled in aerodynamics.

Second, the very large shape of the blades does not allow an efficient aerodynamic section distribution along the span because they are decreasing in size from the tip toward the hub (reverse tapering) and the high increase in the twist at root section does not compensate what has been lost by the chord decrease.

Third, the massive amount of material used, typically from 4 to 8 times the material used for the normal noise fan blades, and the increase in the time to produce a single blade determine a remarkable increase in their cost.

Fourth, the increase in the clearance between the blade tip and the fan ring when the fan rotates, generates an additional loss in the aerodynamic efficiency and an additional increase in the acoustic emission. This effect will become clearer after the following explanation. At the tip section of the blades, some reverse air flow occurs, which is responsible for decrease in lift and for generation of vortex wakes. The importance of these phenomena is directly proportional to the amplitude of the clearance: the larger is the gap, the larger are their intensity and consequently their detrimental effects on blade acoustic and aerodynamic performance. To minimize these negative effects, the tip clearance has to be uniform and minimum all along the tip section, but it occurs only at one pitch angle.

Most of these fans have an adjustable pitch angle and the same blade can be used in situations where the pitch angle is very large, typical for low speed. Changing the pitch, both the tip leading edge and the tip trailing edge go away from the ring and this displacement becomes greater when larger is the chord and bigger is the pitch. Therefore, for an ultra-low noise fan blade the detrimental effects of the clearance on the aeraulic and acoustic performance are amplified if compared to the normal noise fan blade. In figures 8 and 9 the increase in the tip clearance with the pitch angle is shown for a typical ultra-low noise fan blade of a large diameter axial fan.

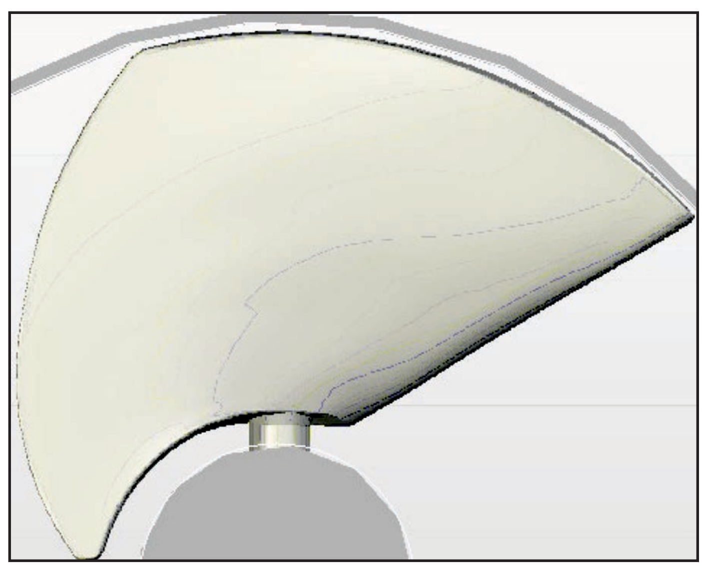


Figure 8 - Minimum clearance at optimal pitch

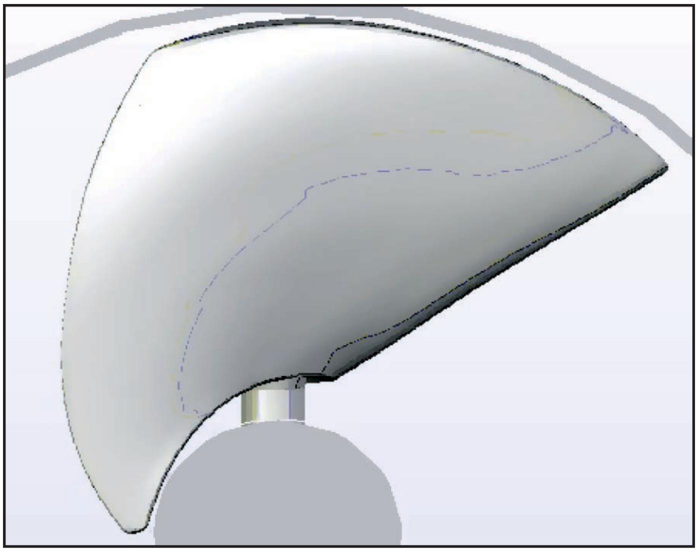


Figure 9 – Non-uniform clearance at a pitch different from the optimal

Fifth, the increase in the chord length makes these blades difficult to balance with the standard static moment balancing procedure. For the larger diameters, the dimension of these rotors makes also almost impossible to balance them dynamically, therefore in some cases the on-site balancing procedure is needed, which is expensive and has to be repeated each time a blade is replaced.

Last, their weight and size oblige the use of special cranes for the installation and to adopt taller fan ring and to toughen the structure supporting them with a strong impact on the cost of the entire cooling system and its erection.

Based on the above considerations it is possible to conclude that all the systems and methods today available on the market to reduce the noise of large fans have very important drawbacks consisting in large reduction of aerodynamic efficiency, in very high costs and huge installation problems.

Although the last generation of ultra-low noise fan blades have partially mitigated the described negative effects, however all of them remain unsolved.

Stealth Technology

To provide a definitive solution to the unsolved problems, an innovative technology, called Stealth, has been developed, applicable to the whole range of fan diameters, which obtains the same noise emission level of the best ultra-low noise fan blades, but maintaining an aerodynamic efficiency equal or even better when compared with normal noise fan blades, with a modest increase in weight and size which are only marginally affecting the cost of the cooling system.

The new blade is derived from the high efficiency airfoils used in normal noise applications. In its projection on a plane perpendicular to that of rotation, it is forming a V shape along its span, as shown in figure 10. This shape is obtained by joining an inner blade part with an outer blade part, to form an optimal angle. This type of blade has a particular constructive simplicity compared to the existing ultra-low noise fan blades.

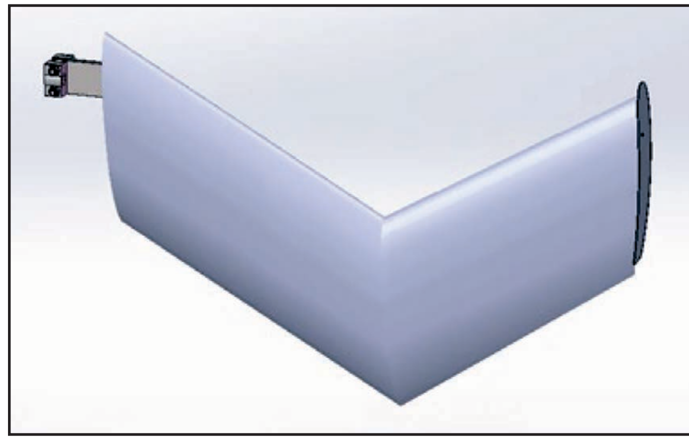


Figure 10 – New ultra-low noise fan blade

The reasons why the new blades can get the same noise emission level of the best ultra-low noise blades, preserving or even increasing the high efficiency of common blades are hereinafter explained:

- the described geometry is realized stacking in the blade span direction wing profiles having very high aerodynamic efficiency, higher than those used in common ultra-low noise blades;
- the blade aspect ratio decreases substantially less than the ultra-low noise fan blade, consequently the blade efficiency decrease is negligible;
- the average gap on the tip will be much smaller because the chord is smaller and the noise originated by the tip vortices will be reduced;
- the relatively small size of tip chord is allowing to apply as standard the aerodynamic devices which improve the efficiency allowing less backflow to pass;
- the reduced chord length distribution all along the radial span is making the new fan blade lighter than the existing ultra-low noise blades, consequently the bending and axial loads at the radial sections is reduced, particularly at the root;
- the reduced chord length, particularly at the outer part of the blade, contribute to reduce the inertial torsional moment;
- the higher efficiency of the blade means lower drag force at the same lift, with a consequent reduction of shear loads at the radial sections, particularly at the root.

The developed Stealth fan blade has also an additional advantage: it can be manufactured with the SmartFans technology which can substantially smooth the vibrations induced into the fan supporting structure.

Comparative Tests

An extensive test program on a 10 feet diameter axial flow fan was performed in order to compare the aerodynamic and acoustic performance of the Stealth blades with the developed geometry and those ones of the best ultra-low noise fan blades. The most significant results are summarized in the flowing paragraphs.

Testing equipment

The experimental measurements were conducted in Axial Fans International Research Center in Besnate, Italy.

The testing equipment is a wind tunnel designed according to BS 848.

Fan of 3.048m (10ft) is driven by a three phases 50Hz induced electrical motor, 55kW rated power. An inverter can regulate the speed to the desired value. A sound absorbing cabinet is installed on the motor.

The duty point can be changed regulating the inclination of the louvers installed at the inlet section of the tunnel; air straighteners just behind the louvers are making the air stream parallel to the tunnel axis and are smoothing the turbulences.

The aeraulic performance are measured inside the tunnel through 40 anemometers distributed along four radiuses, 90 degrees spaced one to each other and located in the center of equivalent areas, 30 pitot tubes, distributed along three radiuses, 120 degrees spaced one to each other and located in the center of equivalent areas, 8 static pressure probes, 45 degrees spaced one to each other and distributed on the wall of the tunnel.

All the instruments, the acquisition system and the post-processing software are proprietary; measurements accuracy, uncertainties and repeatability are within +/-0.5%.

Sound pressure level is measured with a phonometer at 1.5m, 45° from the discharge section at the same height of the fan centerline.

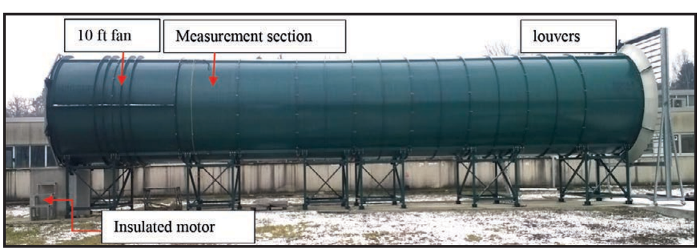


Figure 11 – Wind tunnel

Instruments and testing procedure

The sound pressure level probe is a free field PCB Piezotronics microphone, model 377B02. The microphone is preamplified using PCB Piezotronics preamplifier, model 4261E01.

The post processing spectral analysis of the recorded signal is conducted with the Simus Gmbh suite Apollo Light.

The complete measurement system meets the requirements of Type I as per IEC 61672.

To verify the calibration before and after each set of measurements, a Larson & Davis 60942 is used.

A windscreen on the microphone is also used.

Before starting each fan test, the rotor is balanced to ensure vibrations not greater than 1.5mm/s rms, which is a good value for this type of fan.

Clearance between the blade tips and tunnel wall is set with an average value of 0.4%+/-0.05% of the fan diameter.

To isolate the aerodynamic noise from other noises, a preliminary test on motor and transmission system without the fan is conducted to establish their spectral signature and to allow for a correction of subsequent noise measurements. These tests indicated the driving system noise at the measurement locations is negligible.

The measurement locations are not placed along the fan centerline to avoid the possibility of direct flow interfering with the microphone.

Nevertheless, air speed measurements are carried out in the noise measurement location and results indicate airflow is negligible.

Before starting the test on fans, the background noise is also measured at the measurement locations. Even in this case, the sound intake is negligible.

Tested fans

The tested fans are:

- a fan considered as common reference worldwide for low-noise fans, with 3 fiberglass blades
- AFI 7.1A-3048-04-STD REM2, the ultra-low noise fan with 4 aluminum blades developed according to the new Stealth technology

The main characteristics of the tested fans are summarized in table 1.

Characteristic	Unit	Ultra-low noise fan blade	Stealth fan blade
Fan diameter	mm	3048	3048
Number of blades		3	4
Chord length at tip	mm	1700	1010
Fan weight	kg	280	167

Table 1 – Fan characteristics

The fan adopting the new developed technology has about 40% reduced encumbrance and 40% reduced weight, even if it has 4 blades instead of 3.

Test results

The test is performed at a rotational speed of 219 rpm corresponding to 35m/s as tip speed.

Seven duty points are obtained regulating the louvers position at the inlet section of the wind tunnel.

In the following figure the measured fan curves of the two fans are plot.

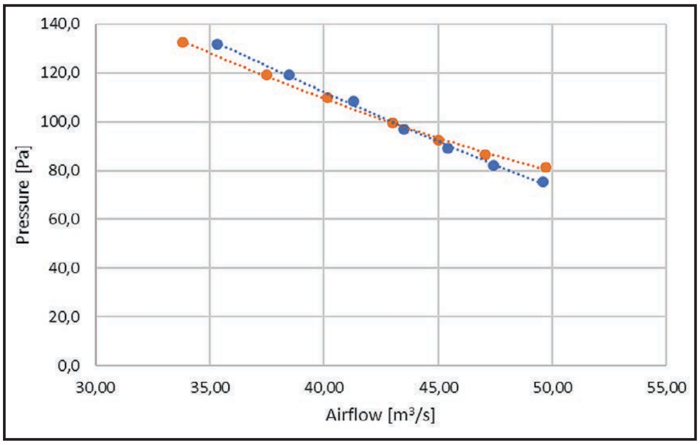


Figure 12 – Fan performance curves (red for Stealth fan – blue for reference fan)

Measured aeraulic and acoustic performance (already deducted the background and driving system noise) are listed in the following tables.

Reference ultra-low noise fan				
Airflow [m3/s]	*Pressure [Pa]*	*Motor Power [kW]*	*Efficiency [%]*	*Sound Pressure [dB(A)]*
49.6	75.3	7.85	47.6	61.1
47.4	82.2	8.15	47.8	61.1
45.4	89.3	8.44	48.0	61.5
43.5	97.1	8.85	47.7	61.5
41.3	108.6	9.25	48.5	62.1
38.5	119.1	9.54	48.0	62.8
35.3	131.9	9.97	46.7	63.3

Table 2 – Measured performance of ultra-low noise reference fan

7.1A-3048-04-STD REM2				
Airflow [m3/s]	*Pressure [Pa]*	*Motor Power [kW]*	*Efficiency [%]*	*Sound Pressure [dB(A)]*
49.7	81.3	7.82	51.7	61.2
47.0	86.6	7.77	52.4	61.5
45.0	92.5	8.07	51.6	61.6
43.0	99.3	8.23	52.0	62.0
40.2	109.8	8.50	51.9	62.3
37.5	119.1	8.64	51.7	62.7
33.8	132.5	8.85	50.0	63.7

Table 3 – Measured performance of Stealth fan

In the following table the acoustical and aeraulic performance of the tested fans are compared in terms of efficiency ratio (ER) and difference in sound pressure level (DLp), defined as follow

$$ER = \frac{Efficiency\_AFI}{Efficiency\_ref}$$

$$DLp = Lp_{AFI} - Lp_{ref}$$

ER (%)	DLp [dB(A)]
108.6	0.1
109.7	0.4
107.5	0.1
108.9	0.5
107.0	0.2
107.7	-0.1
108.4	0.4

Table 4 – Performance comparison

Conclusions

In industrial cooling system, noise requirements are more and more stringent. To reduce the noise emitted from the rotating equipment, the use of the so called ultra-low noise fans is mandatory. But these types of fans have several negative aspects which remarkably weigh on the overall cost of the installation, erection and structure costs.

In this paper a new technology applicable to the whole range of fan diameters able to solve all the negative aspects and assuring the same low sound emission is presented and the acoustical and aeraulic performance are studied with respect to the common ultra-low noise fan through a comprehensive comparative test.

The new technology assures the same noise emission level of the most silent fan available in the market but preserving the aerodynamic efficiency of the standard noise fans and substantially reducing the manufacturing, the erection and the whole structure costs.

Discfiltration For Cooling Water Treatment

William (Bill) Willersdorf

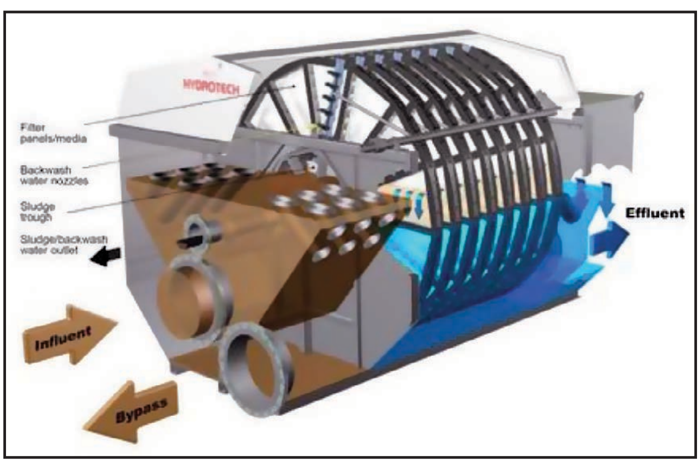
William (Bill) Willersdorf

Abstract

Disc and Drum filtration has been used for many years in both the Municipal and Aquaculture market. One supplier has more than 10,000 units installed worldwide. It became obvious to some that the technology would have multiple applications in the heavy industrial sector. Since Power, HPI/CPI, O&G, P&P and other heavy industries use large volumes of cooling and demin water and at times reclaim water is a source of water, the 'jump' to the industrial market was logical. New uses for the technology continue to develop as industries look for better ways to meet their water and wastewater treatment needs, while achieving sustainability goals.

This paper will review various market sector installations of the technology, while going into depth at particular sites and introduce innovative ways it is being applied.

At one location, which filters 5,000 gpm, a 60% reduction in backwash water volume was achieved when compared to the replaced media filters. In addition, the water quality was improved giving the Owner longer run lengths in their ion exchange units used to make steam for cogeneration- lowering their Opex.



Introduction: A quick summary of how the unit works is as follows:

Woven polyester cloth filter elements are installed on multiple discs; utilizing an inside-out flow pattern, the filter is appropriate for a variety of applications including tertiary wastewater filtration, water reuse, Phosphorus removal, process water-including cooling and storm-water treatment. Water to be treated flows by gravity into the filter segments from the center drum. Media mounted on both sides of the partially submerged discs separates the solids from the water. Filtered water flows through the disc media into the collection tank. Once solids have accumulated on the inside of the media, the discs are cleaned by a high pressure, low volume backwash while the filter continues to provide filtered water.

Orientation Selection: The Engineering firm and/or Owner have a choice of installing frame units into concrete basins (old or new) or using pre-engineered stainless steel tank designs. Either one will result in huge benefits overall and both result in easy to operate and maintain filtration units. If you have ever had to crawl into the plenum under false bottom filters or tried to find one bad strainer in a large filter, then you are aware of the level of difficulty and the labor costs in these tasks! In addition, the filter leaves come installed in the factory, and the design eliminates granular media filling, washing, rinsing and bed leveling during commissioning. Since many older filter designs use sand as a filter media, which is silica based, it can be a health hazard once silica dust is airborne - which can occur especially during loading and unloading media if proper pre-cautions are not taken.

Process Application: The primary purpose of disc filtration is similar to any filter; namely the removal of suspended solids and turbidity reduction. Micron ratings for DiscFilters are typically between 10 - 100 micron for cooling water applications but can go up to 1,000 micron openings, depending on particle size distribution of the solids to be removed and the design parameters specified by the Client. DrumFilters often have larger openings, typically ranging from 30 – 500 micron.

There is the opportunity to remove other specific constituents, such as phosphate, if the proper chemical treatment is used.

Typical Effluent Quality Characteristics:

- **Without chemical pretreatment** (polymer/coagulant): approximately 50% TSS reduction, but reduction can be significantly higher if the majority of solids exceed the micron rating of the filter
- **With chemical pretreatment** (polymer/coagulant): typically down to 5 mg/l or 2 NTU

Typical Industrial Water Sources Involve:

- **Surface water**:
  - Lakes
  - Rivers
  - Ponds
  - Canals
  - Sea & Brackish water
  - Storm water
- **Reclaim water** (sewage plant effluent)
- **Industrial wastewater reuse**
- **Well water**

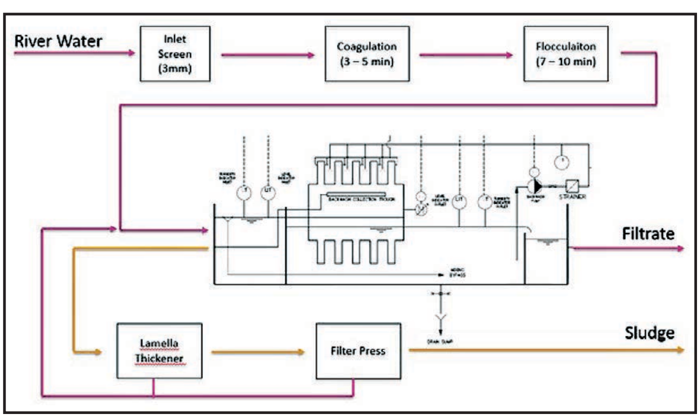
Industrial Applications:

- Cooling Water Treatment: cooling water, especially in heavy industries, typically involves large volumes of water and therefore discfilter benefits become more obvious over other filtration methods.
  - Typical process needs include:
    - Turbidity & TSS reduction
    - Color removal
    - Phosphate removal
  - Application areas to treat Cooling Water:
    - Make-up cooling water filtration
    - Side-stream filtration
    - Cooling Tower Blowdown
- **Post filtration of lime softened water**
- **Reduction of Zebra mussels and other Bio-fouling constituents**

Business Case

A major global Company wanted to upgrade their existing process water systems and as part of that, they installed our DiscFilters in several applications at various facilities in the US. At one large site, the filters were able to handle 5,000 gpm, which then flowed to an ion exchange based demineralizer system. While the design allows for it, no chemical injection as a filter aid is needed after the lime softening clarifier.

Process Knowledge & 'Lessons learned' by Owner and Veolia Hydrotech



Background: The Company had experienced, like many others, media channeling in the conventional filters and as part of the upgrade wanted to prevent that in the future. As stated previously, the water treatment expansion project treats 5,000 gpm from the existing lime softening clarifier discharge pumping system and therefore any channeling in the media may prevent proper filtration of a sizeable quantity of water each minute it is occurring.

Process Description: The treatment process reduces the pH in an adjustment tank with sulfuric acid to mitigate post precipitation of the calcium carbonate and other species. Besides sulfuric acid, a provision to add filter aid in the pH adjustment tank, as needed to enhance the removal of solids was designed in, if needed. Filter panels of the disc filters are rated for 10 micron size, that means particulate matter above 10 microns is retained on the filter panels whereas particulate matter lower than this size passes into filtered water if not aided by a chemical or by larger particles on the filter panels during the filtration cycle. Based on current operations, clarified and filtered water quality filter aid dosing has not been implemented.

Following the pH adjustment tank the water is processed through two disc filters to remove suspended solids. Normal operation (not design) has each disc filter treating between 1800 - 2500 gpm.

The effluent of the disc filters flows to the filtered water tank. The water in the filtered water tank will be transferred back to the filtered water header feeding the ion exchange based Demineralization system.

The disc filter is provided with a factory mounted Backwash Pump that is automatically operated to clean the filter fabric. The backwash waste flows to the sump. In addition, a Chemically-Enhanced Backwash (CEB) system is integrated into the filter housing for hands-free cleaning. The CEB system is manually operated to clean the filter fabric should the normal backwash process fail to clean the filter fabric.

One of the advantages of disc filters is to lower the backwash water volume used in cleaning the filters.

For example, a 5000 gpm Media Filter system would employ 8 to 10 filters with each filter being 12 feet in diameter, requiring once a day backwash at a flow rate of 1600 gpm for ten minutes and creating a minimum of 150,000 gallons of backwash wastewater per day. The disc filters employ a 160 gpm backwash water pump. The backwash sequence starts automatically based on the level differential in the influent water compartment and lasts approximately one minute. On average, the backwash frequency is observed at once every 10 minutes (dependent upon inlet solids). Backwash totals approximately 38,000 gallons each day per unit. This is a 50% reduction of the backwash wastewater generated, when compared to the conventional media filters previously employed. For the owner, this is an important advantage.

DATA Summary For DiscFilter Operation

	Lime Softened Water	Lime Softened Water	Lime Softened Water		Filtered Water	Filtered Water	Filtered Water	Sample Date
Date	pH	Turbidity In	Conductivity In	Avg Flow	pH	Turbidity	Conductivity	
	Std Unit	NTU	us/cm	gpm	Std Unit	NTU	us/cm	
					control range: 8.0 to 8.3	control range: <2 NTU		
Jan 2018	9.9	3.20	355.00	9340	8.3	3.1	394	
Jan 2018	10	17.00	309.00	9924	8.4	4	320	
Jan 2018	10.37	3.35	304.00	9734	8.5	2.6	316	
Dec 2017	10.3	5	319		7.8	3.8	324	
Dec 2017	11.2	4.3	473		8.6	5.8	358	
Nov 2017	10	4	319	10180	7.7	1.6	319	11/16/2017
Nov 2017	10	3.4	330	10302	8.4	1.1	340	11/2/2017
Oct 2017	10	7.3	320	10010	8.5	3.5	334	10/19/2017
Oct 2017	10.31	4.6	320	9837	8.41	1.4	329	10/5/2017
Sep 2017	10	3.8	301	9980	8.7	1.2		9/22/2017
Sep 2017	10.3	5.2	290	9390	9	1.9	301	9/8/2017
Aug 2017	10.2	3.9	349	10126	9	0.94	324	8/23/2017
Aug 2017	10.7	6.6	330	11920	10.3	5.6	334	8/2/2017
July 2017	10.5	3.9	344	9452	8.55	3	355	7/13/2017
July 2017	10.2	3.4	291	9263	7.2	1.8	311	7/6/2017
June 2017	9.9	3.6	264	10240	7.4	1.4	294	6/29/2017
June 2017	10.2	4.8	240	9714	7.1	1.2	244	6/8/2017
May 2017	10	2.8	250	9684	7	1.3	260	5/11/2017
Apr 2017	10.2	3.5	300	11050	7	2.9	312	4/27/2017
Apr 2017	10.1	3.5	260	9510	7	1	274	4/6/2017
Mar 2017	10.2	3	280	8940	7.5	1.6	300	3/21/2017
Mar 2017	10.2	3.5	300	8360	7.5	0.8	327	3/8/2017
Feb 2017	10.3	2	280	7970	7.7	1.2	298	2/22/2017
Feb 2017	10.4	2.2	283	9310	7.2	1.2	291	2/9/2017
Jan 2017	10.4	2.2	326	9557	7	1.4	302	1/26/2017
Jan 2017	10.5	3.6	300	10096	8.5	2	317	1/5/2017
Dec 2016	10.3	4	356	10590	6.9	1.1	375	12/21/2016
Dec 2016	10.6	5	340	9804	9.5	3.3	352	12/7/2016
Nov 2016	10.3	5.2	360	11215	7.5	1	370	11/23/2016
Nov 2016	10.3	5	419	10620	8.8	3.4		11/2/2016
Oct 2016	10.1	4.6	325	10332	7	3.8	346	10/26/2016
Oct 2016	9.8	7.8	290	12060	8.5	3.4	298	10/5/2016
Sep 2016	10.2	14	318	11020	9	6	299	9/28/2016
Sep 2016	9.8	6.3	260	9703	7.9	2.4	275	9/18/2016
August	9.8	6	296	10899	7.7	3.9	312	8/24/2016
Aug 2016	10.2	5	287	7920	8.35	1.8	292	8/17/2016

Lessons learned :

- Provide dedicated feed pumps or feed water source for disc filter system, avoid taking tap off from pressurized header. Tapping off from a pressurized header creates process upsets due to pressure fluctuations in the header. High pressure in the clarified water header induces excessive vibration and noise in the influent pipeline, resulting from pressure restriction & controlling devices needed to discharge into an atmospheric tank.
- pH adjustment of lime softened clarified water: Promote use of CO2, which is a weak acid to reduce and adjust the pH of lime softened water. The Company used sulfuric acid, a strong acid and controlling the pH in the narrow range 8.0 to 8.3 has been a challenge from the beginning. The pH adjustment tank of 16,000 gallon capacity has aided the process to an extent. A sparger and chemical distributor in the tank could be considered as well. Sulfuric acid adds sulfates to water and increases the anionic load on the downstream demineralizers. Carbon dioxide would be an advantage in this regard as well.
- Include ultrasonic level transmitters used to monitor the level and trigger the automatic backwash instead of level switches.
- Automatic versus Manual CEB (Chemically Enhanced Backwash):
- Initiation of the CEB can be manual from the HMI; however CEB sequence once initiated from HMI, should step through automatically to save time. This can occur if the requisite interlock permissives are met. Size, capacity & layout of the system, location of HMI and CEB system with respect to disc filters can also influence such decision.
- The location & design of the CEB header including spray nozzles can be improved to ensure uniform spray of the chemical solution on the disc panels. There were a few attempts at modifying the system with partial success. As a result, the spray pattern has improved, however it can be further improved by changes in the design to ensure a more efficient cleaning system.
- At the conclusion of CEB, a filtered water flush is necessary through the CEB system, a separate connection to the filtered water system is needed to affect this. Presently it is performed through a separate tote using the CEB pump.
- Filtered water from two disc filters is discharged in to a common header and flows by gravity to the filtered water tank. There is no isolation valve on the filtered water line from a disc filter. When performing CEB on one disc filter, the filtered water can be contaminated when the other filter is in service. Additionally for performing maintenance of drive mechanism, isolation of the filters becomes essential. The Company retrofitted isolation valves on the 24" filtered water line downstream of each disc filter.
- When the disc filters of this size are elevated on a platform, consider providing staircase instead of a caged ladder.

However, once these were resolved, the Owner sees many benefits to DiscFiltration over conventional filtration. The two main operating benefits:

- **Reduction of approximately 50-60% of dirty backwash water volume vs. the previously installed media filters**
- **Improved water quality (no media channeling) which results in longer downstream ion exchange demineralizer run lengths**

Owner also highlights other well-known aspects on the application of disc filters as side stream or full flow filtration for a cooling circuit:

- Reduction in make-up water requirement as a result of reduced blow down
- Reduction in energy consumption (result of reduced scale or corrosion of the heat exchange surfaces)

ABOUT SOLUGEN

Solugen is decarbonizing the chemicals industry. Protecting the natural environment means our chemicals are manufactured through a carbon-negative process using plant-based feedstock instead of petroleum.

Our technology is the epitome of sustainability because the more products we make to support our customers, the more CO_2 we remove from the environment. A win-win situation in the truest sense.

SOLUGEN'S PRODUCTS

BioChelate™

Non-toxic and readily biodegradable chelating agent for iron or Fe3+ and copper which is commercial today

BioChelate™ Pro

Non-toxic and readily biodegradable chelating agent for various metals which is similar to EDTA but carbon-negative

BENEFITS OF BIOCHELATE™

BioChelate™ improves scale inhibitor performance and controls corrosion

BioChelate™ is **a synergist** that can be added at very low dosages

BioChelate™ **reduces phosphonate usage by up to 50%** while increasing the performance of scale inhibitors

BioChelate™ **increases polymer performance** by scavenging trace cations such as iron

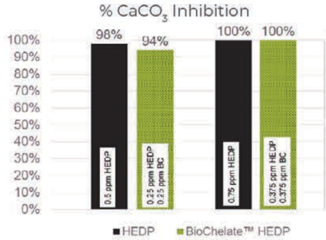
BioChelate™ **prevents pitting**

LIFE CYCLE ANALYSIS

Solugen's process has a favorable Life Cycle Analysis for greenhouse gas (GHG) emissions compared to other competing chemical processes. A third-party company validated that the use of Solugen's BioChelate™ reduces GHGs 3x more than alternative products when used to displace HEDP.

TECHNOLOGY FOR TODAY

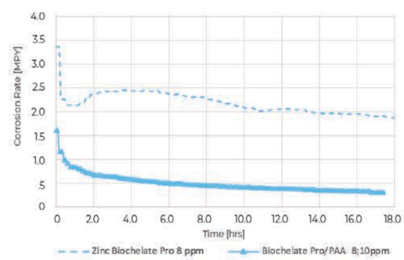
Solugen enhances the performance of our customer's existing technology such as phosphates and acyrlate polymers.



When 50% of HEDP is displaced by BioChelate™, similar scaling inhibition is observed

TECHNOLOGY FOR TOMORROW

Solugen has new molecules that build the foundation for a No Phosphate, No Zinc cooling tower program.



BioChelate™ Pro enables zinc-free, phosphonate-free corrosion control solutions

Solugen is the technology leader in green chemistry manufacturing. Solugen's technology is a solution for your current scale and corrosion issues as well as the future growth of your company.

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- Reduction in chemical used as dispersants in the water treatment program
- Installed cost is comparatively lower than conventional filtration due to several factors including reduced plot space, while being able to handle higher flow rates and much lower backwash rates- therefore no surging dirty backwash water to handle in sumps, large transfer pumps, etc.
- Lower maintenance costs, reduced shut down frequency, improved productivity as well as reliability because of the cleaner cooling system
- Improved control of biological growth (suspended solids promote transport mechanism of micro-biological activity in the system)

The majority of the above benefits reduces operating costs and therefore increase profitability yearly, as well as aid in meeting Sustainability goals, which most major Corporations have targeted.

Energy reduction: While water consumption and chemical costs are important, Energy can be 70% of operating costs for a cooling tower. Veolia operates many industrial plants' water systems globally- especially in Southeast Asia and China and have benchmarked performance for major industrial clients across their fleet.

Energy reduction is therefore a key target to reduce operating costs and can be achieved in many ways, **including using cleaner water, which allows a higher efficiency fill material to be used in the tower.**

'Smart' controls to enhance chemical regimes and online training for operators can all lead to improvements as well.

Cooling Tower Side-stream application: We were able to receive samples from a Client not far from our labs in Houston, so the samples were delivered the same day.

Below are some of the results. We were particularly interested in particle size distribution in the tower.

Water in the Inlet Chamber- Average particle size = 14.169 microns

CW Supply- sample of the cooling water that is recycling and tapped for filtration in the disc filters.

Filtered Water- Average particle size = 1.582 microns

Particle size values helps validate a 10 micron leaf is removing much smaller particles (solids removed acting like a pre-coat, in author's view). Others in the Industry have noted this phenomenon previously.

BW Water Strainer Drain: The TSS was two times the inlet value and average particle size was 1.578 microns

BW data shows the high pressure spray from backwash breaks up solids into smaller particles. Since solids and turbidity are higher in the backwash water, one can conclude the disc filters are working to help keep the basin cleaner.

The reason this customer repeatedly chooses our technology is that both the accountant and the operator are happy. The nine-year-old installation diligently does its job with "less than recommended maintenance attention." Additionally, the routine maintenance task of draining the cooling tower basin for cleaning is skipped because "there is no dirt or sludge in the basin."

EXTRACT From US Department of Energy's (DOE) Fact sheet

Instead of suppliers spouting the benefits of filtering cooling water, we insert the US Department of Energy's words from DOE Fact sheet PNNL-SA-91274 October 2012 on the merit of Side-stream Filtration.

"Cooling tower systems operation is most efficient when the heat transfer surfaces are clean. However, these are dynamic systems due in part to their operating environment and because of the nature of their application. Cooling towers operate outside and therefore are open to the elements, making them susceptible to dirt and debris carried by the wind **(including natural materials- such as cottonseed and sand)**. Further, they often experience wide load variations and their operation can be significantly influenced by the quality of the water used for makeup in the system.

The combination of process and environmental factors can contribute to four primary treatment concerns encountered in most open-recirculating cooling systems: corrosion, scaling, fouling, and microbiological

Activity. Side stream filtration systems reduce suspended solids and debris in the system cooling water, which leads to less fouling in the system. Decreasing suspended solids can also help reduce biological

growth in the system because suspended solids are a good source of food for microbiological organisms. Decreasing biological growth in turn helps to reduce microbiologically influenced corrosion.

In addition, scaling can be reduced from side stream filtration by limiting fouling and corrosion byproducts which can also contribute to scale formation on the heat exchange surfaces. Effectively managing these conditions can optimize system performance, often resulting in moderate to significant energy and water savings.

Full flow and side stream filtration are the two most common methods used to filter the water that is pumped into the circulation systems. Full flow filtration uses a filter installed after the cooling tower on the discharge side of the pump. This filter continuously filters all of the recirculating system water in the system. Inherently, the filter must be sized to handle the system's design recirculation rate. Side stream filtration, on the other hand, continuously filters a percentage of the flow instead of the entire flow. It can be a cost-effective alternative to full flow filtration that can easily improve the water quality to reduce water consumption and ensure efficiency of the cooling systems. And unlike full flow filtration, side stream filtration systems can be cleaned while the cooling systems are online, avoiding the need for planned downtime" (BAC 2012).

"These systems remove suspended solids, organics, and silt particles for a portion of the water system on a continuous basis, reducing the likelihood of fouling and biological growth, which helps to control other issues in the system such as scaling and corrosion. This improves system efficiency and often reduces the amount of water rejected from the system… Side stream filtration increases water and energy efficiency and reduces cost."

Table 1. Relative Size of Common Cooling Water Contaminants (McDonald 2009)

Particle Microns:

- Sand .... 100 to 2,000
- Pollens .... 10 to 1,000
- Mold Spores........................ 0 to 30
- Bacteria 3

Energy is the largest operating cost of the Tower. Not chemicals and not water, which explains why the DOE focuses on cooling towers. Again, from the same DOE fact sheet as above:

> **"Reduction In Energy Consumption:**
>
> **Side stream filtration reduces the likelihood of scale and fouling on the heat exchangers. Even the smallest layer of scale or fouling can reduce the rate of heat exchange, forcing the system to work harder to achieve the required cooling."**

Additionally, the US DOE reports side-stream filtration can reduce the need for chemicals- specifically dispersants and biocides. Note not eliminate, but reduce. Moreover, of course it will reduce the amount of tower basin cleanings required- which typically needs the tower to be offline and drained. Finally, they report the likelihood of improved productivity since heat exchange equipment will require less cleanings and can remain online longer.

For Power companies and industrial cogeneration facilities, this is especially important as it directly affects revenue and profitability.

Other Industrial Applications:

- Cooling tower blowdown treatment - to meet specific discharge goals set by environmental agencies.
- Aquaculture
- General industrial wastewater treatment
- Storm-water abatement
- Wastewater pond volume reduction

It is the large flows for cooling tower make-up that creates a situation resulting in even larger savings in space and greater savings in capital and installation costs as well as operating costs.

Conventional media filters typically require the following:

1. Larger quantities of interconnecting piping & valves
2. Air blowers for backwash
3. Large piping, valves and sumps for dirty backwash handling
4. More complex controls & sequencing
5. Media loading and unloading due to more frequent replacement
6. Much larger plot space (filters and sumps)
7. Often a clean backwash water holding tank and transfer pump(s)
8. Additional operator attention, especially during backwash cycles, media change-outs and inspections to insure internals (often hard or nearly impossible to see) are in good condition.

Comparing costs to conventional filtration:

A cooling tower with recirculation flow of 8,000 m3/h (35,200 gpm), a side-stream filter should be designed for 400 m3/h (1760 gpm).

A filter sized at 400 m3/h will have the characteristics described below.

Note others performed this study for a project in Egypt. Data based upon a pilot study exceeding 3 months performed in cooperation with Behira Water & Drainage Company and National Organization for Potable Water and Sanitary Drainage.

Note power consumption for a pressurized media filter is 10X that of a DiscFilter.

EGP = Egyptian Pound ($)

	Gravity Sand Filter	Pressure Media Filter	Hydrotech Discfilter
Filtration time per day (h/d)	23.5	23.5	24
Average number of man hours necessary for O&M (h/d)	2.5	6.5	0.5
Treated water reused for backwash (%)	3%	3%	1.75%
Total Headloss (mWC)	3	10	0.5
Necessary power supply (kW)	278	240	32.2

	Gravity Sand Filter	Pressure Media Filter	Hydrotech Discfilter
Design filtration rate ($m^3/h/m^2$)	8	12	7.9
Number of filters required	4	12	2
Continuous/discontinuous operation	discontinuous (stop at backwash)	discontinuous (stop at backwash)	Continuous
Surface required – footprint (m^2)	498	425	82
Surface required per m^3/h of water treated ($m^2/m^3/h$)	0.8	0.68	0.13

	Gravity Sand Filter	Pressure Media Filter	Hydrotech Discfilter
Cost of civil work (EGP)	2,980,000	510,000	160,000
Cost of electro-mechanical equipment (EGP)	6,385,000	7,000,000	6,100,000
TOTAL CAPEX (EGP)	**9,365,000**	**7,510,000**	**6,260,000**
Maintenance & Spares (EGP/yr)	146,000	130,000	82,900
Electricity (kWh/yr)	296,015	828,915	79,935
Electricity (EGP/yr)	74,000	207,230	19,980
TOTAL ANNUAL OPEX (EGP)	**220,000**	**337,230**	**102,880**
TOTAL CAPEX + 10 YEAR OPEX (EGP)	**11,565,000**	**10,882,300**	**7,288,800**

At times, other filter types require a pressurized water supply. Disc filters are gravity fed, using hydraulic profiles to their advantage. Typical pressure drop across the filter media is approximately 1" water column when it is clean and design DP is typically 10".

During normal operation the DP fluctuates from approximately a low of 1 - 2" to about 6" - 8".

- Today's power plants and other industrial plants are often designed to come up to service conditions quickly. Since disc filters supply their own clean backwash water while also providing continuous filtration they are normally always available on demand.
- The source and quality of feedwater will determine if a clarifier is required ahead of the disc filter, as it would for any filter.
- Industrial plants and Mining operations often have ponds for various reasons. Pond size reduction or elimination has been a targeted use of disc filters. They are relatively easy to drop in place on level land or a pad- close to ponds and only require a correct hydraulic profile and a low amount of electricity.
- Many filter installations are now past their predicted life and some abandoned or by-passed due to maintenance headaches. Owners can now replace them with disc filter designs that occupy much less space.

« Frame type » DiscFilters retrofitted into major US Power generator's old cooling water filtration system; only 3 of 8 basins were required

Other Industrial & Commercial Markets

Markets such as Food & Beverage, Automotive, Metals, Microelectronics, etc. all have applications, which can be very different or very similar depending upon the situation.

Since the basic principle of filtering a solid particle from a liquid is simplistic, the technology fits in many markets and in many applications. Considering the low cost involved for a disc filter and its ancillary system requirements, the ROI is very attractive.

Technological Advancements

Recent technological advancements have resulted in expanded industrial applications, including the following:

Softening - Most readers are familiar with what is typically referred to as cold lime softening. Softening also has the potential to reduce silica by co-precipitation with magnesium or by reaction with natural aluminum salts present in the feed water. Naturally occurring magnesium will result in some silica reduction; however supplemental magnesium oxide (MgO) or magnesium chloride (MgCl2) may be required. Disc filters can be used down-stream of cold lime softeners and just as we do for media filters, a small dose of acid is injected after the clarifier to prevent post precipitation of CaCO3 in the filter. However, if precipitation were to happen in a disc filter unit, it would be much easier to clean versus a sand media filter that tends to be more like concrete than a granular media.

Over an eighteen-month period and following the softening clarifier, the DiscFilter's performance was < 4 NTU turbidity approximately 92% of the time and < 3 NTU 70% of the time.

Bio-Fouling: Some organisms live in some stage of their lives on submerged surfaces. There is a great variety of species of zoological as well as botanic origin. Most predominant in salt-water are the phylae of molluscs, especially the bivalves (mussels). They tend to settle on surfaces with ambient food, as they are filter feeders, needing proper water current to pass by them. Therefore, pipes and fish farmer's nets, boats etc. are ideal locations.

The Company has installed filters in the South African Abalone industry; many of these installations are on inlet water in order to secure optimal water quality. Filters deal with both contamination by inorganic origin as well as being a barrier against introduction of mussels into pipe systems.

It has been determined that if mussels are the primary issue, 30 micron filters are sufficient in most cases to remove the larvae (veligers) and of course, the more typically used in cooling water systems- the10 micron leaves, will remove a higher percentage of organisms

Conclusions

As stated in the beginning, the concept of this paper is to acknowledge DiscFiltration is not new, and any time there is a need to filter a particle, this technology should be considered. It has been shown removal of specific constituents can be handled very effectively, including following cold lime softening.

While the DiscFilter's primary proven applications have been municipal wastewater and aquaculture; recent studies and installations are showing applications such as industrial process filtration, including post cold lime softening, side-stream filtration for cooling towers and in some cases even direct filtration of surface waters are practical. This is due to designs that are more advanced and tighter membrane availability as well as the industrial market learning more about the technology.

Technically, the concern that 10 micron leaves may not be tight enough for side-stream filtration has been mitigated in trials and applications, perhaps because the pore size gets smaller as operated. It is worth considering DiscFiltration as an option to MMF or other types of filters especially when comparing costs, water usage, and energy use, as well as performance.

Final comment: After careful consideration and studies, The City of Houston Texas selected our DiscFilters for the expansion of their 69th Street WWTP. Treatment of **440 MGD (305,500 gpm)** will make it the world's largest Discfilter installation.

Acknowledgement

The author wishes to thank 'The Company's' Water Specialists who must remain anonymous due to their corporate policy.

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Rapid Microbial Detection, Quantification, And Control

Justin Hutcherson & Mark Reed, Buckman

Mark Reed

Abstract

Microbial control continues to be a major topic in cooling water applications, with changes in physical conditions and inflow rapidly impacting the ability of a biocide regimen to adequately control the populations of microbes. ATP and petri-films have long been the standard for microbial detection, but these technologies either fail to provide specificity regarding the microbes being measured, or do not provide data in a duration that allows for adjustment of the control regimen.

By using a molecular approach, the detection system can be used for bacteria, fungi, and algae. The detection system can provide an early warning for processes and allow for a tailored and optimized biocide treatment regimen. The system has a high sensitivity, online capability and is portable. This new method can allow a user to optimize chemical usage and have greater control over its microbial treatment plans.

In identifying a rapid molecular measurement for bioburden and digitally coupling this near real-time assessment with delivery of proven biocidal technologies (such as monochloramine), there exists an exciting opportunity to know better the fluctuations in bioburden that can impact cooling water applications, be alerted digitally when these changes occur, and more readily address bioburden in a timely fashion.

Introduction

Microbiological contamination in cooling water applications can have a significant impact on asset performance. Slime-formers can colonize heat exchangers and reduce the overall cooling efficiency of the asset, while there are always concerns regarding the health implications associated with sub-optimal microbial control (Ludensky 2004, Paschke et al., 2019). While the incoming water into a cooling tower can be relatively free of microbes, the units themselves are open to contamination from air-borne particles that themselves may be colonized by microbes and can ultimately provide nutrients that can promote further microbial growth (McCoy 1980). Factoring in the range of contaminants and physical conditions present in a cooling tower (e.g. temperature, pH, retention time, etc.) means that each location is different and dynamic, leading to challenges associated with microbial control.

Monitoring and diagnosis of microbial bioburden is important as it allows the cooling tower operator a window into how the system is functioning, and thus the operator can potentially identify and proactively address the source and scope of incoming microbes using an appropriate microbial control regimen. There are many techniques available to measure bioburden, and a key challenge is finding a method that is A) accurate in providing a reproducible value of microbes present in a sample, B) fast enough to provide data upon which decisions can be made regarding appropriate system treatment and C) amenable to deployment at the sample location so as to make the data as relevant as possible to the application itself (and to prevent change in the microbial populations present in the sample).

Petrifilms or plate count methodologies are an excellent means to visualize the numbers of microbes present in a sample. These methods are typified by a solid medium system designed to provide the nutrients needed to maintain a microbial population. In the case of petrifilm technology, a cold-water gelling agent and suitable indicator dye allows for a low sample footprint and easier visual enumeration of colonies following incubation (Smith et al. 1985). Despite a clear visual representation of the microbes in the samples, solid media methods do have some drawbacks. Plate counts or petrifilms require time to adequately generate colonies large enough to visualize and count. Typical incubation time for aerobic species is around 48 hours, and this means that a potential excursion in bioburden cannot be readily addressed until after the issue has established itself. Furthermore, the selection of media for the plate or petrifilm will play a role in which microbes can grow and how quickly. In effect, there can be a selection bias in the sample that can lead to an under-estimation of the number or type of microbe that is present in a sample, particularly if the populations represented in a sample are unknown (Staley & Konopka 1985). Ultimately, this could represent an opportunity for an excursion to go unaddressed if the method in use is not the most suitable for the microbes causing the issues in the system.

Measurement of adenosine triphosphate (ATP) represents an alternative means to obtain an indication of bioburden in an aqueous sample. ATP is a metabolic marker that is present in all living cells, and there are several commercially available

kits that can allow a user to measure a sample in as little as 5-10 minutes (including sample preparation). This assists in addressing the challenge of speed-to-result, and ATP tests have become a commonplace tool in measuring bioburden in aqueous systems. In utilizing ATP, there are some key challenges that must be considered. Due to the presence of ATP in all living cells, there can be challenges with sample background. Some kits address this by providing separate measures of "free" versus "cell-based" ATP, and this can be useful in resolving background from microbial ATP in a system (Vang et al. 2014). However, the technique cannot be used to resolve the types of microbes that the ATP comes from (microbial vs. algal etc.), therefore restricting the specificity of the measurement and impacting the selection of a subsequent treatment regimen. The tests themselves can also be subject to the inhibitory effect of chemistries present in the sample (e.g. cleaning agents or disinfectants) (Velazquez and Feirtag 1996, Lappalainen et al. 1999), and while this can be mitigated, it ultimately impacts the throughput of samples using the method.

Quantitative polymerase chain reaction (qPCR) technology is a method that uses genetic information as a template for signal amplification (reviewed in Deepak et al. 2007). In combination with probes that are specific for certain genetic markers, a polymerase enzyme replicates a given sequence utilizing optimized cycles of denaturation, annealing and extension. Use of either Taqman or SYBR-based methodologies allows amplification of the marker of interest to be associated with an increase in fluorescence signal (these technologies are reviewed and compared more fully elsewhere) (Cao & Shockey 2012). This change in fluorescence over a number of cycles can be calibrated to a known quantity of the microbes of interest, and this can be used to provide an estimate of quantity in a greatly shortened time versus plate counts and petrifilms, shortening time-to-result from 48 hours to less than 1 hour. The method of qPCR is well established in medical diagnostics (Bastien et al. 2012, Ward et al. 2004), and over time, the complexity of sample preparation and the equipment needed to run a test has lessened. Indeed, with the more modern equipment available today, it is possible to complete sample preparation in a field environment and complete the qPCR protocol in as little as 30 minutes, depending on the nature of the protocol and number of microbes present. An added benefit of the technique is that it does not need a large volume sample to make a measurement, and this can assist in instances where a more "complex" sample needs to be analyzed (e.g. higher suspended solids).

In the study described herein, we demonstrate the speed, sensitivity and repeatability of quantitative PCR as a diagnostic method for cooling tower application by comparing it to traditional field measurement techniques such as petrifilms and ATP measurement. The data shows that qPCR shows correlation to known quantities of bacteria measured in a laboratory setting. Furthermore, given the portability and low sample processing requirements for qPCR, samples can be rapidly and reproducibly prepared on-site to allow for microbial detection, with the results reflecting the dynamic nature of cooling tower applications. Overall, qPCR represents an important tool for detection and quantification of microbes and could facilitate more proactive control when excursions occur.

Methods

ATP

Measurement of ATP in samples was achieved using a 3M Clean-Trace™ kit per the manufacturer's instructions. Briefly, 100 µl of neat water sample was treated with the kit's extractant solution for 2 minutes, with minimal agitation. A further 100 µl of reconstituted enzyme solution was added to the sample and the luminescence generated by the reaction was measured immediately via analysis with a handheld Clean-Trace NG unit (3M). All samples were run in duplicate to assess measurement variability. Signal stability of the method was further analyzed through repeat measurements of the prepared sample at various time points after the initial measurement.

Petrifilm

Samples containing microbes were serially diluted to obtain a readable number of colonies following incubation. Typically, this entailed a dilution range of 10^{-1} to 10^{-6} wherein the sample was serially diluted using sterile water. 1 ml of the diluted sample was transferred to 3M aerobic count petrifilms per the manufacturer's instructions, with the petrifilms being incubated at 37 °C for 48 hours prior to enumeration. Results provided represent the average of petrifilms containing 10-200 colonies at time of counting, to prevent any over- or under-estimation as a result of the plating technique.

Quantitative Polymerase Chain Reaction (qPCR)

Samples containing microbes were serially diluted in molecular grade water, and primers specific to the bacterial 16S sequence were used in conjunction with a proprietary protocol using a thermocycler. Briefly, primers targeting the 16S bacterial gene were used to amplify over 40 cycles using Perfecta™ SYBR™ Green FastMix™ (Quanta Biosciences). Data generated by the thermocycler was communicated to a PC via Bluetooth connection for analysis. The thermocycler reported the results as Cq values, cycle quantification values, which represent the cycle number at which the instrument detects a real signal from the samples reaction. Subsequent Cq values generated by the protocol were converted to CFU/mL using a pre-generated standard curve.

Laboratory generation of qPCR standard curve

A culture of Pseudomonas aeruginosa was prepared overnight using ATCC strain 15442. This culture was serially diluted 1 in 10 to provide a range of microbe concentrations between 5 $\log_{10}$ CFU/mL and 9 $\log_{10}$ CFU/mL that could be assessed by petrifilm and qPCR analysis. The results were generated as described above with data being plotted as a correlation between the two methods.

Field Comparison

To provide an example of field application of qPCR technology, samples were collected from 5 locations associated with a power station cooling tower in the Southern United States (Figure 1). The cooling tower was a 1.1-million-gallon unit with a 30.5 hour retention time. One sample was taken from the influent water coming into the facility ("Influent"), three samples were measured from separate locations along the cooling tower basin ("Basin 1, 2 & 3") and one sample was taken from the blow-down leaving the tower ("Blow-down"). The site itself was subject to periodic dosing of monochloramine three times a day to maintain control of bacteria, and the site was considered "well controlled" during the time of the visit. ATP, petrifilms and qPCR were used to assess the system on-site at two different time points: 1) 4 hours after treatment ("Timepoint 1"), and 2) 6 hours after treatment ("Timepoint 2"). On a separate day, 4 influent water samples were taken to reflect water prior to biocide application, 15-minutes into application, 30 minutes into application and immediately post application to observe if there were fluctuations in incoming bioburden. All analyses were undertaken at the test location to compare the different methods in real-world application and to minimize any impact of population change resulting from sample transport.

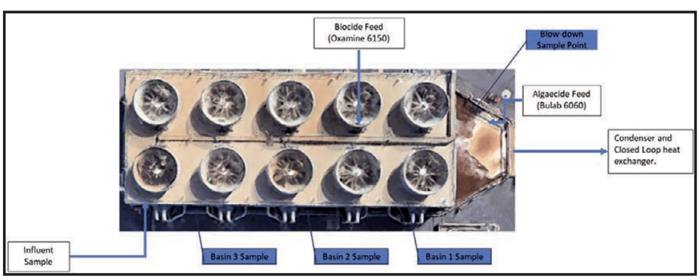

Figure 1. Overview of cooling tower and sample locations. Cooling tower overview: 1.1 million gallon capacity, 3.5 cycles, 1500 gallon per minute (GPM) evaporation, 600 GPM blow-down, 2100 GPM make-up, 30.5 hour retention time, pH 7.7.

Results

Lab correlation between petrifilm and qPCR using a known bacterial strain

In comparing known quantities of Pseudomonas aeruginosa bacteria measured by petrifilm, to Cq values generated by qPCR, it was possible to generate a standard curve for subsequent analysis of bacterial bioburden using 16S primers. Figure 2 shows the comparison of known quantities of bacteria to the calculated log10 CFU/mL equivalents generated by qPCR. The data shows that excellent correlation was achieved between the methods utilizing a single culture organism under laboratory conditions, with the line of best fit of the data exceeding an R2 value of 0.99.

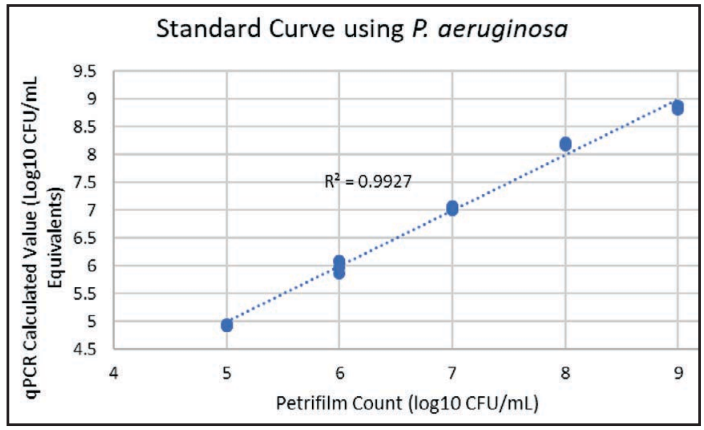

Figure 2. Standard curve for qPCR generated using Pseudomonas aeruginosa.

Field comparison of ATP measurement, petrifilm measurement and qPCR measurement

ATP measurements were taken across the five sample locations and compared across the two time-points (Figure 3). The data shows that Timepoint 1 samples had the lowest ATP measurements in general. Interestingly, the influent water was typically the lowest value measured at each time point, although this difference was not always significant due to the variability of the test.

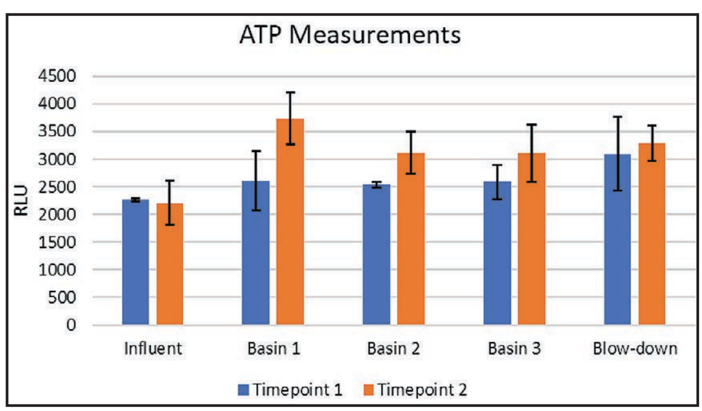

Figure 3. ATP comparison of five sample points at two time-points: Timepoint 1 (4 hours after biocide treatment), Timepoint 2 (6 hours after biocide treatment). Data shows the average and standard deviation of technical duplicate samples using a commercially available ATP kit.

In generating the ATP data, we noticed differences between duplicate samples taken at the same time point, with standard deviation representing anywhere from 2% - 20.6% of the mean reading measured. In order to ascertain what might be driving these differences we looked at assay signal stability during testing. We took one sample from the blow-down sample point and following addition of the reconstituted enzyme mixture to the sample (per the manufacturers instructions), we measured the sample over 5 different time points 15-180 seconds. Figure 4 shows the results of this test, with the sample signal degrading almost linearly during the time course. We found this signal stability to be consistent across all samples with respect to rate (data not shown). This data is interesting because it underscores the need for consistency during testing and understanding the impact of the sample on the test method itself.

Analysis of the same samples using petrifilms was also undertaken. This data (Figure 5) shows a similar trend to ATP measurement in that the influent samples demonstrated a lower level of bioburden versus the samples taken from the cooling tower itself. Samples taken throughout the system were measured between 4.82-5.06 log10 CFU/mL, with bacterial counts slightly elevated in the sample taken further after biocide treatment.

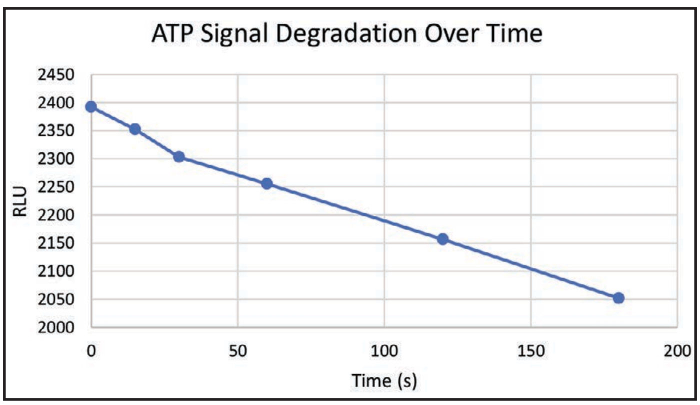

Figure 4. Example time-course replicate testing of one influent water sample using ATP test kit.

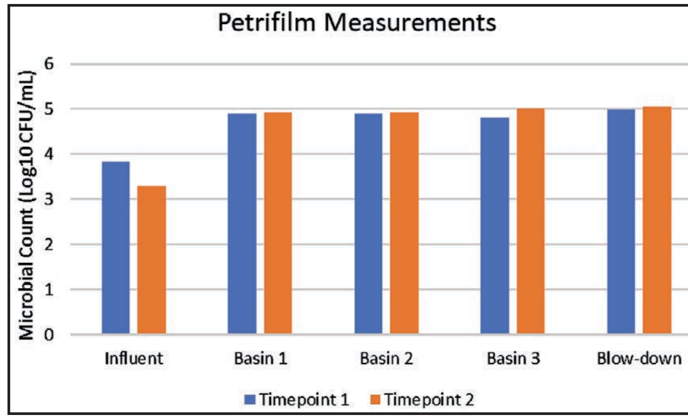

Figure 5. Petrifilm comparison of five sample points at two time-points: Timepoint 1 (4 hours after biocide treatment), Timepoint 2 (6 hours after biocide treatment).

Analysis of the same samples by qPCR (Figure 6) showed agreement with ATP and petrifilms in that the influent samples had the lowest measured bioburden and that measurements within the cooling tower itself remained steady throughout. Relative to petrifilms, the level of microbes detected was 3.04 to 4.41 log10 CFU/mL higher using qPCR. Furthermore, Timepoint 2 data points were typically observed to be lower than Timepoint 1 using qPCR which was an opposite trend.

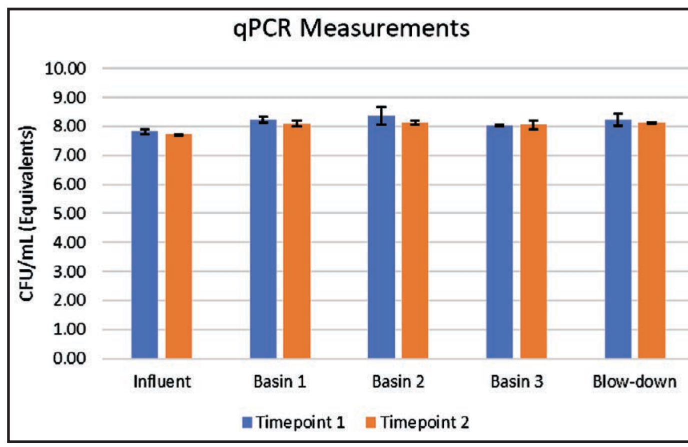

Figure 6. qPCR comparison of five sample points at two time-points: Timepoint 1 (4 hours after biocide treatment), Timepoint 2 (6 hours after biocide treatment). Data was the mean of two replicates with standard deviation shown.

In looking at the correlation between the methods used on the samples using Timepoint 1 and 2 data, the correlation coefficient was highest between petrifilms and qPCR (Table 1, Figure 7), wherein a correlation coefficient of >0.7 is considered a strong correlation. Petrifilms and ATP had the second highest correlation coefficient at 0.70, and qPCR and ATP had the lowest at 0.41. This supports the observation that qPCR demonstrated good agreement with petrifilms.

Methods Compared	Correlation Coefficient (2 d.p.)
qPCR vs Petrifilm	0.85
qPCR vs ATP	0.41
Petrifilm vs ATP	0.70

Table 1. Comparison of correlation coefficients between the three measurement methods.

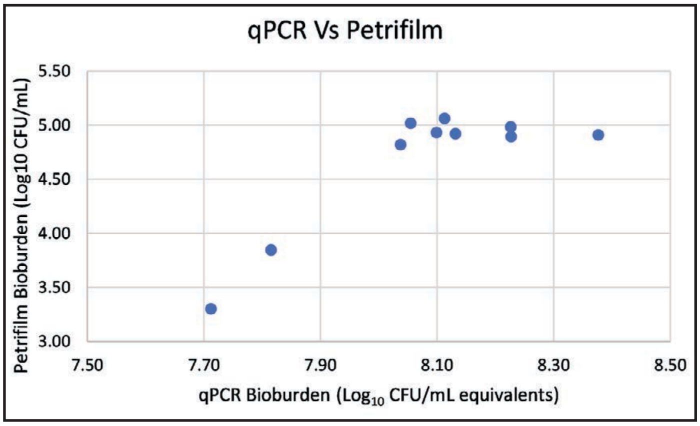

Figure 7. Correlation plot showing petrifilm and qPCR data points. All data provided in log10 CFU/mL (or equivalents).

In looking to understand if qPCR could be used to track dynamic changes in bioburden, samples of influent water were taken on a separate day at 4 different timepoints to capture water bacterial bioburden prior to biocide application, 15 minutes into application, 30 minutes into application and immediately post application. Figure 8 shows that the data collected demonstrates significant fluctuation of incoming bioburden during the hour observed, with bioburden being measured from 5 log10 CFU/mL to 7.34 log10 CFU/mL. Overall this reflects more than a 100-fold increase in bacteria entering the system within a short space of time. Furthermore, the data was interesting because it shows how levels of bacteria were different on different days at the same location, with Timepoint 1 and 2 showing generally higher bioburden in the influent water. This kind of analysis could be important in understanding what constitutes the "normal" level of bioburden entering a facility so that biocide dosing regimens can be altered appropriately. Further work would need to be completed to understand the impact of the biocide treatment regimen on incoming bioburden.

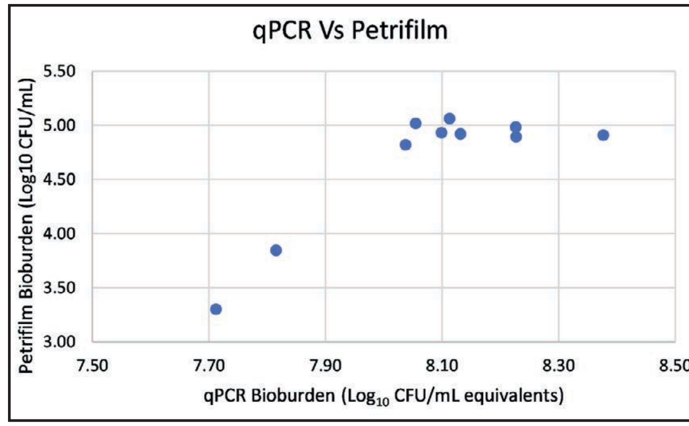

Figure 8. Time course showing qPCR measurement of bioburden across 4 samples taken within an hour. All timepoints are the mean of duplicate samples.

Discussion

Analysis of cooling tower water samples for bioburden is important to ensure that fluctuations in microbial loading are closely monitored and that the application of a biocide treatment regimen is suitable for mitigating build-up of microorganisms that can negatively impact cooling tower efficiency and lead to damage of the asset. In this study, on-site measurement of bioburden was undertaken using petrifilms, ATP and qPCR to understand if there was an optimum means to obtain accurate enumeration of bacteria in a shorter period ("speed-to-result"). The data showed that qPCR was a highly suitable field-based method for rapid bacterial enumeration, showing better correlation to petrifilms than ATP, and with equal to, or better, sample throughput and variability. It was possible to obtain qPCR results in around an hour for up to 48 samples, a significant improvement over 48-hour incubation for petrifilms, plus additional time needed for counts and data recording. Although the ATP method used was able to produce individual data points quickly, it was observed that it would be difficult to readily process multiple samples, particularly if there were concerns with signal stability. In the case of this study, we observed degradation of the ATP signal, and we assume that this is a result of either direct impact on the enzyme-substrate complex used in the ATP kit, or as a result of quenching of the fluorescent signal itself (Velazquez and Feirtag 1996, Lappalainen et al. 1999). It would be important to assess signal stability at any location where ATP testing was to be used or utilize a sample preparation method (e.g. filtration) to allow removal of chemistries that would impact the assay.

The qPCR data showed higher absolute values for bacterial bioburden and this was supportive of previous work showing how plate-counting methods can underestimate the population of microbes due to culture preferences (Staley & Konopka 1985). In looking to adopt qPCR as a regular monitoring technology, it would be important to ensure that a new baseline is measured for any given location and that any biocide treatment regimen's performance was measured relative to this new baseline. It was observed during this study, that the correlation between qPCR and petrifilms in the field was lower than what was observed in the lab, and this is hypothesized to be due to the multi-species nature of the field sample being analyzed. Further study would be needed to understand the impact of multiple species on the relative accuracy of qPCR versus other measurement techniques. While it was not demonstrated as a component of this study, the targeted sensitivity of qPCR allows for the user to measure specific subsets of microbes, be that specific bacteria or an assessment of algal or fungal contaminants. This would further increase the benefit of qPCR as a field-based measurement technique by being able to target keystone organisms or organisms of significant economic or health-related importance.

Due to the connectivity of the qPCR method, it is possible to have the data generated by the method made available to make biocide dosing decisions leveraging the improved speed-to-result, and this is important in considering the dynamic nature of cooling towers. Fluctuations in influent water bioburden, as demonstrated herein, or via transfer of airborne particles into open cooling towers, can impact the ability of a biocide treatment regimen to fully mitigate build-up of microbes. Therefore, the ability to get closer to real-time information from a method such as qPCR can be important in maintaining control of microbial contamination.

Overall, the data shown within this study shows that qPCR is a strong tool in the toolkit for microbial measurement and mitigation. The technology provides rapid bacteria enumeration at the sample site and considers the full population of microbes present in a sample. It provides data in a time-scale that allows operational decisions to be made in near real-time and can be used to help to fully characterize a cooling tower as a dynamic system.

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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 80 cooling tower manufacturers are currently active in the program. In addition, 19 of the manufacturers also market products as private brands through other companies.

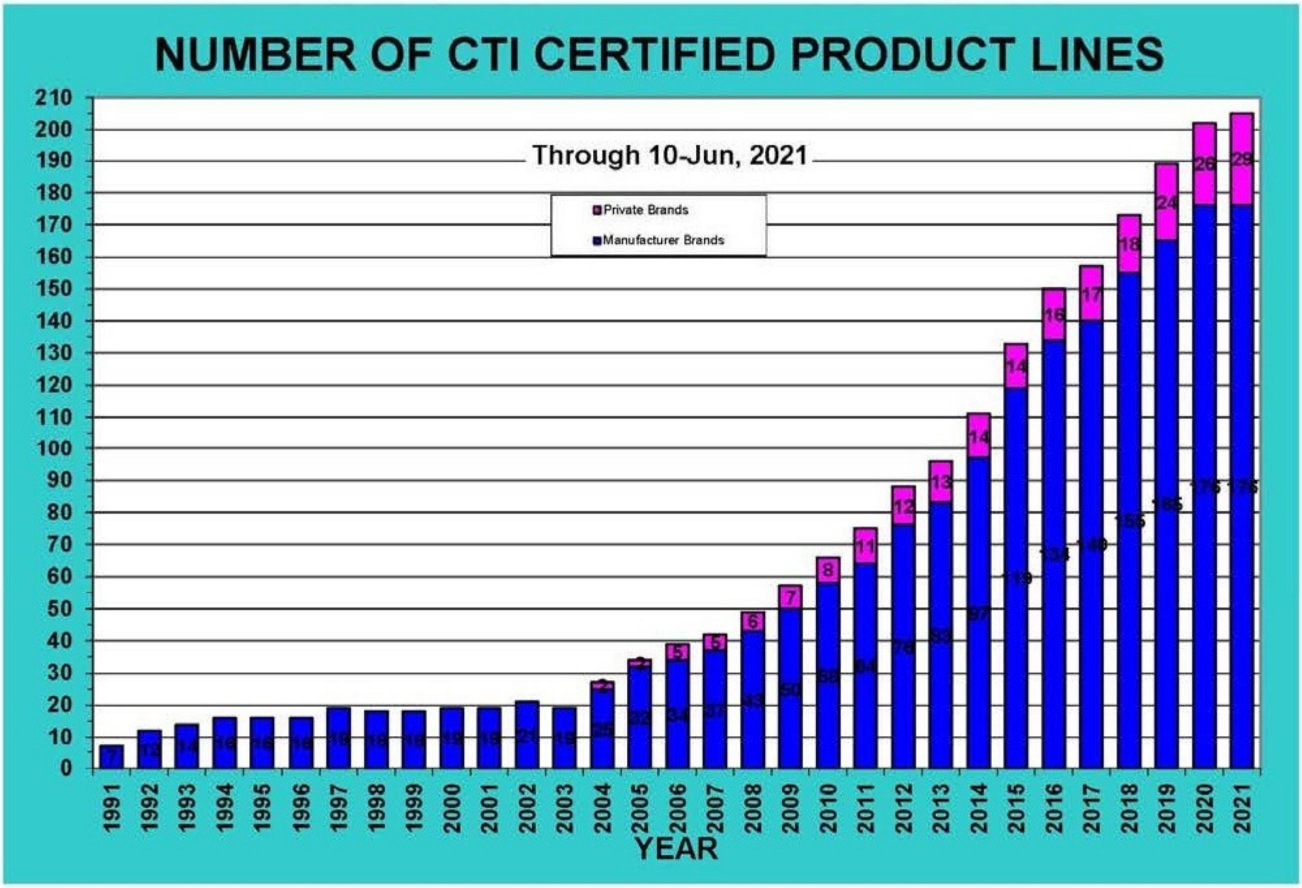
While in competition with each other, these manufacturers benefit from knowing that they each achieve their published performance capability and distinguish themselves by providing the Owner/Operator's required thermal performance. The participating manufacturers currently have 176 certified product lines plus 29 product lines marketed as private brands which result in approximately 51,200 CTI Certified cooling tower models to select from.

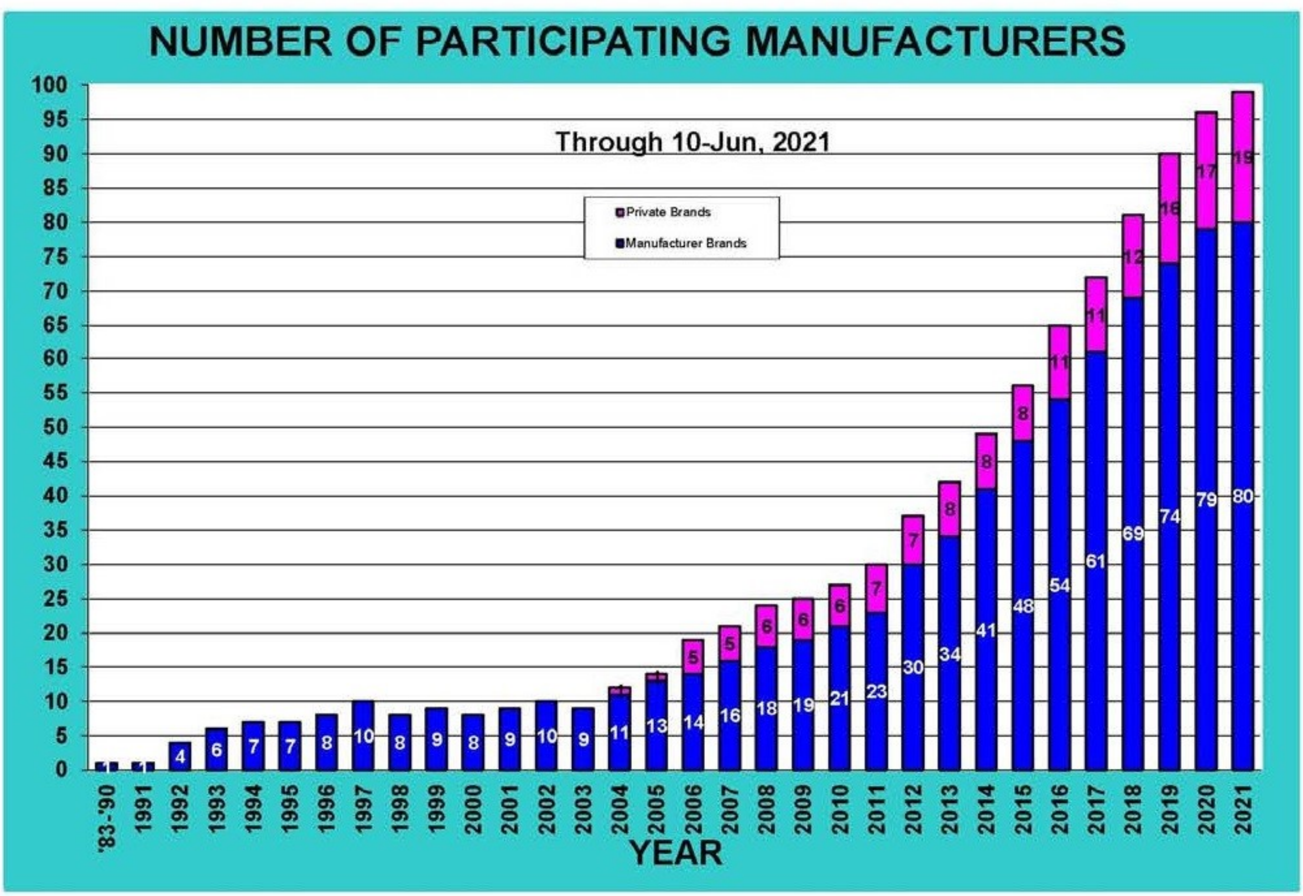
For a complete listing of certified product lines, and listings of all CTI Certified models, please see:

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 for more details.

Thermal Certification Program Participation





Current Program Participants

(as of June 10, 2021)

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.

A

Advance Cooling Towers, Pvt.,Ltd.

Advance 2020 Series A *Validation No. C31A-07R03*
NTM Line *Validation No. C31B-19R00*

Aggreko Cooling Tower Services

AG Line *Validation No. C34A-08R02*

Amcot Cooling Tower Corp.

AST *Validation No. C106A-19R00*
Series R-LC *Validation No. C11E-11R03*

American Cooling Tower, Inc.

ACF Series *Validation No. C38D-18R00*
ACX Series *Validation No. C38C-18R00*

AONE E&C Corporation, Ltd.

ACT-C Line *Validation No. C28B-09R01*
ACT Line *Validation No. C28A-05R07*

Approach Engineering Co., Ltd

NSA Line *Validation No. C76B-20R00*

Axima (China) Energy Technology Co., Ltd.

EWX Line *Validation No. C72A-15R03*

B

Baltimore Aircoil Company, Inc.

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 & 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 & Smart *Validation No. C11F-92R19*

Bell Cooling Tower Pvt, Ltd

BCTI Line *Validation No. C43A-12R02*

Brapu (China) Cooling Equipment Co., Ltd

BPC-DE/CH Series *Validation No. C110A-20R00*
BPO-DE/CH Series *Validation No. C110B-20R00*

C

Cenk Endüstri Tesisleri Imalat Ve Taahüt A.Ş.

LEON Line *Validation No. C89A-17R02*
LISA Line *Validation No. C89B-17R01*
ISTANBUL Line *Validation No. C89C-19R00*
ODIN Line *Validation No. C89D-20R01*

Chengdu Xingli Refrigeration Equipment Co., Ltd

HBL-HS Series *Validation No. C115A-19R00*

Chongqing Yinengfu Technology Co., Ltd

YNF Series *Validation No. C103A-18R00*

Composite Cooling Solutions Inc.

PhoenixPL *Validation No. C79B-20R00*

Cool Water Technologies

RTAi Line *Validation No. C52A-13R03*
RTi Line *Validation No. C52A-13R02*

D

Dalian Spindle Environmental Facilities Co., Ltd

DC Series *Validation No. C112A-19R00*
DF Series *Validation No. C112B-19R01*
DX Series *Validation No. C112C-19R01*

Decsa

TMA-EU Series *Validation No. C42C-17R00*

Delta Cooling Tower, Inc.

TM Series *Validation No. 02-24-01*

Delta (India) Cooling Tower Pvt, Ltd

DFC-60UX Line *Validation No. C85A-18R00*

Dezhou Beitai Refrigeration Equipment Co. Ltd.

$DBHZ_2$ *Validation No. C104A-19R00*

Dezhou Zhongwei Liangji Cooling Equipment Co., Ltd.

JH Line *Validation No. C66A-15R03*
JHB Line *Validation No. C66B-20R00*

Dongguan Kuken Cooling Tower Co.,Ltd.

GXC Series *Validation No. C81B-16R01*
GXE Series *Validation No. C81A-16R01*

Dongguan Ryoden Cooling Equipment Co., Ltd
RT-L&U Series *Validation No. C71A-15R03*
RTM-L Series *Validation No. C71B-15R00*

Dunham-Bush (China) Co., Ltd
BHC Series *Validation No. C107A-19R00*

E

Elendoo Technology (Beijing) Co., Ltd.
EL Line *Validation No. C50C-15R04*
ELOP Line *Validation No. C50B-14R04*

Ebara Refrigeration Equipment & Systems Co.
CDW Line *Validation No. C53A-13R04*
CNW Line *Validation No. C53C-18R00*
CXW Line *Validation No. C53B-14R04*

Evapco, Inc.
AT Series *Validation No. C13A-99R22*
ATWB Series *Validation No. C13F-09R10*
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-16R01*
MX Series *Validation No. C67B-16R00*

Guangdong EnZen Energy Saving Technology Co., Ltd
YZC Series *Validation No.C109A-19R00*

Guangdong Feiyang Industry Co., Ltd
RT-L&U Series *Validation No.C71A-15R03*

Guangdong Green Cooling Equipment Co., Ltd
GLR-E Series *Validation No.C97B-18R02*

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-15R03*
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

Hanf Cooling Equipment Co., Ltd
GTC Series *Validation No. C101B-19R01*
GTN Series *Validation No. C101A-18R01*
GTS Series *Validation No. C101C-20R00*

Hon Ming (Guang Dong) Air Conditioning Equipment Company, Ltd.
HM Series *Validation No. C66B-20R00*
MK Series *Validation No. C66A-15R03*

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-05R07*

I

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 *Validation No. C46E-18R01*
VAP Line *Validation No. C46C-16R02*

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.
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*

KIMCO (Kyung In Machinery Company, Ltd.)
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*

Kongsung Machinery Co., Ltd.
SK-FCR Line *Validation No. C120A-21R00*

Korytko Systems, Ltd.
KDI Line *Validation No. C70A-16R02*

KSN Co., Ltd
KSNC Series *Validation No. C44A-12R03*
KSNX Series *Validation No. C44B-12R01*
KSNC-C Series *Validation No. C44C-14R01*
KSNX-C Series *Validation No. C44D-14R01*

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-08R10*
MH Series *Validation No. C14G-04R13*
NC Series *Validation No. C14A-92R21*
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. C44B-12R01*
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*
FXS Series *Validation No. C27G-20R00*

Q

Qinyang Zhonghe Zhi Da Technology Co., Ltd.
HLO Series *Validation No. C99B-20R00*
HL-SC Series *Validation No. C99A-18R00*

R

Reymsa Cooling Towers, Inc. (Fabrica Mexicana de Torres, SA de CV)
HFC Line *Validation No. C22F-10R06*
RT & RTM Series *Validation No. C22G-13R08*

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

Shandong 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*

ST Engineering & Cooling Co., LTD
SK-FCR Line *Validation No. C120A-21R00*

Sung Ji Air-Conditioning Technology Co., Ltd.
SJCO Series *Validation No. C74B-16R01*
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 and VX-S Series *Validation No.C41B-12R07*
TKS Series *Validation No.C41D-18R00*

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 Sanjiu Cooling Equipment Co., Ltd.
GOM Line *Validation C45E-16R03*

Wuxi Zhishui Environmental Co., Ltd.
ZSBN Series *Validation C113A-20R00*

Y

YM Tech Co., Ltd.
Csta Line *Validation No. C108D-20R00*
Xsta Line *Validation No. C108B-19R01*
YFO Line *Validation No. C108A-19R00*
YFOL Line *Validation No. C108C-20R00*

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-05R06*

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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Certification Validation Number

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