CTI Journal

The Official Publication of the Cooling Technology Institute

www.cti.org

Winter 2017
Volume 38, No. 1

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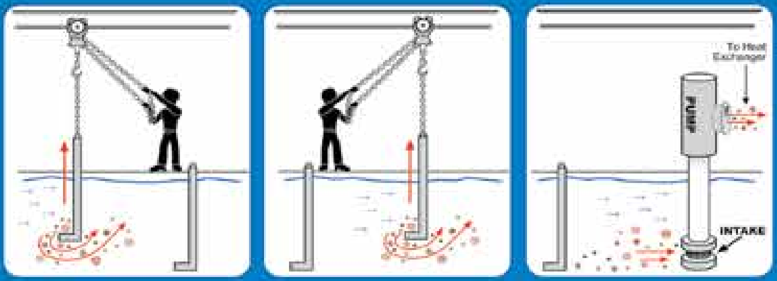

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The CTI Journal

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

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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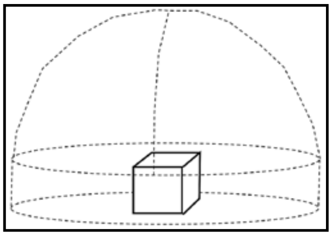

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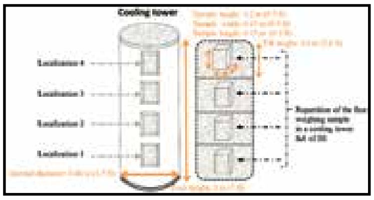

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Boundary	Boundary Type	Species	Boundary Condition
Inlet (blower outlet)	Inlet	B	Specified velocity (mass flow rate)
Outlet-2(cooling tower inlet)	Outlet	Not applicable	Static pressure, with target mass flow rate
Outer rectangular face	Inlet	A	Specified wind speed
Outer rectangular surfaces	Opening	Not applicable	Open to atmosphere
Bottom surface	Wall	Not applicable	No-slip

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CTI Journal
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Vol. 38 No. 1 **Winter 2017**

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For Immediate Release
Contact: Chairman, CTI Multi-Agency Testing Committee
Houston, Texas
2-December-2016

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 August 1, 2017, at the CTI address listed.

Future Meeting Dates

Committee Workshop	Annual Conference
July 16-19, 2017 Hilton Orlando – Lake Buena Vista Florida	February 5-9, 2017 Sheraton New Orleans New Orleans, LA
July 15-18, 2018 La Cantera San Antonio, TX	February 4-8, 2018 Hilton Houston North Houston, TX


Real experts, real results

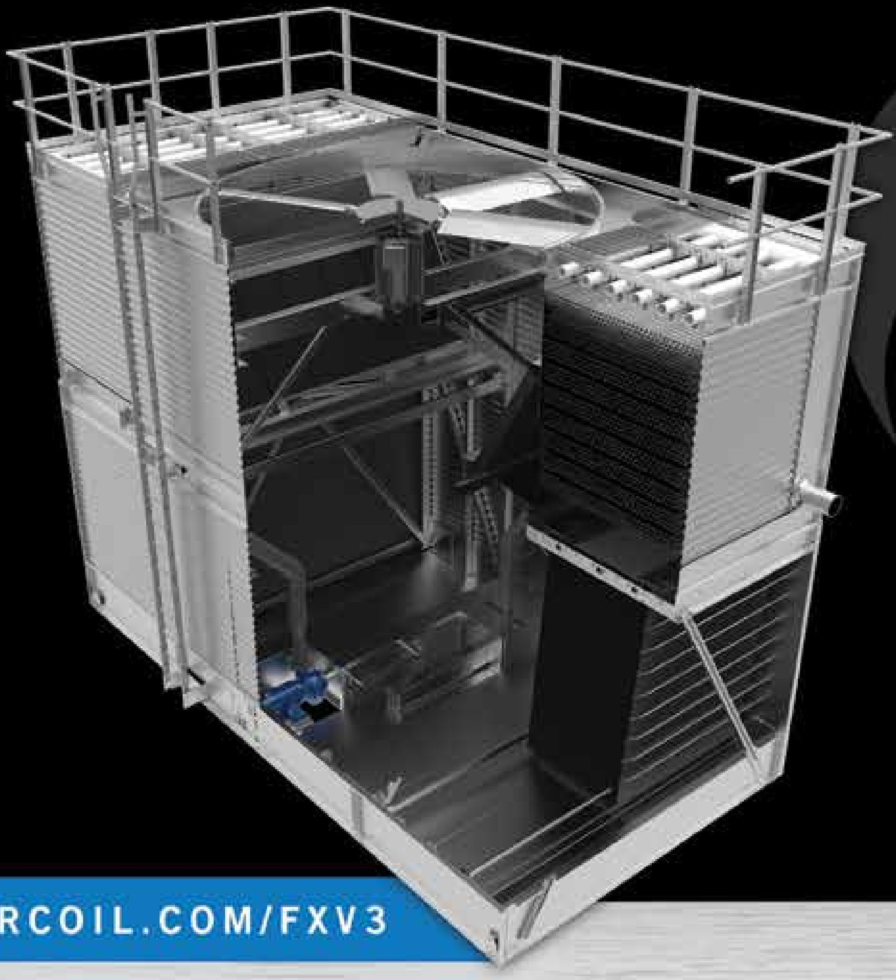
View From The Tower

Standing on the fan deck of a cooling tower that is in excess of 50 ft. above grade gives you a great "view from the tower!" You can see for miles on a clear day. How is your vision and can you see for miles on any given day? Water is one of our most important resources on our planet and seeing into the future on one of our most precious resources should remain in the forefront of everyone involved in cooling technologies. Hot topics such as clean pure water, water treatment, water conservation, education on water use and yes even Legionella in water all take on a new meaning recently, especially when considering the environment and our commitment to our planet and all its inhabitants.

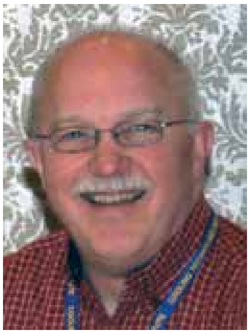
Have you looked at the recently improved CTI website and our mission and our objectives as an organization? CTI is the global leader when it comes to cooling technologies and this is through education and resources due to you, your direct involvement and commitment to CTI. Each and every one of you! We all play an important role in ensuring the success of CTI but also in the success of our programs within CTI which allow us to manage and help control the use of water on our planet. The human race will continue to expand its technological abilities, but with organizations such as CTI, this will be done in an environmentally responsible and friendly manner, especially when it comes to water.

So the next time you are atop a cooling tower, look out and see just how far you can see, look to the future, maybe even plant a seed in those around you that we are indeed responsible for ensuring the success of our planet. Each one of us has the ability to shape its future and you and your involvement within CTI, through the help of a vast plethora of qualified individuals, is a great mechanism to propel both CTI as well as our planet well into a successful future! So ask not what CTI can do for you, rather ask what you can do for CTI and by all means, join in, get involved, learn, educate others, participate and thrive!

Sincerely and respectfully,
Bill W. Howard, P.E.
CTI President



Editor's Corner



Dear Journal Reader,

A new year for CTI started after the CTI Annual Meeting in February, 2016. Bill Howard of CTD,Inc., has started the second year of his two-year term as President of CTI. Outside influences and emerging activities continue to have an impact on CTI. Here's an update on what is happening:

Outside Influences:

DOE Fan Rule: My last Editor's Corner made CTI Members aware that a Department of Energy rulemaking is in progress with regard to fans, which could include any of the products of interest to CTI that move air with a fan or blower. CTI has asked for exemption of heat rejection equipment from the rule, and have been successful in gaining the exemption in the term sheet agreed upon by the working group. The DOE is writing the final rule, and have just released an update analysis package which shifts some of the assumptions to be used in the rulemaking. A CTI comment has been prepared and issued, and should be on the DOE docket. Understandably, the DOE may be pushing to move some of their activities before the upcoming administration change, so things could happen quickly. CTI members who produce or embed fans in equipment for any purpose should be aware that they could be affected by this rulemaking, which will set minimum fan efficiencies by fan and equipment types. For more information, contact Larry Burdick, Frank Morrison, or me.

Legionnaires Disease: Outbreaks in New York City and Flint, MI, have brought media attention to the issue, and in the case of NYC/NYS have focused on cooling towers. Since then, the CDC has become vocal about the need for a whole building approach to Legionnaires Disease risk, and has published a nicely done Toolkit to supplement ASHRAE STD-188 (2015) Legionella: Risk Management for Building Water Systems. CTI's GDL-159 is expected to be a useful tool with this standard when completed, hopefully, this year. The CDC toolkit and the ASHRAE standard are available on their websites. An Alliance to Prevent Legionnaires disease has been formed, and has a website, www.preventlegionnaires.org, that should be of interest to our industry.

China Cooling Tower Institute: This organization has been growing in China, and has reached out to CTI to explore ways the two organizations can work together. Several meetings have occurred between the organizations, and we continue to work toward future cooperation on several activities.

Emerging Activities:

CTI Research Update: A research grant was awarded to CleanAir to complete Pitot tip investigations to find a replacement for the (no longer commercially available) Simplex tip, which has been the CTI water flow measurement standard. CleanAir continues to work on this, the first research project developed under the relatively new CTI Research and Development Committee. A delay in access at the laboratory at which the measurements are to be taken has delayed the project. Projects are proposed via the standing technical committees, and proceed through a process administered by the R&D committee. Funding is raised and administered via the CTI Finance Committee. Other projects are under consideration, and new ones may be proposed within the standing technical committees at any time.

Licensed Sound Testing: Licensed sound testing is in its second year of operation in 2017. We look forward to growth in this testing service by CTI.

There is much happening with our very active CTI volunteer technical organization; we again encourage you to get involved in the CTI technical committees.

Respectfully,

Paul Lindahl, CTI Journal Editor

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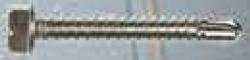

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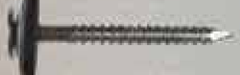

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Comparison Of Fouling Kinetics On Four Different Fills Operated In Pilot Cooling Towers

Aurelie Mabrouk, Mohamed Azarou and Cyril Marconnet; Edf

Aurelie Mabrouk

Abstract

EDF operates 30 condenser open cooling circuits in its French nuclear power plants (NPP). In order to extend their lifetime, the company has to carry out major renovations of the fills located in the cooling towers, which need to be replaced after around 30 years.

To determine the most adapted fill a serie of four tests is conducted: mechanical strength, fire resistance, thermal performance, and evaluation of fouling risk.

An experimental study was realized in order to study and differentiate the deposition risk of four different fills on an industrial pilot unit. The pilot unit is constituted of four reduced-scale open cooling circuits (around 15 thermal kW or 14 BTU/s) able to mimic the thermal and chemical behavior of an industrial cooling circuit such as those found in nuclear power plants.

To allow this comparison for a duration limited to a few months, the four pilots were operated in scaling conditions, fed by Seine river water (calcium concentration around 90 mg/L and hydrogen carbonates concentration around 230 mg/L), with a Concentration Factor (CF, also called Cycles Of Concentration) equal to 2, without injection of acid, and while maintaining the temperature at the output of the condenser at 40°C (104°F). Among the tested fills, two were trickle fills and two were film fills. All the fills were distributed on four levels of 0.5 meter (1.6 foot) high each. The measurement of weight gain was realized once a week for three months.

Deposition has been estimated by mass measurements on fill samples located at different level of the cooling tower. Contrary to expectations, the two trickle fills were heavily weighted. One of the film fill showed a lower weight and the other gave results comparable to trickle fills. These results were homogeneous whatever the level within the tower.

This accelerated test, carried out on reduced-scale open cooling circuit pilots and in scaling conditions, was able to discriminate the deposition potential of four different fills, which can help the tower designer to choose the best packing. These results would need to be compared to data collected directly from fills present in the industrial towers, so as to consolidate the comparison of the deposition potentials of the different fills. On the whole, these results show that the pilots represent the thermal and chemical behavior of an industrial cooling circuit such as those found in nuclear power plants, even if some modifications could be done on this unit to improve its representativeness for the next experimentation.

KEYWORDS: scaling, fouling, fill, pilot unit, condenser open cooling circuit.

Introduction

Some of EDF pressurised water reactors (PWR) cooling circuits are subject to hard and charged feed-water, leaving condensers and cooling towers susceptible to water-formed deposition constituted by accumulation of insoluble material derived from water or formed by the reaction of water upon surfaces: including scale (deposition of calcite), sludge, foulants (deposition of suspended substances like clay, alumina, or silica), sediments, corrosion products or biological deposits (water-formed deposits of organisms or their waste products, by biofouling) [3]. This phenomenon has consequences linked to important economic costs because of the decrease of the efficiency of the heat transfer, maintenance and replacement of condenser and cooling tower fill, and in the end a potential for plant shutdown.

To limit these drawbacks, EDF, which aims at extending the operating time of these nuclear power plants, has to renovate cooling towers with the most adapted fills. The choice of a fill is determined by the results of preliminary tests [1]. The following tests are conducted on fill: mechanical strength, fire resistance, thermal performance, and evaluation of water-formed deposition risk.

EDF uses two methods to estimate the water-formed deposition risk for a fill: the first one is the use of a criterion based on the linear flow rate; the second one is based on a weighing campaign directly on the cooling tower thanks to weighing fills samples [1]. These results on weight gain have to be taken into account with caution because they are realized in situ on an operation site, on specific locations within the cooling tower. Consequently, tests are submitted to different uncontrollable parameters, which change every day, like the operating conditions. In addition, these tests last several years, so as to determine the behaviour of the fills on several operation cycles. This is a problem for the new fills which have to be tested for several years and for which on site results may not be available for upcoming renovations. In this context, a new method had to be developed to evaluate water-formed deposition risk more quickly, an appropriate time scale being a few months.

More generally, to tackle these problems, EDF, has decided to work with three different ways. We work on the materials which are in the cooling tower (like fill), on the treatment during the operation time and on the cleaning during shutdown. In order to work on treatment, we develop a modelling computer program called CooliSS©, to help optimize chemical treatment [2].

This paper presents an experimental study which was carried out to study the water-formed deposition risk of four different fills on an industrial pilot unit. The pilot unit is first presented. Then the principle and the results of the experimental study are provided. To finish, conclusion and perspectives are given.

Pilot Plant Presentation

- General description of the pilot named SPECTRE (located in Nogent-sur-Seine, on the Seine river, France):

SPECTRE pilot is a 1 : 100,000 scale reproduction of an open cooling circuit equipped with a cooling tower. It is composed of four loops operated in parallel. Each loop consists of three skids :

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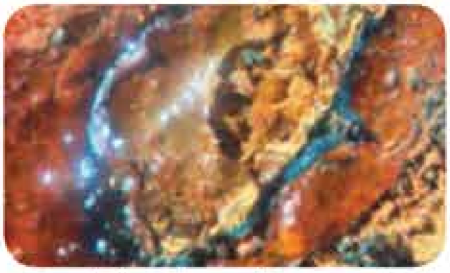
Microbially-influenced Corrosion (MIC)


Scale embedded in biofilm on tower pack

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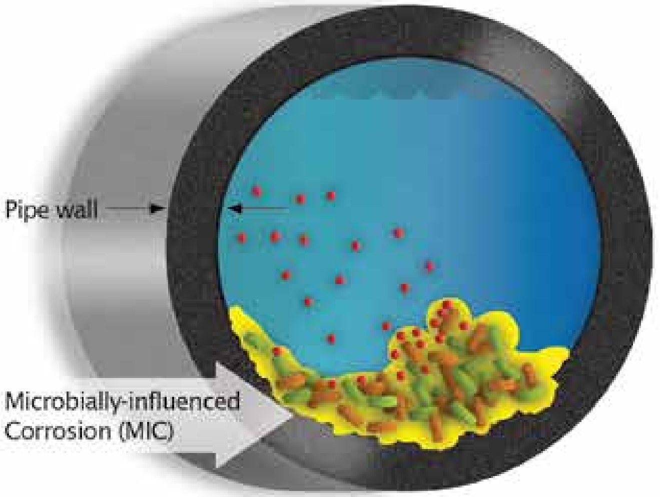
How a Biofilm Control Program Works

Without **BCP™ chemistry (DTEA II™)**

- Oxidizing and non-oxidizing biocides have limited penetration into biofilm.
- The metal pipe wall shows evidence of MIC beneath biofouling deposits.



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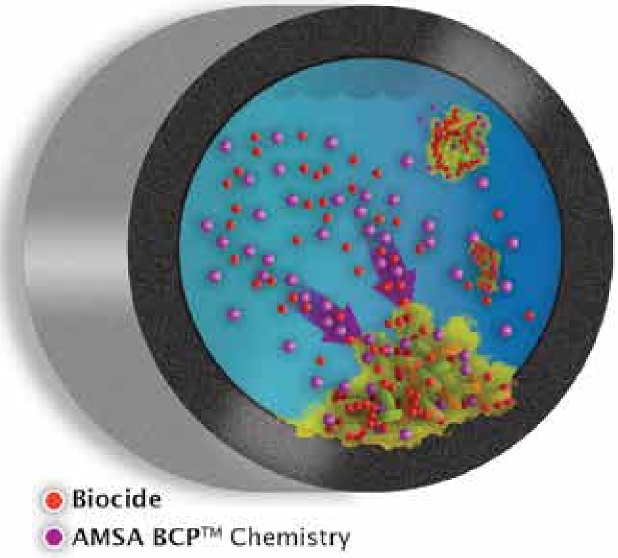
With **BCP™ chemistry (DTEA II™)**

The penetration/dispersion/cleaning properties result in:

- Deeper penetration of biocides into biofilm allowing better bacteria kill
- Destabilized biofouling deposits removed from surfaces
- Cleaner surfaces with less MIC & better heat transfer



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- Skid A (cooling tower): cooling tower + treatment of cooling tower vents (bleach) + conditioning of the cooling air (heating + humidification).
- Skid B (boiler): steam generator (boiler) / condenser exchanger + hot basin tank + electric cabinet with controllers.
- Skid C (tank): feedwater + cold basin tank + circulation pump + blow-down.

The four loops are connected to a disinfection system whose aim is to treat waste water with bleach.

Figure 1 shows pictures of the SPECTRE pilot located in Nogent-sur-Seine on a nuclear power plant.

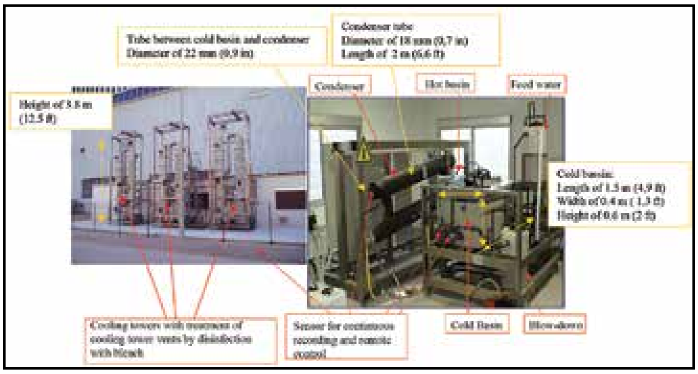


Figure 1: SPECTRE pilot of Nogent-sur-Seine in France

Each loop includes:

- A cold basin of a maximum volume of 0.500 m^3 (132 gal US) (adjustable).
- A tubular stainless steel condenser, total length of 14 m (46 ft), formed by 7 sections of 2 m (6.6 ft), put in series.
- A warm basin of a maximum volume of 0.080 m^3 (21 gal US) (adjustable).
- A cooling tower air flow rate of 1000 m3 / h (264,172 gal US/h).
- A feed water adjustable flowrate of 0 to 0.1 m^3/h (0 to 26 gal US/h).
- A blow-down adjustable flowrate of 0 to 0.1 m^3 / h (0 to 26 gal US/h).

The operating variables settings are summarized below:

- Circulation flow within the condenser: 0.2 to 1.6 m^3 / h (53 to 423 gal US / h)
- Condenser inlet temperature: 20-35 ° C (68-95°F)
- Condenser outlet temperature: 30-45 ° C (86-113°F)
- Flow speed in the condenser of the order of 1.8 m / s (3.3 ft/s)
- Concentration factor from 1.2 to 5
- Water feed from the nuclear power plant of Nogent-sur-Seine (Seine river water)

Overall operations of the circuit:

The cold water pumped from the feed water circuit is fed to the cold basin. It is then directed to the condenser via a circulation pump. The condenser is constituted in the lower part of a boiler (steam generator vacuum), and in the upper part of a stainless steel tube (length and diameter equivalent to those of the condensers of Nogent-sur-Seine Nuclear Power Plant). The steam in contact with the tube causes the warming of the water. The water heated in the tube passes through a tank (hot basin), then is cooled by spraying over the packing in the cooling tower thanks to contact with the air flow. The packing used in the loop is equivalent to the one placed in situ (Nuclear Power Plant cooling tower).

All air and water are treated by continuous chlorination for safety reasons related to the potential presence of pathogens.

Experimental Approach

General organization

The experimental approach was organized in two main phases: the preparation phase of the pilot and the phase of actual testing. Key points of the program are detailed below.

Preparation phase:

The goal of this phase is to start the experiment with clean systems, with a minimum of water-formed deposit in the circuits, and in a similar state for the four loops. It will then be possible to compare the behavior of the different fills implemented in the different loops.

The preparation phase includes a cleaning and a disinfection of each loop. The settings required for the instrumentation are also realized during this preparation phase.

We observed on certain brand new film fills the presence of a thin "oily" layer. During precedent studies, we observed at the beginning of the test a mass diminution of the fill. In order to avoid this phenomenon and to have all the sample in the same state, fills have to be prepared with a conditioning step by "soaking" in tap water (during 1 month with changing of tap water twice a week to prevent algal blooms) and cutting fill elements to the dimensions of the loops. Fills are also cut as samples in order to be weighed, as shown on Figure 2. These samples are placed in the tower full of fills.

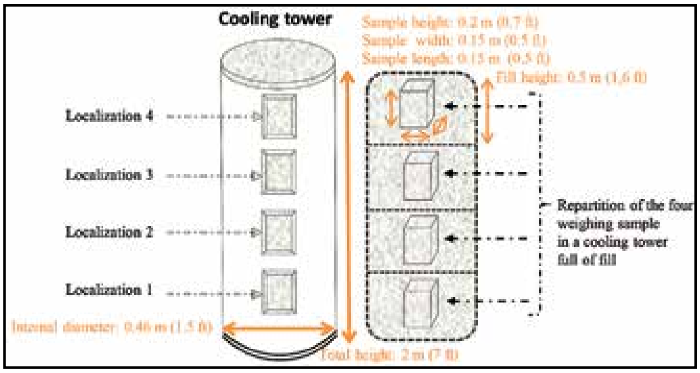
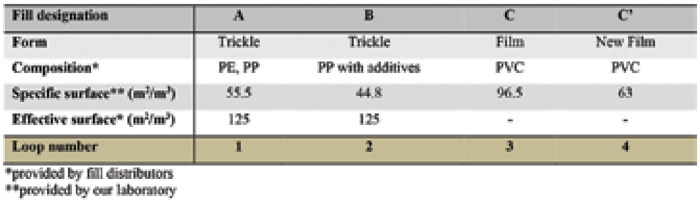


Figure 2: Presentation of the cooling tower of the pilot, with the numbers of the sample localizations used for weighing

Testing phase:

The four loops are operated in parallel. Each cooling tower is filled with a specific packing. Thus four different fills were studied in parallel: two trickle fills from two different distributors (fill A and fill B), and two film fills of a second distributor with a new (fill C) and an older film fill (fill C'). The "old film fill" (fill C') is the most commonly used in EDF cooling towers.

The following table shows the packings chosen by EDF to be tested in this study.



Fill designation	A	B	C	C'
Form	Trickle	Trickle	Film	New Film
Composition*	PE, PP	PP with additives	PVC	PVC
Specific surface** (m^2/m^3)	55.5	44.8	96.5	63
Effective surface* (m^2/m^3)	125	125	-	-
Loop number	1	2	3	4

*provided by fill distributors
**provided by our laboratory

Table 1: Packings studied and their main characteristics

The operating conditions of the testing phase were selected to help maintain similarity in each loop to compare fill behaviors.

To allow this comparison for a duration limited to a few months, the four pilots were operated in scaling conditions, fed by Seine river water (calcium concentration around 90 mg/L and hydrogen car-

bonates concentration around 230 mg/L), with a Concentration Factor (CF), also called Cycles of Concentration (CoC), equal to 2, without injection of acid, and while maintaining the temperature at the output of the condenser at 40°C (104°F).

Details of the operating conditions are presented in Table 2.

Kind of fill	Kind of packing Y
Air processing	Exterior temperature* and variable air ventilation **
Kind of water	Seine Water (Langelier Saturation Index of 0.86 at the beginning)
Temperature	40 °C (104 °F) at the output of the condenser (with a ΔT of 10 °C)
Circulation flow rate	0.115 m³/h (30 gal US/h)
Concentration factor* **	2
Acid sulphuric flow rate	0
Monitoring	See next paragraph (section 3.2)

* natural meteorological conditions
** automatic in order to obtain ΔT asked
*** controlled by feedwater flow rate

Table 2: Operating conditions in each loop of the pilot

Measurement program

The measurement program set up during the test aimed to check the good behavior of the pilot, monitor the water quality in the feed and in the circuits, quantify and characterize the deposits, as well as ensure a microbiological monitoring in water.

Table 3 shows global measurement program:

Kind of monitoring	Kind of sample	Direct data	Calculated data	Frequency	Objectives
Pilot monitoring	Probe	Temperature	ΔT of Cooling Tower	Continuous	Good operation of the pilot
	Probe	Flow rate	Physical concentration factor	Daily	
	Liquid sample	Chloride concentration	Chemical concentration factor	Continuous	
Monitoring of water quality in feed water and circuits	Liquid sample	Calcium concentration, Alkalinity, pH, Conductivity	Calcium balance and scaling index	Daily	Estimation of scaling ability of feed water & effective scaling in the circuit
		Total Suspended Solids (TSS)	Suspended solids balance	Daily	Estimation of the fouling ability of feed water
Monitoring mass of water-formed deposit	Solid sample	Weighing	Weight gain related to volume, rate of weight gain	Weekly	General water-formed deposition sensibility of fills in cooling tower (global and on multiple localization)
Deposit characterization	Solid fraction sampled on the fills	Dry substance , Volatile substance at 977 °F and 1652 °F	Percentage	At the end	Organic and mineral matters proportions, calcite and other minerals proportions in the deposits
Microbiological monitoring	Liquid sample	*Required (by law) monitoring*			
	Solid sample				

Table 3: Measurement program on the pilot

Results Of The Comparative Study Of The Water-Formed Deposit Rate Of Four Different Fills

Foreword on water quality during tests

The water quality has a direct impact on the water-formed deposit. For this reason the first step of this study had to be an analysis of water quality during the experimentation.

Scaling is usually the main fraction of water-formed deposit. Figure 3 shows the evolution of the main contributors to scaling: calcium concentration (mg / L), alkalinity (mg / L) and conductivity at 25°C (mS/m).

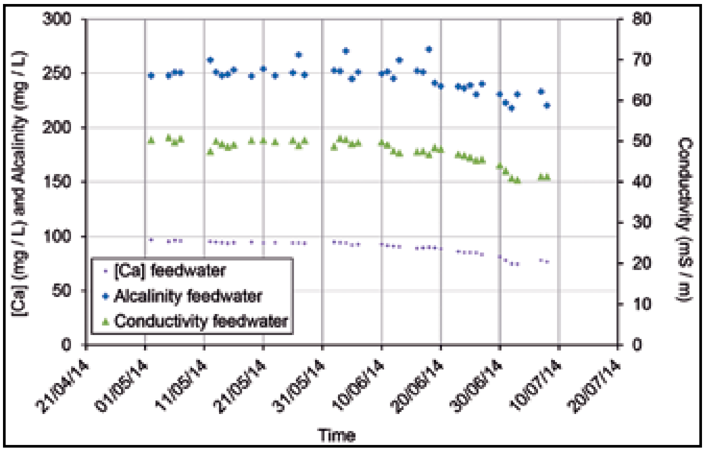


Figure 3: Calcium concentration, alkalinity and conductivity of the feed water as a function of time

The results show that concentrations were stable during the first month of the test; afterwards the three considered parameters decrease in parallel, showing an improvement of the feed water quality during the last weeks of the test. Those results were similar to the follow-up of the Seine river quality. Pilots feed water evolved naturally with the season. Thus, the scaling potential of the feed water was higher at the beginning of the test than at the end.

For the other part of the water-formed deposit, the main parameter analyzed in the water is the total suspended solids (TSS), whose evolution is presented in Figure 4.

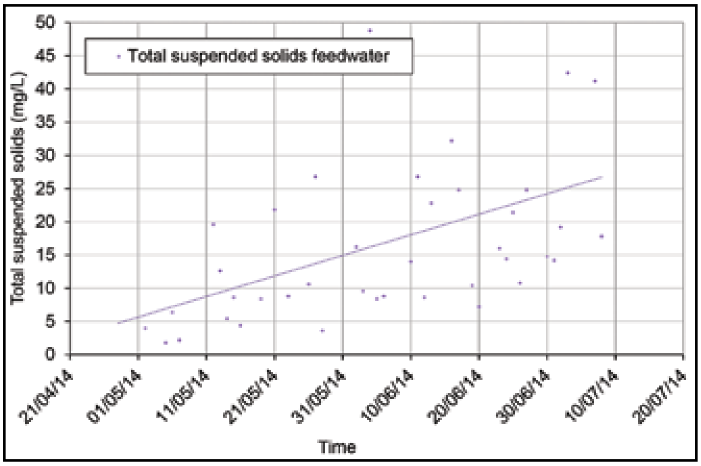


Figure 4: Total Suspended Solids (TSS) as a function of time

TSS concentrations have fluctuated throughout the test. The global evolution is an increase, with higher values at the end. Thus, contrary to the scaling potential, the fouling potential (other than scaling) of the feed water was higher during the last weeks of the test.

Still the four loops were fed the same water quality the whole test long, therefore the comparison of the four fill deposit evolution is possible.

Weighing test

Weighing tests aim to estimate the weight of the water-formed deposit on the fill. This deposition includes mainly deposition from scaling and from fouling. Respect to the definition from CTI nomenclature: "Scale - The deposition on surfaces of dissolved minerals that have exceeded their saturation limit, as opposed to fouling, which is deposition of material normally in suspension." [3]

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Evolution of gravimetric measurements:

The main result of the study is synthesized on Figure 5. It shows the evolution of gravimetric measurement weekly carried out on the 4 fills.

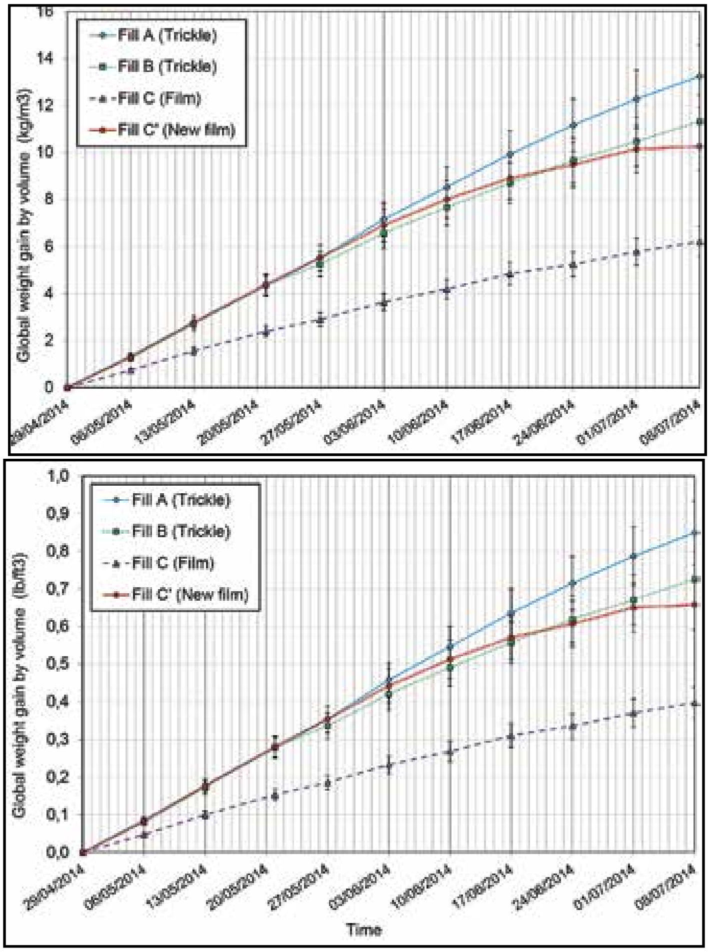

Figure 5: Global weight gain (sum of the four localizations) of fill A, B, C and C' by volume for all the sample in the cooling tower function of time- 1st graphic: International System units – 2nd graphic: American units

These results highlighted the different behaviors of fills towards water-formed deposit :

- Fill C has by far the lower weight gain by volume and is the less prone to deposition during the tests (currently used in EDF cooling tower).
- Fill A improve it weight gain more quickly than the others, with the most important total weight gain of practically 14 kg/m^3 (0.9 lb/ft^3).
- The weight gain by volume of fills B and C' decreased earlier than for fill A. At the end of the test, fills B and C' samples were lighter than fill A sample. Fills B and C' have a quasi similar deposition behavior.
- During the three final weeks, shapes of the curves show a stage: maybe because of fewer calcium concentration and alkalinity; or maybe because after weighing of samples, the water-formed depositions are taking down during repositioning of sample in the cooling tower.

Thus, it is the "old film fill", classically used in EDF cooling towers, which gives the lower weight gain/volume during these tests. These results consider water-formed deposit constituted mostly by foulants (suspended solids, biological growth, and any system contaminants) and scales (originally dissolved minerals that have precipitated and come out of solution to form solids on the fill material). Behavior with respect of each aspect (fouling vs scaling) will be explored in the following paragraph (see section 4.3 - page 14).

Figure 6 shows the evolution of the deposition rate along the test. These results show that the kinetics change during the experiment. First week the water-formed deposition has been quick but after 7 weeks the weighing shows that the fill C' begin to stop his weight gain. More generally, the weight gain rate decreases with time for the four fills. This could be due to the decrease of the scaling potential of feed water along the test.

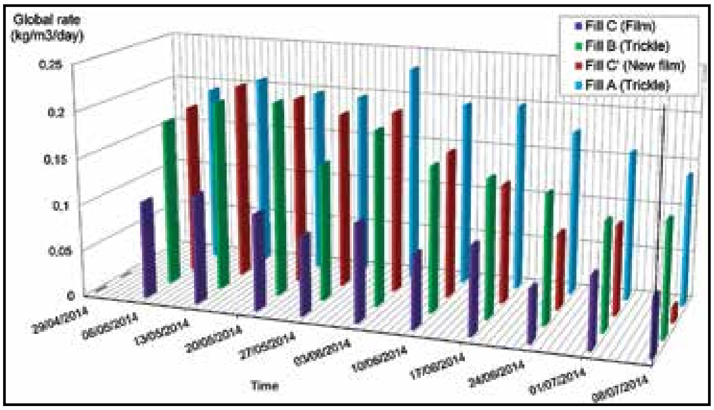

Figure 6: Global rate of fill A, B, C and C' function of time

- Influence of the fill position in the cooling tower on its deposition kinetics

Figure 7 shows the weight gain of each level in the cooling tower (level numbering are defined in Figure 2).

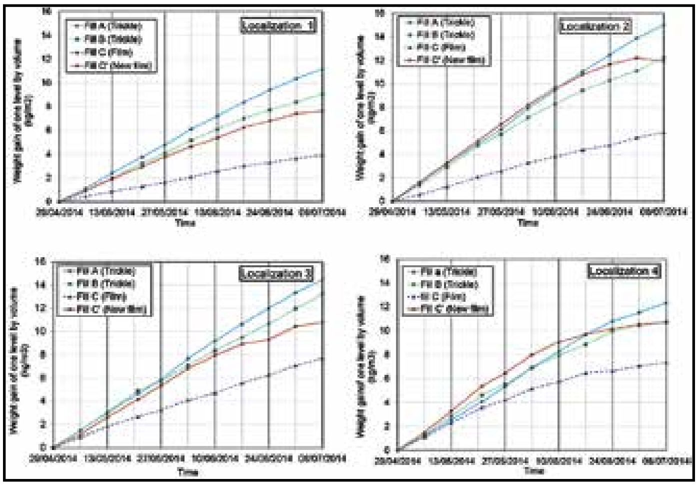

Figure 7: Weight gain of fill A, B, C and C' by volume of each level in the cooling tower function of time

The rankings are broadly similar to that achieved in the previous graphic (Figure 5), except the level 4 located at the top of the cooling tower, where the fill C' presents the most important water-formed deposit mass during the first weeks, instead of fill A. Considering the uncertainty, these results are not very meaningful and we could estimate the same behavior of the fill all along the cooling tower.

Table 4 precises the results seen on figure 7.

		Global weight gain (in g)			
		Fill A (Trickle)	Fill B (Trickle)	Fill C (Film)	Fill C' (New film)
Localization in the cooling tower	4	61	51	37	54
	3	72	61	40	56
	2	77	59	29	41
	1	55	44	19	43

Table 4: Global weight gain (in g) of fill A, B, C and C' at each level, at the end of the test


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Looking at the data, the film fills appear to have more weight gain at the top locations (localizations 3 and 4), contrary to the trickle fills which have more weight gain at the center locations (localizations 2 and 3).

Different phenomena have an influence on scaling. It is not the same phenomenon which is predominant at the top or at the bottom of the tower. Water is warmer at the top of the tower so the thermodynamics is favored in this area. Thermodynamics effect (and, to a lower extent, the effect of carbon dioxide degassing) promotes scaling at the top. On the contrary, the air flow more important in the bottom of the tower could favor scaling at the bottom of the tower by evaporation and supersaturation of the water.

As the results show, deposit weights are more important at the top of the cooling tower for film fills. As a consequence, if we consider that deposits mainly are scales (see below paragraph 4.3 - page 14), we could say that thermodynamics effect is stronger than hydrodynamics, for film fills.

Deposits analysis

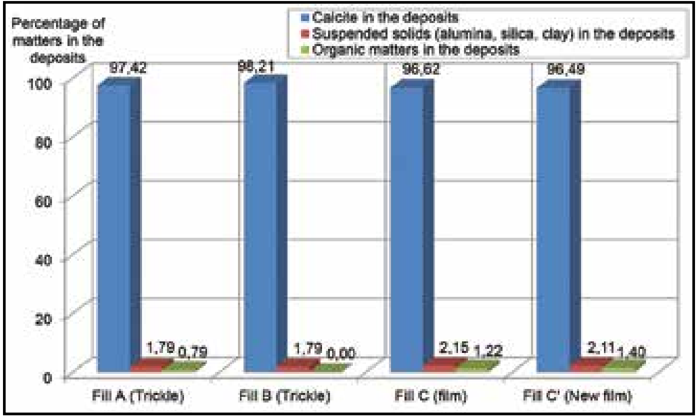

Figure 8: Composition of the deposits of the four different fills at the end of the tests (weight percentages)

Analysis of deposits sampled on each fill at the end of the test is presented in Figure 8.

Deposits are principally composed of calcite on each fill. Less than 3 % of the deposit weight correspond to suspended matters (alumina, silica or clay). These results are consistent with the values of calcium concentration and alkalinity (figure 3), much higher than the TSS amounts (figure 4).

Conclusion

Contrary to expectations based on information given by the manufacturer of the fills, the two trickle fills present a more important kinetics of water-formed deposition than the "classical" film fill. The new film fill developed by the manufacturer also gave poorer results in terms of water-formed deposition evolution than the "classical" one. This ranking of fills according to their deposition ability was globally the same whatever the level within the cooling tower.

This accelerated test, carried out on reduced-scale open cooling circuit pilots and in scaling conditions, was able to discriminate the water-formed deposition potential of four different packings, which can help the tower designer to choose the best packing. These results would need to be compared to data collected directly from fills present in the industrial towers, so as to consolidate the comparison of the deposition potentials of the different fills. On the whole, these results show that the pilots represent the thermal and chemical behaviour of an industrial cooling circuit such as those found in nuclear power plants.

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3. Nomenclature for Industrial Water-Cooling Towers. CTI-BUL-109.


CONFIDENCE.

A CMIT/MIT Surfactant Blend to Control Biofilms In Industrial Water Systems

Brian Corbin, Dow Chemical Company

Brian Corbin

Abstract

Isothiazolone biocides are used to control bacteria, algae, fungi and biofilms in industrial water systems. Surfactants are also known to directly influence biofilm formation and stability. In this report, we describe a new, one-drum liquid product solution that combines 5-Chloro-2-Methyl-4-Isothiazolin-3-one (CMIT) and 2-Methyl-4-Isothiazolin-3-one (MIT) with a high-performance, low aquatic toxicity surfactant. The solution is stable, low foaming and effective at controlling microorganisms at low parts per million levels. The methods used to evaluate the performance of the product and laboratory and field testing results will be presented.

Introduction

Bacteria in natural environments typically exist within microbial communities referred to as biofilms. The densely packed communities consist of microorganisms adhered to abiotic (non-living) or biotic (living) surfaces encased within an extracellular polymeric substance (EPS), often referred to as glycocalyx or slime. The secreted slime layer is composed of fibrous polysaccharides and globular glycoproteins loosely associated with the cell wall. Depending on the species involved, a biofilm may be composed of 10-25% cells and 75-90% EPS[1]. Biofilms can be composed of single-species populations but often exist as a mixed community of bacteria, fungi, algae, and protozoa.

Biofilm formation frequently causes biofouling and is a major concern in water treatment applications due to microbially influenced corrosion, reduction in process efficiency (heat transfer and evaporative cooling), system cleanliness, and potential health concerns [2, 3]. Various groups of microorganisms are well recognized as major causes of these problems including aerobic and anaerobic bacteria, fungi, algae, and protozoa. Diverse groups can include sulfate reducers *(Desulfovibrio)*, acid-producers *(Clostridium)*, filamentous types *(Sphaerotilus, Leptothrix)*, general slime forming organisms *(Pseudomonas, Enterobacter, Klebsiella)*, and health-related species *(Legionella pneumophila)*. Cyanobacteria (formerly known as blue-green algae) found in cooling tower waters can include *Phormidium, Anabaena, Oscillatoria,* and *Anacystis* species. Green algae in cooling water systems include *Chlorella, Scenedesmus, Chlorococcum, Ulothrix*, and *Spirogyra*. Fungal contaminants occur less frequently, but are still considered problematic in air washer applications, papermaking, and in deterioration of wood cooling towers.

Industrial biocides are critical to a successful water treatment program to reduce microbial populations on surfaces and those introduced into the bulk water from external sources. Biocides used today to inhibit microbial growth and fouling include oxidizers (chlorine, bromine, ozone, chlorine dioxide, and peracetic acid) and non-oxidizing biocides including isothiazolones, glutaraldehyde, DBNPA and bronopol. Many common treatment programs employ non-oxidizers in conjunction with standard oxidant programs to ensure a broad-based approach to microbial control.

Biofilms can be difficult to eradicate because sessile bacteria are generally more tolerant to antimicrobial agents including biocides, bacteriophages, antibodies and antibiotics[4]. Tolerance may be due to the slow penetration of biocides through a biofilm matrix, giving biofilm cells a chance to initiate stress responses. The biocide may either react chemically with the biofilm matrix components or attach to the polysaccharides. In addition, microorganisms within biofilms may enter a less susceptible, dormant physiological state as the concentrations of nutrients and oxygen vary with the depth of the biofilm. Strategies to control biofilm formation and development often include a surface active compound (surfactant) in combination with biocide treatment. Surfactants function as penetrants that loosen the complex matrix of biofilms allowing biocides to reach the organisms more effectively. As the surface tension is decreased, microbial attachment to surfaces is prevented and microorganisms detach from the adhesion surface[5].

One of the most frequently used non-oxidizing biocide products in water treatment is a 3:1 ratio of 5-Chloro-2-Methyl-4-Isothiazolin-3-one (CMIT) and 2-Methyl-4-Isothiazolin-3-one (MIT). CMIT/MIT has broad-spectrum efficacy against bacteria (including sulfate-reducing bacteria, *Legionella* and spore formers), algae and fungi at low parts-per-million (ppm) levels over a wide pH range. It can also inhibit biofilm formation and control growth but, like most biocides, may not be effective in biofilm removal, leaving biomass on a surface that may contribute to microbial recovery and biofilm regrowth. Therefore, the use of a surfactant to improve biofilm control is a well known practice in the water treatment industry. This report describes a series of studies designed to identify potential surfactants that can be used in a single-drum combination product formulation with CMIT/MIT. The most attractive surfactants for a combination product have low environmental toxicity and biodegradable properties. The combination product of CMIT/MIT plus surfactant should be low-foaming and demonstrate good physical and chemical compatibility, especially under storage at elevated temperatures. In addition, the product should have improved biofilm control compared to CMIT/MIT treatment alone.

Materials And Methods

Effect of non-ionic surfactants on biofilm stability

A model biofilm system was used to evaluate the efficacy of CMIT/MIT biocide and surfactant treatments (alone and in combination) for eradication of established biofilms. The system involved growing biofilms on a glass microscope slide in a phosphate-buffered saline solution (100 ml) with 1% trypticase soy broth. A mixture of three bacteria (Pseudomonas aeruginosa ATCC 15442, *Enterobacter clo-*

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acae ATCC 13047, and *Klebsiella pneumoniae* ATCC 10031) was used as the inocula for the biofilm samples. After 24-48 hrs incubation with agitation (150-200 rpm) at 30° C the pre-grown biofilm slides were rinsed in phosphate buffered-saline and transferred to biocide-treated contact solutions containing synthetic cooling water (584 mg/l $CaCl_2$-$2H_2O$), 203 mg/l $MgCl_2$-$6H_2O$), 84 mg/l $NaHCO_3$, 5 mg/l acrylate polymer, and 0.1% trypticase soy broth). After a defined contact period (4-24 hr), biofilms were rinsed, scraped and viable counts of surviving bacteria were determined by plate counting or Most Probable Number technique (MPN) using trypticase soy broth (TSB) medium (30° C).

Stability of CMIT/MIT surfactant formulations

Combination formulations of CMIT/MIT with surfactants were tested for chemical and physical stability over time. End use formulations were prepared by dilution of 14% CMIT/MIT to 1.5% total active ingredient in distilled water with appropriate stabilizer. Surfactants were added at 1% and 5% active ingredient. Solutions were heat aged at 25, 40, or 55° C and analyzed for active ingredient by High Performance Liquid Chromatography (HPLC). Visual observations were also noted. Formulations which phase separated or were turbid in appearance were considered unacceptable. Excessive foaming and color change were also considered as failures. Adequate chemical stability was considered when >95% of the active ingredient remained at the temperature and time interval.

Bulk water sample collection and monitoring in Spring House cooling tower

Water samples were collected daily from a cooling tower located in Spring House, Pennsylvania. Samples were collected from the sample collection port located off the tower return pipe. The temperature, conductivity and pH were measured during the collection process. On days that coupons were collected, water samples from cell 3 and the sump were also collected. The samples were then transported back to the lab for additional testing. Each water sample was plated on Trypticase Soy Agar, to enumerate, isolate and identify the different species of bacteria in the tower. Samples were also diluted in Trypticase Soy Broth to determine the most probable number (MPN) of organisms in the samples. When the cooling tower was dosed with 1.5% CMIT/MIT, the CMIT/MIT levels were measured by HPLC at time zero and 3hrs, 24hrs, and 48hrs after dosing.

Biofilm monitoring during Spring House cooling tower field trial

Biofilm coupons or mesh screen were placed in three distribution pans (C1, C2, C3) on the top of Spring House cooling tower or in the sump. Coupons/mesh screens were made of aluminum, solid stainless steel (304L and 316L), mild steel or copper. Coupons were labeled according to their location. Multiple coupons of each type were placed in the same location to measure reproducibility. Coupons were arbitrarily labeled #1, #2 or #3 and had the same dimensions.

Most Probable Number (MPN) enumeration

The number of bacteria in the samples (cells/ml) was determined by using an MPN statistical method combined with a microtiter plate system. The MPN method is an established method for the quantitation of viable microorganisms. Trypticase Soy Broth was used as the growth media for this assay. Coupons were placed in 100 mL of Phosphate Buffer with $MgCl_2$ and shaken. After the biofilm was removed from the coupons, 20 µl of each sample was transferred by pipette to the first column of the first four rows of the 96-well microtiter plate used for MPN enumeration. Two biofilm or bulk water samples were tested per plate. The plates were then incubated in the 30°C incubator for forty-eight hours. After incubation, the plates were read by determining the number of wells in each column containing microbial growth. Microbial growth was determined by wells that were turbid as opposed to transparent wells which contained no microbial growth. Statistical tables were used to calculate the most probable number estimate of the microbial population in the sample from a combination of positive growth readings in the 96 well plate[6].

High Resolution Minimum Inhibitory Concentration Evaluations

Microorganisms were recovered from frozen cryovials prior to testing. Bacteria were grown on TSA at 30°C for 48 hours. Fungi were grown on Sabouraud Dextrose Agar (SDA) at 30°C for 48 hours. The lowest concentration of CMIT/MIT and CMIT/MIT + surfactant required to inhibit bacteria and fungi was determined by a high resolution minimum inhibitory concentration (HRMIC) test. Varying amounts of each microbiocide were added to media in a 96-well microtiter plate. The media used for the HRMIC tests was TSB for bacteria and Sabouraud Dextrose Broth (SDB) for fungi. Stationary phase bacteria were grown overnight at 30°C in a rotary shaking incubator (125 reciprocations per minute) in TSB. Phosphate buffer suspensions of fungi were prepared and diluted into SDB. The overnight cultures were calibrated to an optical density (OD) value of 0.40 to ensure a starting bacterial suspension of ~1.0×10^8 CFU/mL. Appropriate dilutions were performed in the appropriate test media and inoculated into the test to provide approximately 10^6 CFU/mL in each well for bacteria or 10^5 CFU/mL in each well for fungi. Triplicate cell suspensions were prepared for all organisms. The microtiter plates were incubated at 30°C for 24 hours for bacteria and 25°C for seven days for fungi and were then checked for the presence or absence of microbial growth by observing the turbidity in each well.

Results And Discussion

Effect of non-ionic surfactants on biofilm stability

A variety of commercially available, industrial surfactants were evaluated for use in a single-drum combination product formulation with CMIT/MIT. The surfactants chosen have the following main characteristics: low foaming, biodegradable, low ecotoxicology, high water solubility, stability under acidic conditions, compatibility with common corrosion and scale inhibitors and no phase change up to 40° C.

Using a laboratory biofilm model system, a bacterial biofilm comprised of *Pseudomonas aeruginosa*, *Enterobacter cloacae* and *Klebsiella pneumoniae* was grown to a cell density of 6.2-6.8 $\log_{10}$ CFU/cm^2 after 24-48 hours incubation. Exposure to various non-ionic surfactants showed no measurable biofilm control (log reduction) at levels ranging from 5-50 parts per million (ppm) at 4 and 24 hours (Figure 1, 2 and data not shown). This indicates that the surfactants alone did not reduce biofilm populations by either a toxic response or by a physical cleaning mechanism (removal). In contrast, exposure to 1.5% CMIT/MIT for 4 hours and 24 hours led to a 2.3 and 1.7 log reduction of biofilm cells, respectively, compared to the untreated control. Efficacy was measured by reduction in viable counts of bacteria on the sample surfaces at various contact times and concentrations. In general, an increase in the log reduction efficacy of at least 0.5 log units versus the control or another treatment was evidence of a minimal improvement and a 1.0-log or greater improvement was considered significant.

In this study, several non-ionic surfactants were evaluated for their ability to enhance the biofilm control properties of CMIT/MIT. Sur-

factants tested were of varying molecular weight and composition. A mixed bacterial biofilm comprised of Pseudomonas aeruginosa, Enterobacter cloacae and Klebsiella pneumoniae was grown to a cell density of 6.4 – 6.9 log10 CFU/cm2 in 24-48 hr. Exposure to CMIT/MIT for 4 hr and 24 hours led to a 1.2 and 2.2 log reduction in cell density, respectively, as compared to the untreated control (Figure 3 and 4). Surfactants alone had no effect on biofilm cell density in this experiment (data not shown).

The combinations of 1.5 ppm CMIT/MIT with Surfactant C, Surfactant E, Surfactant F, Surfactant G or Surfactant H led to a 2-2.8 log reduction of biofilm cell density after a 4 hr exposure. No viable bacteria were detected at 24 hrs. Minimal synergy was observed with Surfactant A in these experiments. Enhanced biofilm control was observed with Surfactant B at 4 hr and 24 hr but was not as effective as other combinations tested. These studies indicate that the efficacy of CMIT/MIT against biofilm bacteria can be enhanced in the presence of several surfactants or dispersants.

Compatibility screening of surfactants with the CMIT/MIT Microbiocide

Compatibility screening was conducted to further evaluate CMIT/MIT formulations containing a surfactant that were previously shown to have enhanced efficacy against biofilms.

End use formulations were prepared by dilution of 14% CMIT/MIT to 1.5% total active ingredient in distilled water with appropriate stabilizer. Surfactants were then added at 1% and 5% active ingredient and samples heat aged at 25° C, 40° C, and 55° C. The active ingredient remaining in solution was measured by HPLC on day 4, 7, 60, 90 and 180. Visual observations were also noted. Formulations which phase separated or were turbid in appearance were considered unacceptable. Excessive foaming and color change were also considered as failures. Adequate chemical stability was considered when >95% of the active ingredient remained at the temperature and time interval.

In an initial screen, several polymers were evaluated at 1% and 5% in combination with 1.5% CMIT/MIT. The physical stability of the biocide with surfactant was evaluated at 40° C for one week (Figure 5). We found that formulations of Surfactant H (at 1 or 5%) with CMIT/MIT caused phase separation and would therefore be unsuitable for use. Phase separation of CMIT/MIT formulations with Surfactant I was also seen at 1%, but not at 5%. Surfactant G, however, showed no phase separation in combination with CMIT/MIT. Based on these screening results, formulations of CMIT/MIT with Surfactant G would be suitable for further compatibility testing.

Next, we conducted additional stability studies on formulations containing CMIT/MIT in combination with different surfactants under conditions of extended heat aging. Analysis revealed that a CMIT/MIT solution was physically clear, colorless, and free of precipitates when stabilized with potassium iodate (Figure 6). Removal of the stabilizer in the 1.5% CMIT/MIT formulation caused discoloration and precipitate formation at 40° C and 55° C. Surfactant A and Surfactant F (with or without CMIT/MIT) were physically unsuitable (cloudy or gelled) at time zero and were not tested further. Surfactant B and Surfactant H showed variable results in combination with CMIT/MIT and are not considered suitable due to cloudiness, color, or high foam. Surfactant C and Surfactant E showed excellent physical properties and compatibility when formulated at 5% with 1.5% CMIT/MIT biocide. These formulations were typically clear, free of cloudiness or color, with minimal to no foaming after short term heat aging up to 55° C.

Additional stability testing was conducted on CMIT/MIT formulations containing Surfactant B, Surfactant C and Surfactant E to assess their long term physical and chemical compatibility. Testing was done at 25°, 40°, and 55° C and analyzed for active ingredient by HPLC. Results showed that after 2 months (Figure 7A), all formulations, except Surfactant E + CMIT/MIT stored at 55° C, showed excellent chemical stability (>95% of initial concentration CMIT/MIT remaining) and physical appearance (clear, no precipitates or haze). Some light foam and color was observed in the formulations containing Surfactant B with CMIT/MIT. After 3 months of aging (Figure 7B), a slight loss of CMIT active (94% remaining) was seen with Surfactant C at 55°C. A moderate loss of CMIT (89% remaining) and yellow discoloration was seen with Surfactant B at 55° C. All other combinations tested showed excellent physical and chemical compatibility. After 6 months (Figure 7C), all samples aged at room temperature were very stable and physically compatible. As expected, additional loss of biocide at elevated temperatures was noted for some formulations, but 6 months storage at 40° and 55° C is extremely aggressive storage conditions. Based on the results of these studies, a combination formulation containing 1.5% CMIT/MIT biocide with 5% Surfactant C should be suitable candidates for developing a stable, commercial one-drum product.

Field evaluation of a CMIT/MIT Surfactant C formulation

Based on several factors including product stability, efficacy, environmental toxicity, and cost, the CMIT/MIT, 5% Surfactant C combination formulation was chosen for further evaluation in a cooling tower field trial. A cooling tower located in Spring House, PA, was identified as the testing site. The product was evaluated in the field by enumerating the CFU/ml in bulk water samples and growth of biofilm on metal coupons and mesh placed in distribution pans on top of the cooling tower and in the sump. We found that dosing 1.5 ppm CMIT/MIT twice a week and BCDMH once a week for three weeks maintained the bulk water bacterial counts at approximately 1.2 x 10^3 CFU/ml (Figure 8). MPN enumeration of the mesh coupons identified some biofilms that contain >6.9 x 10^{12} cells/cm^2 (Figure 8). These results demonstrate that the “background” dosing scheme of CMIT/MIT and BCDMH was able to maintain very low levels of bacterial counts in the bulk water and on solid surfaces, but allowed bacterial biofilm to form on the mesh coupons to a high level. Bulk water counts were approximately 5.7 x 10^2 CFU/ml in the cooling tower when dosing CMIT/MIT in combination with Surfactant C (Figure 9). In addition, biofilm cell density was reduced to 10^3 to 10^4 CFU/ml on the mesh coupons and screens after 72 hrs. This is a greater than 9-log reduction over CMIT/MIT treatment alone. These results suggest that the CMIT/MIT surfactant combination product is extremely effective at controlling biofilm growth in cooling towers.

Foaming was a significant issue during the trial (Figure 10) but could be held to a manageable level with the addition of a defoamer. Unfortunately, the addition of a defoamer prior to use would be of less commercial value than products that can be used independently. Through these evaluations, it became clear that reducing the level of surfactant in the formulation would be of great benefit to our customers.

Stability of CMIT/MIT formulations containing reduced levels of Surfactant C

A significant amount of foam was generated in the cooling tower upon dosing the 1.5% CMIT/MIT, 5% surfactant combination product. Because foaming is detrimental to nearby equipment, we reformulated the product to contain reduced levels of Surfactant C. Stability testing was conducted over a four week period on samples incubated at 25°C, 40°C, and 55°C. Samples were analyzed by

high pressure liquid chromatography (HPLC) to determine the percentage of active ingredient remaining over the testing period. Samples containing Surfactant D were cloudy after one week of heat aging. In addition, samples containing Surfactant B that were heat aged at 55°C for one week were also cloudy. After heat aging for four weeks, all samples that were not cloudy remained fairly stable, except for the unstabilized CMIT/MIT samples (Figure 11).

Efficacy of a CMIT/MIT formulation containing 1.5% surfactant against microorganisms

We compared the efficacy of a CMIT/MIT product formulation containing a reduced level of surfactant C (1.5%) to CMIT/MIT treatment alone. We found that the CMIT/MIT/surfactant combination has enhanced efficacy against bacteria (Figure 12A) and fungi (Figure 12B) compared to CMIT/MIT treatment alone. Minimum inhibitory concentration (MIC) values against *Pseudomonas aeruginosa* in this study was determined to be 3 ppm a.i. In contrast, the MIC value for the biocide surfactant blend was 0.3 ppm a.i. The MIC was also decreased 25-fold against fungi when using the biocide/surfactant combination formulation compared to biocide treatment alone. Together, these results suggest that a product containing 1.5% CMIT/MIT and 1.5% Surfactant C will be effective in preserving industrial water treatment systems.

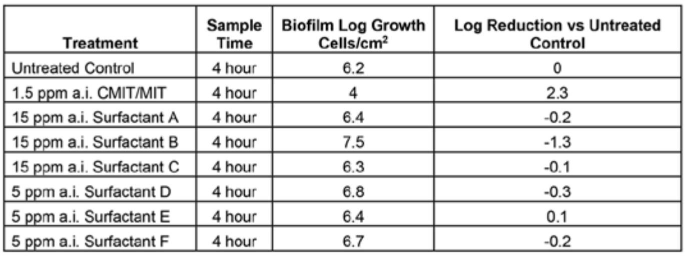
Summary And Conclusions

This report described a series of studies designed to identify potential surfactants that can be used in a single-drum combination product formulation with CMIT/MIT. A one drum solution eliminates using two-part (two drum) treatments for microbial control that would require additional pumps, timers, tubing, electricity, inventory, space, and maintenance. Our studies identified a biodispersant that is stable, low-foaming and demonstrates good physical and chemical compatibility. In addition, it has enhanced efficacy against common microorganisms typically encountered in cooling water systems as compared to a CMIT/MIT treatment alone. The product is composed of 1.5% by weight 2-methyl-4-isothiazolin-3-one (methylisothiazolinone, MI): 5-chloro-2-methyl isothiazolin-3-one (methylchlorothiazolinone, MCI) in a ratio of 1:3 with the addition of 1.5% by weight inert surfactant. Dosage in water treatment applications are identical to CMIT/MIT, which range from 33.33 to 866.67 parts per million (ppm) product (0.5 to 13 ppm active ingredient (a.i.). Additional field trials are currently being conducted to further demonstrate the efficacy of the product.

Acknowledgements

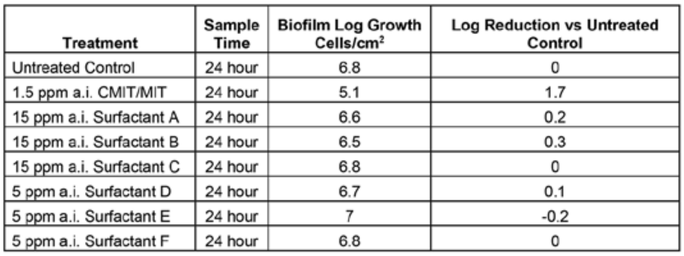
The author would like to acknowledge the following individuals for their assistance in this work: Terry Williams, Christine Schultz, Christine McInnis, Usha Gandhi, Paul Schook, Kim Cagle and Christopher Tallarico.

Figure 1: Biofilm stability after 4 h exposure to CMIT/MIT or individual surfactants.



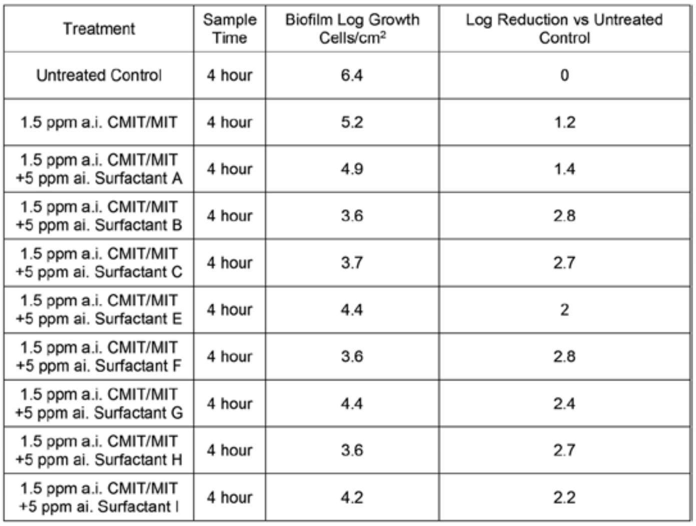
Treatment	Sample Time	Biofilm Log Growth Cells/cm^2	Log Reduction vs Untreated Control
Untreated Control	4 hour	6.2	0
1.5 ppm a.i. CMIT/MIT	4 hour	4	2.3
15 ppm a.i. Surfactant A	4 hour	6.4	-0.2
15 ppm a.i. Surfactant B	4 hour	7.5	-1.3
15 ppm a.i. Surfactant C	4 hour	6.3	-0.1
5 ppm a.i. Surfactant D	4 hour	6.8	-0.3
5 ppm a.i. Surfactant E	4 hour	6.4	0.1
5 ppm a.i. Surfactant F	4 hour	6.7	-0.2

Figure 2: Biofilm stability after 24 h exposure to CMIT/MIT or individual surfactants.



Treatment	Sample Time	Biofilm Log Growth Cells/cm^2	Log Reduction vs Untreated Control
Untreated Control	24 hour	6.8	0
1.5 ppm a.i. CMIT/MIT	24 hour	5.1	1.7
15 ppm a.i. Surfactant A	24 hour	6.6	0.2
15 ppm a.i. Surfactant B	24 hour	6.5	0.3
15 ppm a.i. Surfactant C	24 hour	6.8	0
5 ppm a.i. Surfactant D	24 hour	6.7	0.1
5 ppm a.i. Surfactant E	24 hour	7	-0.2
5 ppm a.i. Surfactant F	24 hour	6.8	0

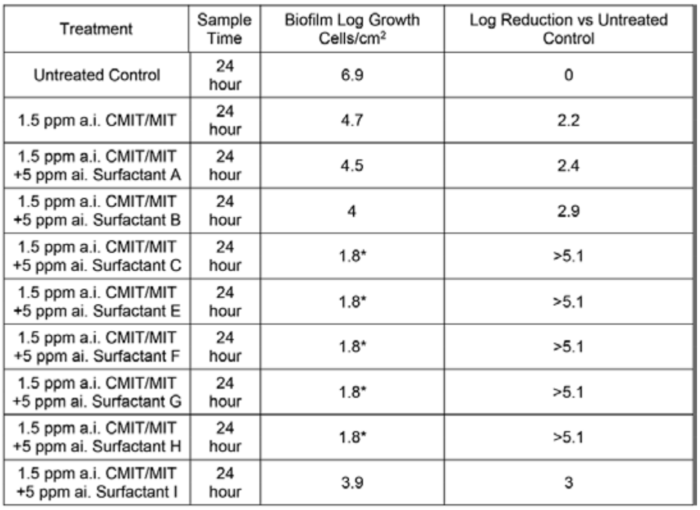
Figure 3: Biofilm stability after 4 h exposure to CMIT/MIT or CMIT/MIT + surfactant.



Treatment	Sample Time	Biofilm Log Growth Cells/cm^2	Log Reduction vs Untreated Control
Untreated Control	4 hour	6.4	0
1.5 ppm a.i. CMIT/MIT	4 hour	5.2	1.2
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant A	4 hour	4.9	1.4
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant B	4 hour	3.6	2.8
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant C	4 hour	3.7	2.7
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant E	4 hour	4.4	2
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant F	4 hour	3.6	2.8
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant G	4 hour	4.4	2.4
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant H	4 hour	3.6	2.7
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant I	4 hour	4.2	2.2

**Limit of detection = no viable cells recovered*

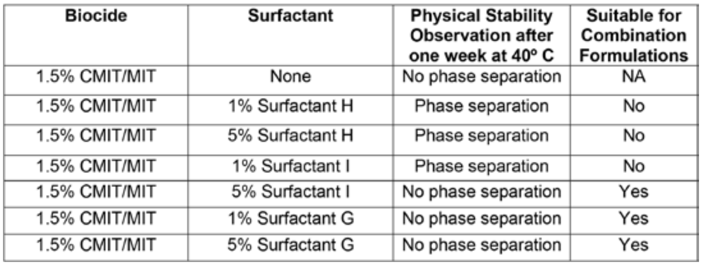
Figure 4: Biofilm stability after 24 h exposure to CMIT/MIT or CMIT/MIT + surfactant.



Treatment	Sample Time	Biofilm Log Growth Cells/cm^2	Log Reduction vs Untreated Control
Untreated Control	24 hour	6.9	0
1.5 ppm a.i. CMIT/MIT	24 hour	4.7	2.2
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant A	24 hour	4.5	2.4
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant B	24 hour	4	2.9
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant C	24 hour	1.8*	>5.1
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant E	24 hour	1.8*	>5.1
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant F	24 hour	1.8*	>5.1
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant G	24 hour	1.8*	>5.1
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant H	24 hour	1.8*	>5.1
1.5 ppm a.i. CMIT/MIT +5 ppm ai. Surfactant I	24 hour	3.9	3

**Limit of detection = no viable cells recovered*

Figure 5: Compatibility Screening of Surfactants with CMIT/MIT biocide.



Biocide	Surfactant	Physical Stability Observation after one week at 40º C	Suitable for Combination Formulations
1.5% CMIT/MIT	None	No phase separation	NA
1.5% CMIT/MIT	1% Surfactant H	Phase separation	No
1.5% CMIT/MIT	5% Surfactant H	Phase separation	No
1.5% CMIT/MIT	1% Surfactant I	Phase separation	No
1.5% CMIT/MIT	5% Surfactant I	No phase separation	Yes
1.5% CMIT/MIT	1% Surfactant G	No phase separation	Yes
1.5% CMIT/MIT	5% Surfactant G	No phase separation	Yes

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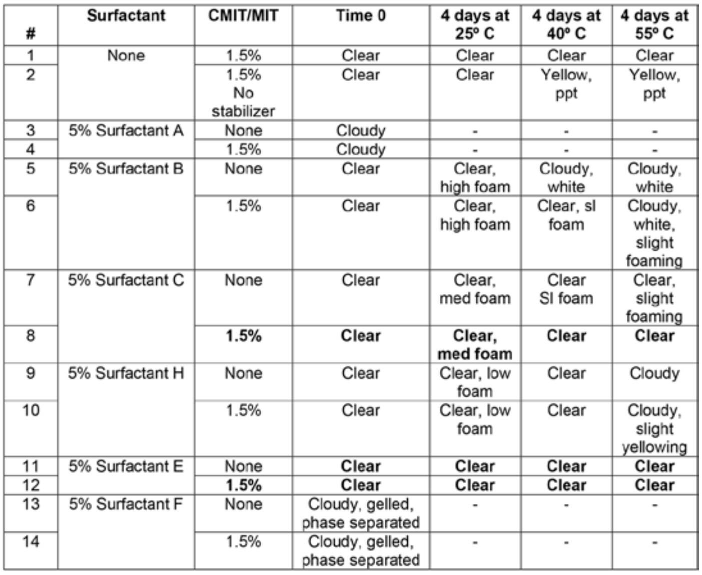
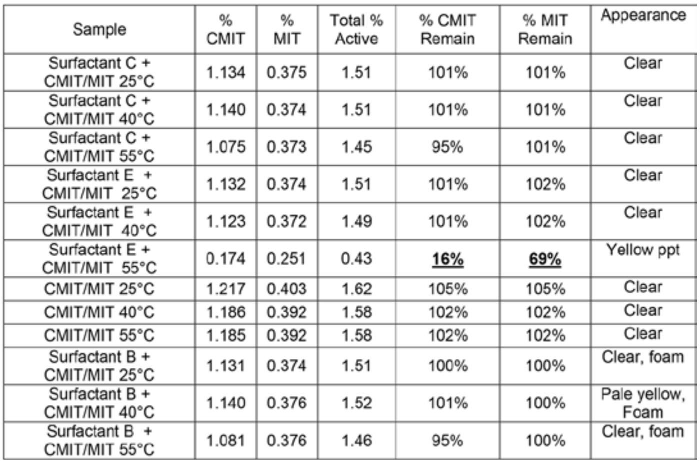
Figure 6: Compatibility screening of CMIT/MIT formulations with various non-ionic surfactants.



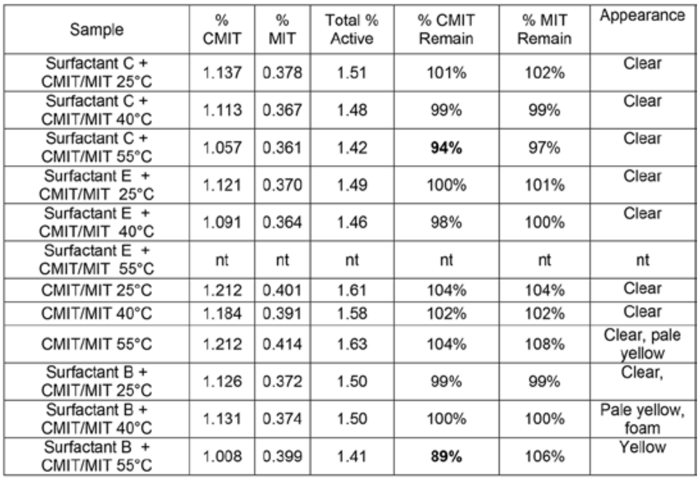
#	Surfactant	CMIT/MIT	Time 0	4 days at 25º C	4 days at 40º C	4 days at 55º C
1	None	1.5%	Clear	Clear	Clear	Clear
2		1.5% No stabilizer	Clear	Clear	Yellow, ppt	Yellow, ppt
3	5% Surfactant A	None	Cloudy	-	-	-
4		1.5%	Cloudy	-	-	-
5	5% Surfactant B	None	Clear	Clear, high foam	Cloudy, white	Cloudy, white
6		1.5%	Clear	Clear, high foam	Clear, sl foam	Cloudy, white, slight foaming
7	5% Surfactant C	None	Clear	Clear, med foam	Clear Sl foam	Clear, slight foaming
8		**1.5%**	**Clear**	**Clear, med foam**	**Clear**	**Clear**
9	5% Surfactant H	None	Clear	Clear, low foam	Clear	Cloudy
10		1.5%	Clear	Clear, low foam	Clear	Cloudy, slight yellowing
11	5% Surfactant E	None	**Clear**	**Clear**	**Clear**	**Clear**
12		**1.5%**	**Clear**	**Clear**	**Clear**	**Clear**
13	5% Surfactant F	None	Cloudy, gelled, phase separated	-	-	-
14		1.5%	Cloudy, gelled, phase separated	-	-	-

Figure 7A: Biocide Stability and Compatibility at 2 Months Storage.

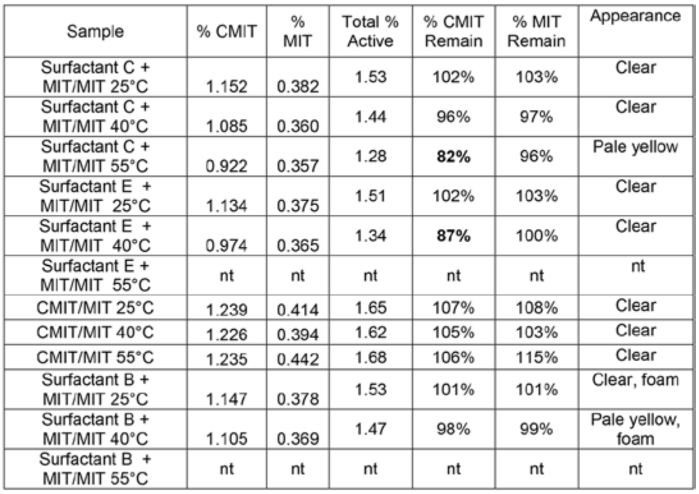


Sample	% CMIT	% MIT	Total % Active	% CMIT Remain	% MIT Remain	Appearance
Surfactant C + CMIT/MIT 25°C	1.134	0.375	1.51	101%	101%	Clear
Surfactant C + CMIT/MIT 40°C	1.140	0.374	1.51	101%	101%	Clear
Surfactant C + CMIT/MIT 55°C	1.075	0.373	1.45	95%	101%	Clear
Surfactant E + CMIT/MIT 25°C	1.132	0.374	1.51	101%	102%	Clear
Surfactant E + CMIT/MIT 40°C	1.123	0.372	1.49	101%	102%	Clear
Surfactant E + CMIT/MIT 55°C	0.174	0.251	0.43	**16%**	**69%**	Yellow ppt
CMIT/MIT 25°C	1.217	0.403	1.62	105%	105%	Clear
CMIT/MIT 40°C	1.186	0.392	1.58	102%	102%	Clear
CMIT/MIT 55°C	1.185	0.392	1.58	102%	102%	Clear
Surfactant B + CMIT/MIT 25°C	1.131	0.374	1.51	100%	100%	Clear, foam
Surfactant B + CMIT/MIT 40°C	1.140	0.376	1.52	101%	100%	Pale yellow, Foam
Surfactant B + CMIT/MIT 55°C	1.081	0.376	1.46	95%	100%	Clear, foam

Figure 7B: Biocide Stability and Compatibility at 3 Months Storage.

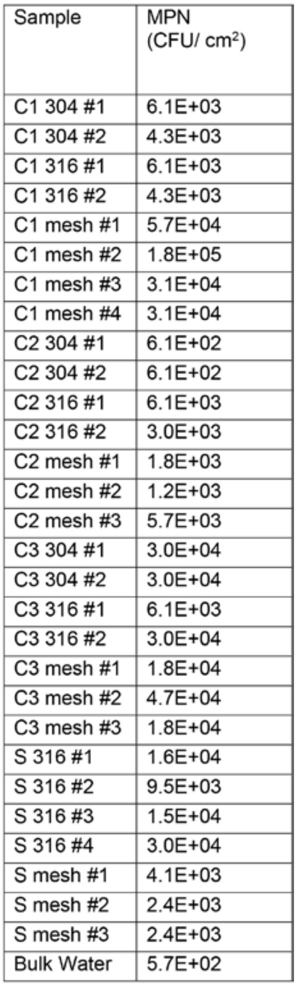


Sample	% CMIT	% MIT	Total % Active	% CMIT Remain	% MIT Remain	Appearance
Surfactant C + CMIT/MIT 25°C	1.137	0.378	1.51	101%	102%	Clear
Surfactant C + CMIT/MIT 40°C	1.113	0.367	1.48	99%	99%	Clear
Surfactant C + CMIT/MIT 55°C	1.057	0.361	1.42	**94%**	97%	Clear
Surfactant E + CMIT/MIT 25°C	1.121	0.370	1.49	100%	101%	Clear
Surfactant E + CMIT/MIT 40°C	1.091	0.364	1.46	98%	100%	Clear
Surfactant E + CMIT/MIT 55°C	nt	nt	nt	nt	nt	nt
CMIT/MIT 25°C	1.212	0.401	1.61	104%	104%	Clear
CMIT/MIT 40°C	1.184	0.391	1.58	102%	102%	Clear
CMIT/MIT 55°C	1.212	0.414	1.63	104%	108%	Clear, pale yellow
Surfactant B + CMIT/MIT 25°C	1.126	0.372	1.50	99%	99%	Clear,
Surfactant B + CMIT/MIT 40°C	1.131	0.374	1.50	100%	100%	Pale yellow, foam
Surfactant B + CMIT/MIT 55°C	1.008	0.399	1.41	**89%**	106%	Yellow



Sample	% CMIT	% MIT	Total % Active	% CMIT Remain	% MIT Remain	Appearance
Surfactant C + MIT/MIT 25°C	1.152	0.382	1.53	102%	103%	Clear
Surfactant C + MIT/MIT 40°C	1.085	0.360	1.44	96%	97%	Clear
Surfactant C + MIT/MIT 55°C	0.922	0.357	1.28	**82%**	96%	Pale yellow
Surfactant E + MIT/MIT 25°C	1.134	0.375	1.51	102%	103%	Clear
Surfactant E + MIT/MIT 40°C	0.974	0.365	1.34	**87%**	100%	Clear
Surfactant E + MIT/MIT 55°C	nt	nt	nt	nt	nt	nt
CMIT/MIT 25°C	1.239	0.414	1.65	107%	108%	Clear
CMIT/MIT 40°C	1.226	0.394	1.62	105%	103%	Clear
CMIT/MIT 55°C	1.235	0.442	1.68	106%	115%	Clear
Surfactant B + MIT/MIT 25°C	1.147	0.378	1.53	101%	101%	Clear, foam
Surfactant B + MIT/MIT 40°C	1.105	0.369	1.47	98%	99%	Pale yellow, foam
Surfactant B + MIT/MIT 55°C	nt	nt	nt	nt	nt	nt

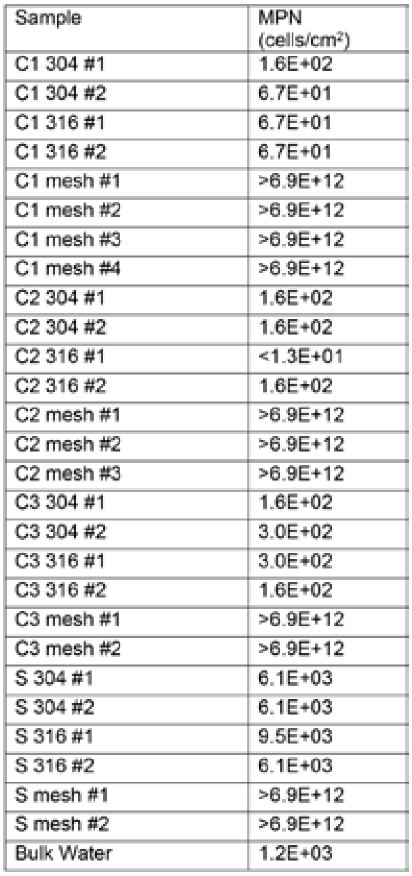
Figure 7C: Biocide Stability and Compatibility at 6 Months Storage.



Sample	MPN (CFU/ cm^2)
C1 304 #1	6.1E+03
C1 304 #2	4.3E+03
C1 316 #1	6.1E+03
C1 316 #2	4.3E+03
C1 mesh #1	5.7E+04
C1 mesh #2	1.8E+05
C1 mesh #3	3.1E+04
C1 mesh #4	3.1E+04
C2 304 #1	6.1E+02
C2 304 #2	6.1E+02
C2 316 #1	6.1E+03
C2 316 #2	3.0E+03
C2 mesh #1	1.8E+03
C2 mesh #2	1.2E+03
C2 mesh #3	5.7E+03
C3 304 #1	3.0E+04
C3 304 #2	3.0E+04
C3 316 #1	6.1E+03
C3 316 #2	3.0E+04
C3 mesh #1	1.8E+04
C3 mesh #2	4.7E+04
C3 mesh #3	1.8E+04
S 316 #1	1.6E+04
S 316 #2	9.5E+03
S 316 #3	1.5E+04
S 316 #4	3.0E+04
S mesh #1	4.1E+03
S mesh #2	2.4E+03
S mesh #3	2.4E+03
Bulk Water	5.7E+02

Figure 8: Biofilm results after three weeks of "background dosing" including twice weekly dosing with 1.5 ppm a.i. CMIT/MIT and once a week dosing with BCDMH.

nd = Not Determined. TNTC = Too Numerous to Count; generally ≥ 10^3 CFU/mL.



Sample	MPN (cells/cm^2)
C1 304 #1	1.6E+02
C1 304 #2	6.7E+01
C1 316 #1	6.7E+01
C1 316 #2	6.7E+01
C1 mesh #1	>6.9E+12
C1 mesh #2	>6.9E+12
C1 mesh #3	>6.9E+12
C1 mesh #4	>6.9E+12
C2 304 #1	1.6E+02
C2 304 #2	1.6E+02
C2 316 #1	<1.3E+01
C2 316 #2	1.6E+02
C2 mesh #1	>6.9E+12
C2 mesh #2	>6.9E+12
C2 mesh #3	>6.9E+12
C3 304 #1	1.6E+02
C3 304 #2	3.0E+02
C3 316 #1	3.0E+02
C3 316 #2	1.6E+02
C3 mesh #1	>6.9E+12
C3 mesh #2	>6.9E+12
S 304 #1	6.1E+03
S 304 #2	6.1E+03
S 316 #1	9.5E+03
S 316 #2	6.1E+03
S mesh #1	>6.9E+12
S mesh #2	>6.9E+12
Bulk Water	1.2E+03

Figure 9: Biofilm results seventy-two hours after dosing with 1.5 ppm a.i. CMIT/MIT and 5 ppm a.i. Surfactant C.

nd = Not Determined. TNTC = Too Numerous to Count; generally ≥ 10^3 CFU/mL.

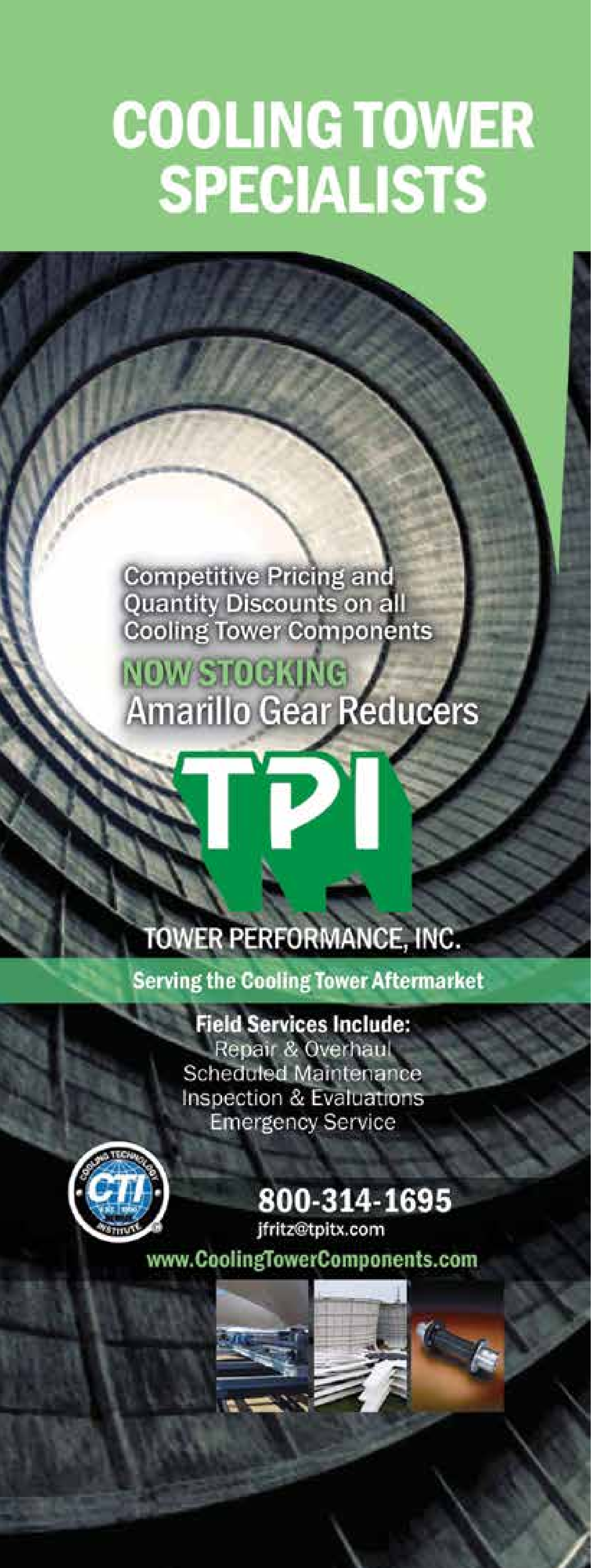


Figure 10: CMIT/MIT Surfactant C formulation causes excessive foaming during field trial testing.

Sample #	Sample	Temp (°C)	Percent Remaining			
			t = 0	t = 1 week	t = 3 weeks	t = 4 weeks
1	CMIT/MIT (no stabilizer)	25	100	101	99	100
2	CMIT/MIT (with stabilizer)	25	100	96	94	95
3	CMIT/MIT+ Surfactant B-1.5%	25	100	99	98	99
4	CMIT/MIT + Surfactant B-3.0%	25	100	102	100	100
5	CMIT/MIT + Surfactant C- 1.5%	25	100	97	98	99
6	CMIT/MIT + Surfactant C - 3.0%	25	100	99	98	98
7	CMIT/MIT + Surfactant D 1.5%	25	Cloudy			
8	CMIT/MIT + Surfactant D - 3.0%	25	Cloudy			
9	CMIT/MIT + Surfactant E 1.5%	25	100	99	98	99
10	CMIT/MIT + Surfactant E 3.0%	25	100	99	97	99
1	CMIT/MIT (no stabilizer)	40	100	97	77	71
2	CMIT/MIT (with stabilizer)	40	100	95	92	95
3	CMIT/MIT +Surfactant B-1.5%	40	100	99	97	98
4	CMIT/MIT + Surfactant B- 3.0%	40	100	100	98	100
5	CMIT/MIT + Surfactant C - 1.5%	40	100	98	98	99
6	CMIT/MIT + Surfactant C - 3.0%	40	100	96	98	98
7	CMIT/MIT + Surfactant D 1.5%	40	Cloudy			
8	CMIT/MIT + Surfactant D - 3.0%	40	Cloudy			
9	CMIT/MIT + Surfactant E 1.5%	40	100	99	93	94
10	CMIT/MIT + Surfactant E 3.0%	40	100	97	93	93
1	CMIT/MIT (no stabilizer)	55	100	85	51	42
2	CMIT/MIT (with stabilizer)	55	100	94	94	95
3	CMIT/MIT + Surfactant B- 1.5%	55	100	Cloudy		
4	CMIT/MIT + Surfactant B - 3.0%	55	100	Cloudy		
5	CMIT/MIT + Surfactant C- 1.5%	55	100	97	97	97
6	CMIT/MIT + Surfactant C - 3.0%	55	100	98	93	94
7	CMIT/MIT + Surfactant D 1.5%	55	Cloudy			
8	CMIT/MIT + Surfactant D - 3.0%	55	Cloudy			
9	CMIT/MIT + Surfactant E 1.5%	55	100	98	96	94
10	CMIT/MIT + Surfactant E 3.0%	55	100	98	95	94

Figure 11: Percent of the total active ingredient remaining after heat aging in each of the CMIT/MIT and surfactant blends.

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	1.5% CMIT/MIT + Surfactant		1.5% CMIT/MIT Microbicide	
Microorganisms	MIC (ppm a.i)	SD (+/-)	MIC (ppm a.i)	SD (+/-)
Pseudomonas aeruginosa (ATCC 15442) and *Staphylococcus aureus* (ATCC 6538)	0.3	0	3	0

	1.5% CMIT/MIT + Surfactant		1.5% CMIT/MIT Microbicide	
Microorganisms	MIC (ppm a.i)	SD (+/-)	MIC (ppm a.i)	SD (+/-)
Pseudomonas aeruginosa (ATCC 15442) and *Staphylococcus aureus* (ATCC 6538)	0.3	0	4	0.86

	1.5% CMIT/MIT + Surfactant		1.5% CMIT/MIT Microbicide	
Microorganisms	MIC (ppm a.i)	SD (+/-)	MIC (ppm a.i)	SD (+/-)
Pseudomonas aeruginosa (ATCC 15442) and *Staphylococcus aureus* (ATCC 6538)	0.3	0	3.5	0.87

Figure 12A: Minimum Inhibitory Concentration of CMIT/MIT + surfactant vs CMIT/MIT Microbiocide against bacteria.

	1.5% CMIT/MIT + Surfactant		1.5% CMIT/MIT Microbicide	
Microorganism	MIC (ppm a.i)	SD (+/-)	MIC (ppm a.i)	SD (+/-)
Candida albicans (ATCC 2091) and *Sacchromyces cerevisiae* (ATCC 18824)	0.06	0	0.45	0

	1.5% CMIT/MIT + Surfactant		1.5% CMIT/MIT Microbicide	
Microorganism	MIC (ppm a.i)	SD (+/-)	MIC (ppm a.i)	SD (+/-)
Candida albicans (ATCC 2091) and *Sacchromyces cerevisiae* (ATCC 18824)	0.045	0	3	0

	1.5% CMIT/MIT + Surfactant		1.5% CMIT/MIT Microbicide	
Microorganism	MIC (ppm a.i)	SD (+/-)	MIC (ppm a.i)	SD (+/-)
Candida albicans (ATCC 2091) and *Sacchromyces cerevisiae* (ATCC 18824)	0.06	0	0.65	0.09

Figure 12B: Minimum Inhibitory Concentration of CMIT/MIT + surfactant vs CMIT/MIT Microbiocide against bacteria.

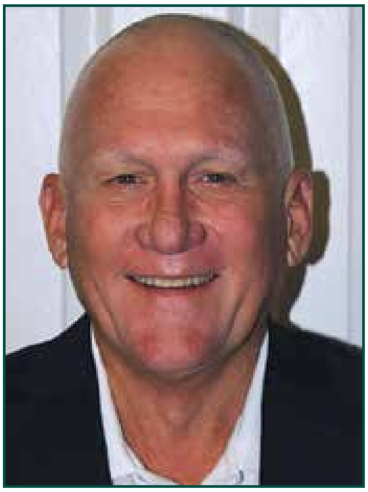
Cooling Water Scale And Corrosion Monitoring

L.J. Aspinall, Aquatech International
Brian Bloxam, Cf Industries

This paper will discuss the results of a field evaluation of a new method of monitoring the performance of cooling water treatment programs using a device which allows modeling of skin temperatures and velocities of process equipment.

The performance of the cooling water system in this ammonia production facility was monitored using Aquatech's patented Test Heat Exchanger Skid over a 46 day exposure period in an effort to compare results obtained by traditional methods of performance monitoring.

Figure #1 is a basic flow diagram of the test heat exchanger skid used during this evaluation.



L.J. Aspinall

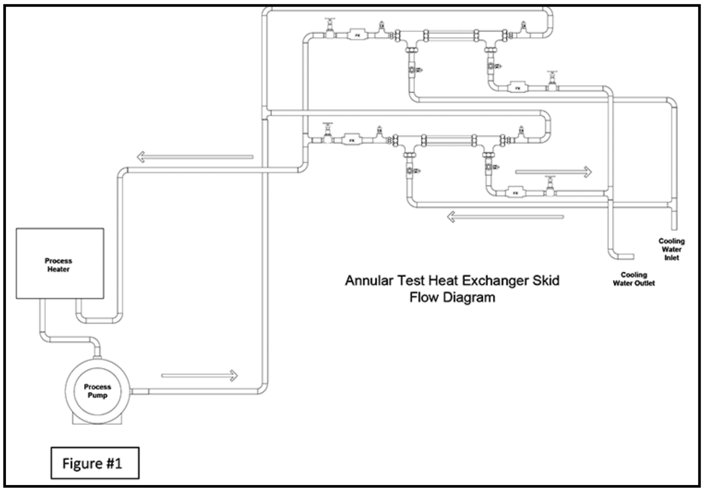


Figure #1

Monitoring Operating Conditions:

The test heat exchanger skid contained two annular exchangers consisting of a ½' OD carbon steel tube inserted in a 1" clear polymer shell. The ½" exchanger tubes were pre-weighed before exposure to the cooling water, similar to a corrosion coupon. The exposed surface consisted of 18" on each tube. Cooling water flowed through the exchanger on the shell side (outside the ½' tube) and process water flowed inside the ½" tube simulating the process and providing the required heat to duplicate the actual skin temperatures of the process equipment. The unique aspect of this annular test heat exchanger is the liquid/liquid nature of the process. Previous types of exchangers like these used an electric heater which could not provide a uniform contact with the metal surfaces and resulted in hot spots and artificial heat transfer conditions.

The objective of this study was to model the velocity and the skin temperature of a critical process exchanger. The test heat exchanger cooling water velocities were set and maintained throughout the exposure period in both exchangers at 4.0-4.5 fps.

We modeled two different skin temperatures. Exchanger #1 was set at the design skin temperature of the process exchanger bundle at 115 deg. F. Exchanger #2 was set at 125 deg. F. skin temperature.

The water treatment company installed new corrosion coupons and corrator probes at the beginning of the exposure period. Coupons were removed and analyzed by the company's lab as were the ½" tubes in the exchangers.

Conclusions:

The current cooling water treatment program is experiencing significant carbon steel pitting in excess of 20 mils due to under-deposit conditions caused by iron phosphate precipitation on the heat transfer surfaces. The results observed in the test heat exchangers has NOT been observed on corrosion coupons or corrators installed during the exposure period or in the past.

Corrosion coupon results on supply and exchanger outlet were 1.32 MPY and 1.9 MPY respectively and corrator readings were less than 2.0 MPY during the exposure period.

It is clear from these results that traditional methods of corrosion monitoring (coupons and corrators) are not capable of identifying the corrosion or scale events that occur in the process equipment due to the lack of actual heat transfer.

This study illustrates the importance of having the ability to simulate actual exchanger conditions to better determine the actual scale and corrosion mechanisms in the cooling water system at skin temperature and velocity.

Exchanger Results:

Following are photos of the tubes before and after cleaning. The material that filled the pits was slightly acidic in a distilled water solution and contained low concentrations of chloride and sulfate, but fairly significant amounts of sulfide.

The pits were undercut and showed evidence of acid corrosion due to ion concentration cell formation. There was no evidence of general acid corrosion damage.

The deepest measured pits were 0.024" (24 mils) on Exchanger #1 tube, and 0.021" (21 mils) on Exchanger #2 tube.

The weight following cleaning was 204.505 grams for Exchanger #1 tube, for a loss of 0.915g. The weight following cleaning was 204.073 grams for Exchanger #2, for a loss of 1.847g.

The corrosion rate calculation based upon weight loss was 1.93 MPY for Exchanger #1 tube and 3.88 MPY for Exchanger #2 tube. This calculation would be considered to be an inaccurate\representation of the actual conditions, since both exchanger tubes experienced localized corrosion to depths > 20 mils.

The coupon results from the past year contained few localized corrosion results and no reported pitting to the extent observed on the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exchanger tubes. The following series of photos illustrate the results observed from both Test Heat Exchangers after the 46 day exposure period.

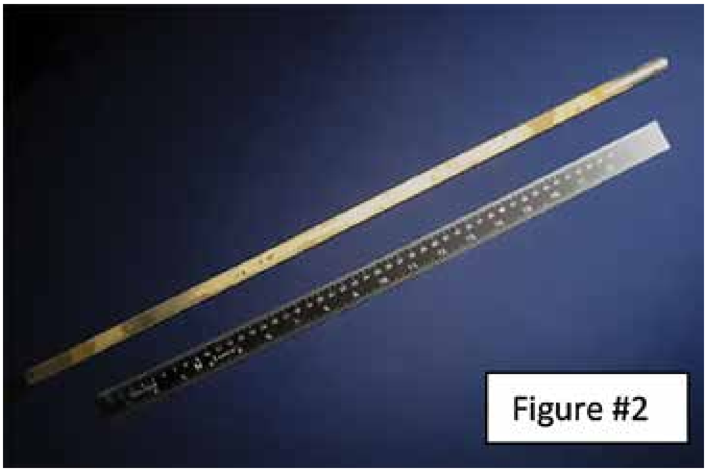


Figure #2


Figure #3

Exchanger #1 tube contained iron phosphate scale and evidence of under deposit concentration mechanism as shown in Figures #2 & #3.

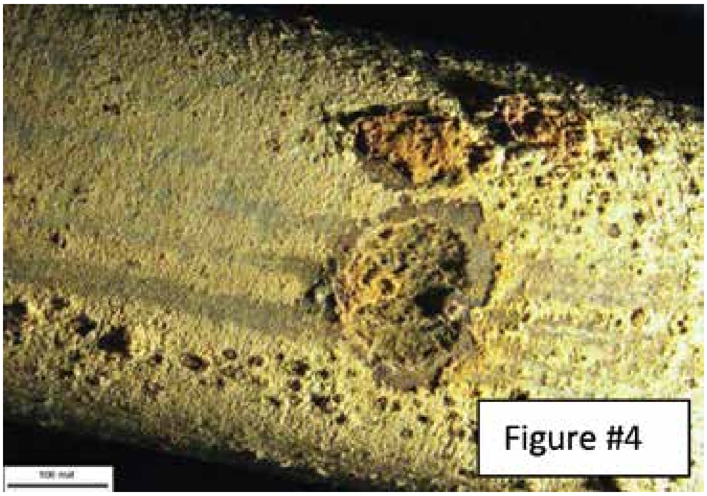


Figure #4

Figure #4 shows under deposit localized metal loss under tubercles before cleaning while Figure #5 reveals >20 mil pits after cleaning of the tube.

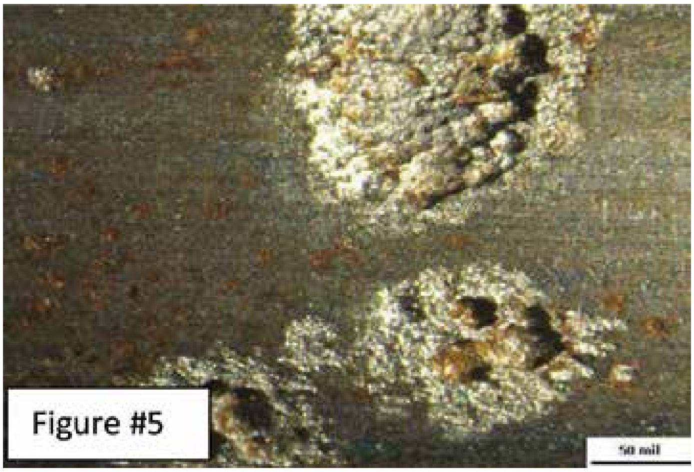


Figure #5

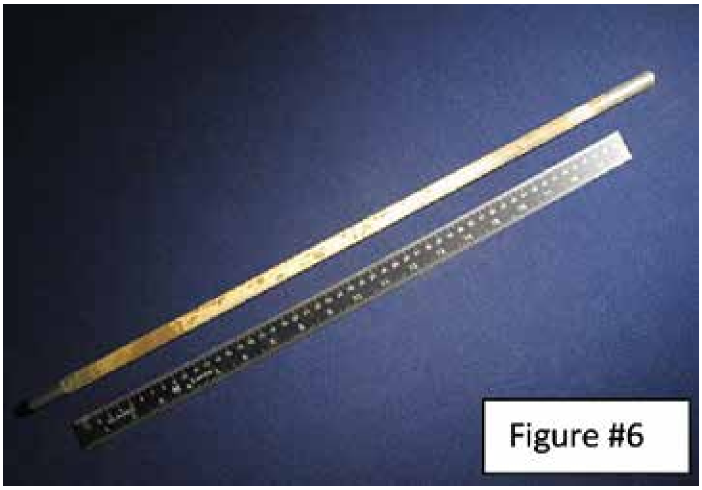


Figure #6


Figure #7

Figures #6 & #7 were taken when Exchanger #2 tube was received before cleaning.

This exchanger was operated at a skin temperature 10 deg. F. higher than Exchanger #1. A thicker deposit of iron phosphate scale was uniformly covering the tube surface, interrupted by iron tubercles from pitting corrosion underneath.

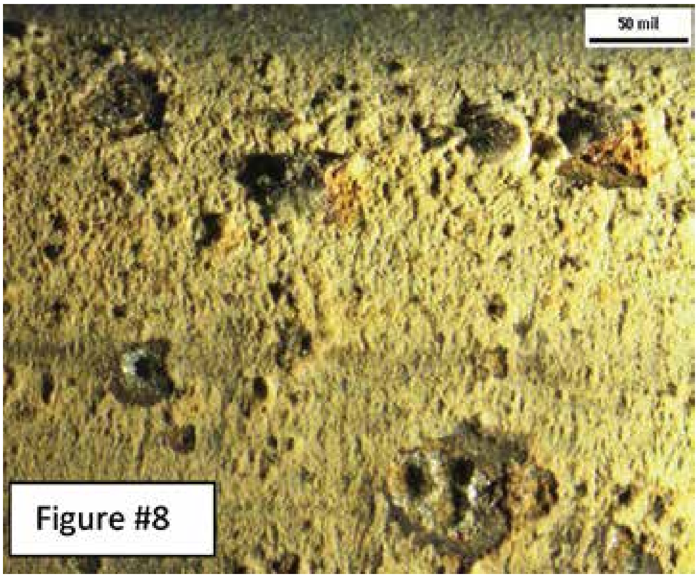


Figure #8

Figure #9

Several deep pits were revealed under the deposits on Exchanger Tube #2 where tubercles were removed as shown in Figures #8 & #9.

Figure #10

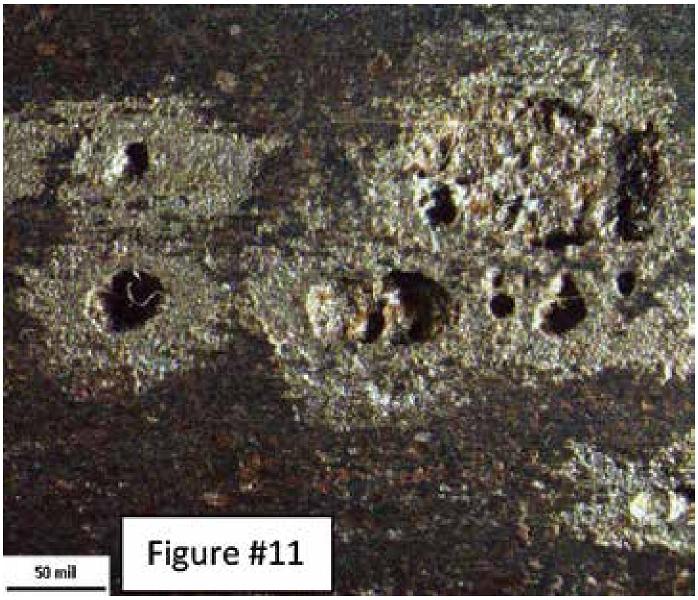
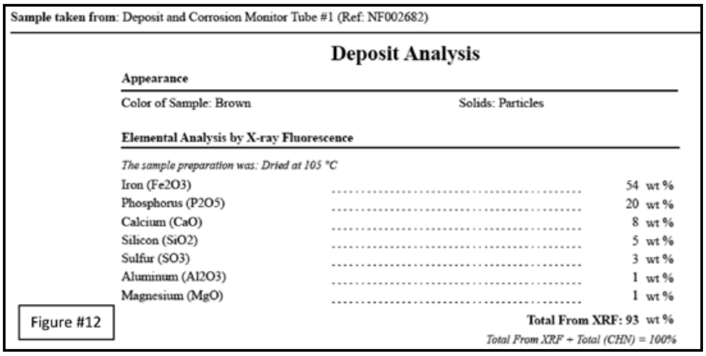


Figure #11

Cleaning of Exchanger Tube #2 revealed widespread pitting throughout the tube surface illustrated in Figure #10 and the most severe pitting of >20 mils shown in Figure #11.

Both exchanger tubes removed from the test heat exchangers following the 46 day exposure period contained mineral scale, observed in the tube photos and discussed earlier in this report. The analysis of this deposit was performed during the tube examination and found to be primarily composed of iron phosphate, described in the deposit analysis results shown in Figures #12 & #13..



Sample taken from: Deposit and Corrosion Monitor Tube #1 (Ref: NF002682)

Deposit Analysis

Appearance

Color of Sample: Brown Solids: Particles

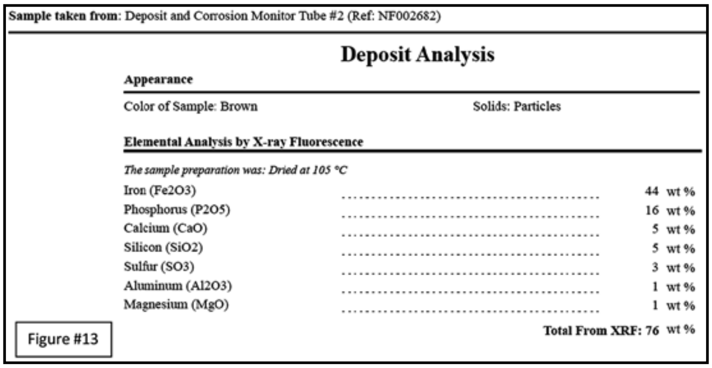
Elemental Analysis by X-ray Fluorescence

The sample preparation was: Dried at 105 °C

Iron (Fe2O3)	54	wt %
Phosphorus (P2O5)	20	wt %
Calcium (CaO)	8	wt %
Silicon (SiO2)	5	wt %
Sulfur (SO3)	3	wt %
Aluminum (Al2O3)	1	wt %
Magnesium (MgO)	1	wt %
Total From XRF:	**93**	wt %

Total From XRF + Total (CHN) = 100%

Figure #12



Sample taken from: Deposit and Corrosion Monitor Tube #2 (Ref: NF002682)

Deposit Analysis

Appearance

Color of Sample: Brown Solids: Particles

Elemental Analysis by X-ray Fluorescence

The sample preparation was: Dried at 105 °C

Iron (Fe2O3)	44	wt %
Phosphorus (P2O5)	16	wt %
Calcium (CaO)	5	wt %
Silicon (SiO2)	5	wt %
Sulfur (SO3)	3	wt %
Aluminum (Al2O3)	1	wt %
Magnesium (MgO)	1	wt %
Total From XRF:	**76**	wt %

Figure #13

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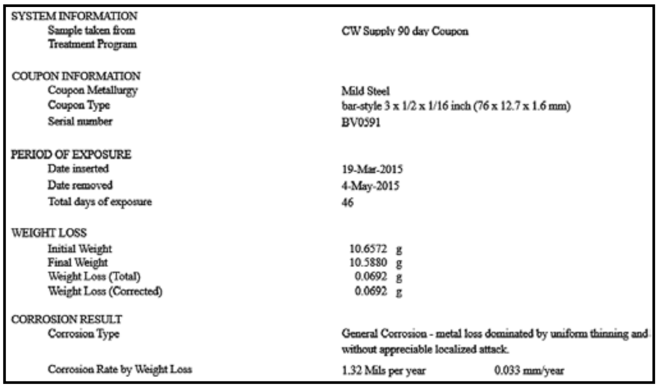
Traditional corrosion monitoring for the same exposure period:

When the Test Heat Exchanger Skid was installed and started the local water treatment representative installed new un-passivated mild steel corrosion coupons as well as new corrator tips. The primary coupon rack is installed on the supply water and therefore is much lower temperature than the process exchangers or the test heat exchangers. There is a rack on the outlet of a process exchanger as well.

The following are the coupon results for the 46 day exposure period for the cooling water supply:

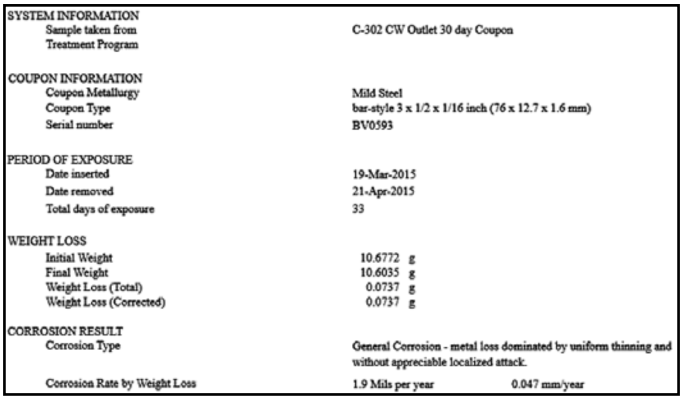


SYSTEM INFORMATION	
Sample taken from	CW Supply 90 day Coupon
Treatment Program	
COUPON INFORMATION	
Coupon Metallurgy	Mild Steel
Coupon Type	bar-style 3 x 1/2 x 1/16 inch (76 x 12.7 x 1.6 mm)
Serial number	BV0591
PERIOD OF EXPOSURE	
Date inserted	19-Mar-2015
Date removed	4-May-2015
Total days of exposure	46
WEIGHT LOSS	
Initial Weight	10.6572 g
Final Weight	10.5880 g
Weight Loss (Total)	0.0692 g
Weight Loss (Corrected)	0.0692 g
CORROSION RESULT	
Corrosion Type	General Corrosion - metal loss dominated by uniform thinning and without appreciable localized attack.
Corrosion Rate by Weight Loss	1.32 Mils per year 0.033 mm/year

Figure #14 Before Cleaning After Cleaning

A general corrosion rate of 1.32 MPY was measured on this coupon shown in Figure #14 and no visible pits or localized metal loss was observed.

The majority of the test heat exchanger exposure period (33 days) was covered by the following coupon result on the outlet of a process exchanger in the operating unit shown in Figure #15.



SYSTEM INFORMATION	
Sample taken from	C-302 CW Outlet 30 day Coupon
Treatment Program	
COUPON INFORMATION	
Coupon Metallurgy	Mild Steel
Coupon Type	bar-style 3 x 1/2 x 1/16 inch (76 x 12.7 x 1.6 mm)
Serial number	BV0593
PERIOD OF EXPOSURE	
Date inserted	19-Mar-2015
Date removed	21-Apr-2015
Total days of exposure	33
WEIGHT LOSS	
Initial Weight	10.6772 g
Final Weight	10.6035 g
Weight Loss (Total)	0.0737 g
Weight Loss (Corrected)	0.0737 g
CORROSION RESULT	
Corrosion Type	General Corrosion - metal loss dominated by uniform thinning and without appreciable localized attack.
Corrosion Rate by Weight Loss	1.9 Mils per year 0.047 mm/year

Figure #15 Before Cleaning After Cleaning

A general corrosion rate of 1.9 MPY was measured on this coupon and no visible pits or localized metal loss was observed. The slightly elevated corrosion rate was due to the higher temperature of this sample point on the outlet of an exchanger.

Another traditional method used during this exposure period was online general corrosion monitoring. The following (Figure #16) is a graphic analysis of the online corrator data collected during the Test Heat Exchanger exposure period. This technology records general corrosion and does not take any specific readings which would indicate the severity of the pitting being experienced. Overall these rates are considered acceptable by most water treatment performance standards.

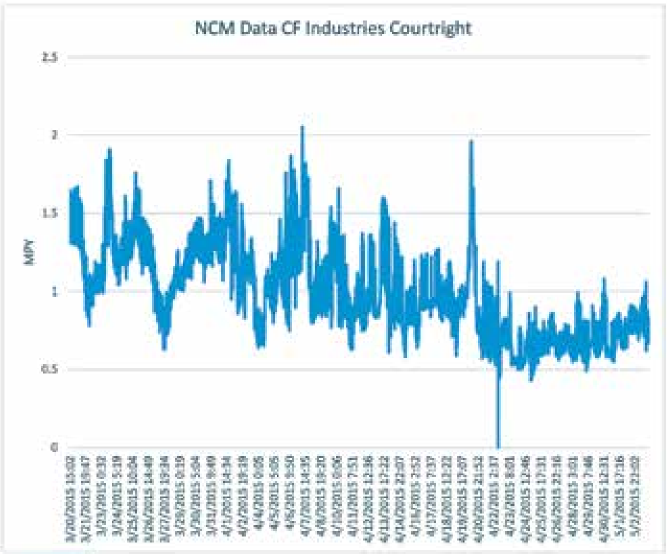


Figure #16

Summary:

The plant has continuously experienced deposition and localized corrosion which was confirmed through the use of the Test Heat Exchanger Monitoring Skid. The traditional methods of corrosion monitoring, coupons and online corrator did not reveal the localized carbon steel metal loss. Monitoring results at skin temperatures and velocity is much more realistic in predicting exchanger performance and reliability.

Acknowledgements:

CF Industries for their participation in the field evaluation of this technology and agreement to co-author this paper.

Nalco Company for their support in metallographic and deposit analysis support.

MODULAR TYPE, FRP TOWER

COUNTER FLOW FRP TOWER

FIELD ERECTED, COUNTER FLOW, PLUME ABATEMENT, CONCRETE TOWER

FIELD ERECTED, COUNTER FLOW, STEEL TOWER

Using ATC-128 For Sound Testing & Verification In The Field

Erik Miller-Klein, SSA Acoustics, LLP

Erik Miller-Klein

Introduction

The current Cooling Technology Institute (CTI) Test Code for the Measurement of Sound from Water-Cooling Towers ATC-128 details test procedures and methods for calculating the sound power level for cooling towers. Over the past 2 years we have been testing the acoustic performance of multiple cooling towers sizes and manufacturers within test stand and field installations conditions using this standard. Through this process some challenges were discovered with respect to the testing and calculation procedures, and opportunities were noted to improve the repeatability, reproducibility, and accuracy of future field measurements using ATC-128.

The current standard for chillers that is comparable to ATC-128 is AHRI 370-2015 Standard for Sound Performance Rating of Large Air-cooled Outdoor Refrigerating and Air-conditioning Equipment. The differences between these test methods and calculations of sound power means that the sound power levels cannot be directly compared to show per ton of cooling capacity cooling towers are usually quieter than chillers. It is suggested that the field conditions be considered to assists users in accurately predicting the noise at nearby receiving locations based on the current published sound pressure levels. This may lead to additional appendices, supplementary documents, or future changes to ATC-128. There have been issues using published sound power data to accurately predict the sound level at adjacent neighbors, which creates noise code issues and has led to environmental noise complaints.

ATC-128 Versus AHRI 370

AHRI 370-2015 Standard for Sound Performance Rating of Large Air-cooled Outdoor Refrigerating and Air-conditioning Equipment provides four methods for evaluating the sound power for chillers and large air-conditioning equipment: 1) laboratory tests in reverberation room with reference sound source (RSS), 2) laboratory tests in hemi-anechoic room, 3) indoor or outdoor tests in qualified free field areas, or 4) sound intensity for the entire unit.

The methods that would be the most practical for comparing cooling towers directly to air-cooled chillers per AHRI 370, would be method 3 measuring sound pressure levels using engineering methods for an essentially free field environment over a reflecting plane per ISO standard 3744 (also referenced as ANSI S12.54) or method 4 measuring sound intensity per AHRI 230. Method 3 is the closest to the current test setup specified for ATC-128. ISO 3744, Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for an essentially free field over a reflecting plane, defines the measurement area as a parallelepiped that just encloses the source under test similar to the sketch shown in Figure 1. These measurement procedures state that the measurements should be completed around the entire unit at a distance of at least 1-meter (3.3-feet) or more, and the sound power level is calculated as a factor of the average sound pressure level corrected for the total surface area measured for the parallelepiped around the unit, shown in Equation 1. This method includes a similar correction for background noise, and is best suited for controlled testing by manufacturers as part of the initial validation and certification. This type of test could be completed as part of the testing to satisfy ATC-128, and would provide a good direct reference of comparison to air-cooled chillers. This would allow cooling towers to be directly compared to chillers with respect to noise.

$$L_W = \overline{L_p} + 10 \lg \frac{S}{S_0} \text{ dB}$$

where

S is the area, in square meters, of the measurement surface;

S_0 = 1 m^2.

Equation 1: Sound Power from Surface Sound Pressure Level

This testing standard and sound power calculation is based on the same equations and concepts. Though the assumptions from Appendix G in ATC 128 for sound power notes that for small towers the emission surface is equally split between each of the five measurements positions. This means that the total sound power assumes that each measurement position is one fifth of a hemisphere.

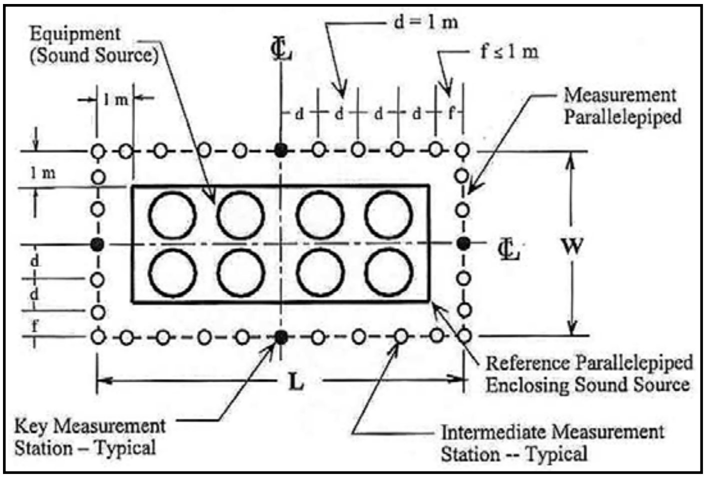


Figure D1. Plan View of Measurment Parallelepiped

The fourth method described in AHRI 370 using sound intensity requires a sound intensity wand, which uses two microphones in-phase and parallel to measure sound as a vector, with both amplitude and


IDEXX

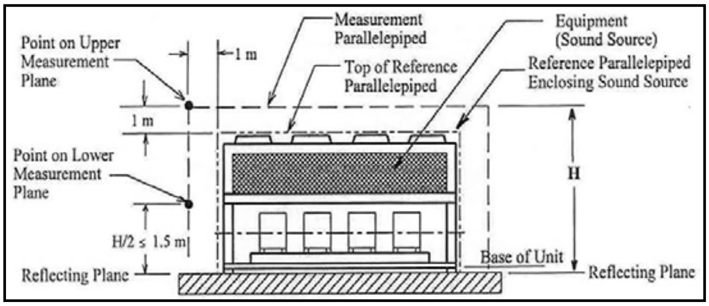


Figure D2. Elevation of Measurment Parallelepiped

direction. This measure allows the user to accurately measure and calculate sound power for a single cooling tower or portion of a tower in the context of other noise generating equipment. The standard notes that the background noise should not be greater than the direct sound from the equipment under test, while with the other free field measurements the background noise must be at least 6 dB less than the noise generating source. The measurement procedures also require a scan or point measurements over a fully enclosed parallelepiped of the cooling tower. The biggest challenge with this method is instrumentation and test operator skill, the AHRI standard states that every 30 days the operator shall be verified using a Reference Sound Source (RSS) or other successful measurements.

After reviewing these standards side-by-side, additional in-depth noise testing using the AHRI methods should be completed in cooperation with cooling tower manufactures, for multiple manufacturers, to determine how well these standards coincide. Without completing these tests across multiple brands, the relevance of the results would not ensure changes will improve ATC-128. Once these standards are compared using the AHRI 370 and ATC-128 methods and procedures. These results can assist manufacturers show the noise differences between cooling towers and chillers. This does not circumvent the current data at 50-feet, which is very valuable because it gives engineers directional sound data for each side of towers. This data can be used effectively to more accurately estimate sound emission levels at nearby receiving locations, which is an advantage over the published data for chillers per AHRI 370.

Calculating Sound Power from Sound Pressure

Through field tests and computational analysis the predicted sound power level per ATC-128 was consistently lower than back calculated value based on field tests of noise at property lines or around test stands. This is due to the calculation of total surface area from ATC-128 original Appendix G and the actual radiation of sound from a standard cooling tower.

The correction factor for ATC-128 is based on splitting the tower into 5 equal portions of a 50-feet radius hemisphere. Though based on our field experience and site sound testing the main fan or fans for most cross and counter flow fans act as a hemispherical sound source above the tower, and the inlet side(s) demonstrate hemispherical behavior for a receiving point at ear height on the ground, which more closely relates to a surface area of a cylinder. For towers that have exceeded noise code to adjacent receivers that have a higher elevation than the cooling tower, the sound propagation has closely matched the expected hemispherical radiation from the outlet fan alone.

Based on our analysis the 50-feet (15-meter) measurements provide a great reference level to use to accurately predict sound emission to adjacent properties. Though the 1/5 hemisphere sound power calculation with these values underestimates the total sound power level for the cooling tower. The common receiving locations with respect to cooling towers tends to be above the tower, or parallel to or below rooftop mounted units. Based on the location of the sources and the shape of most cooling towers the radiated surface area used in Equation 1 should be a cylinder for the inlet and casing portion of the tower and hemisphere for the top fan. For sound sensitive receivers above the cooling tower the outlet fan is a hemispherical sound source. Figure 2 represents a schematic of the proposed cylinder and hemispherical radiation combination. This performance has been verified during some field and test stand measurements at distances of 5-feet, 10-feet, 15-feet, 25-feet, and 50-feet.

The suggestion is a surface area calculated as a cylinder below the height of the top the tower at 50-feet (15-meters) and a hemisphere above the top of the tower at 50-feet (15-meters). This adds about 3.6 dB to the sound power level depending on where the 50-feet (15-meter) radius starts for each cooling tower (center versus face).

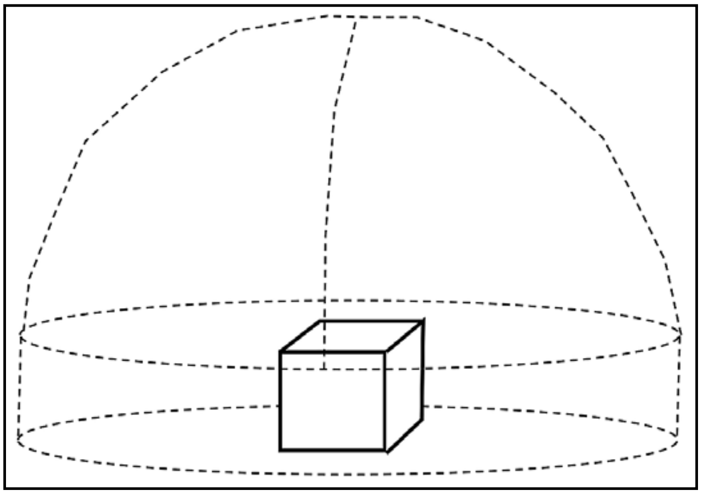


Figure 2

	L_p, dB	r_H, m	S, m^2	10logS	L_w, dB
1	61	15	282.7	24.5	85.5
2	58	15	282.7	24.5	82.5
3	62	15	282.7	24.5	86.5
4	58	15	282.7	24.5	82.5
5	64	15	282.7	24.5	88.5
Total	68.2		1,413.7	24.5	92.7

Figure 3: Example G.3 from Appendix G of ATC-128

	L_p, dB	**r_H, m**	**S, m^2**	**10logS**	**L_w, dB**
1	61	15	131.3	21.2	82.2
2	58	15	131.3	21.2	79.2
3	62	15	131.3	21.2	83.2
4	58	15	131.3	21.2	79.2
5	64	15	1,413.7	31.5	95.5
Total	68.2		1,939.1		96.1

Table 1: Example Sound Power Using Alternate Surface Area

Reference Measurement Distance

During recent field and test stand acoustical tests additional investigations were completed to determine what options were feasible for measuring cooling towers in elevated background noise environments. This involved measuring the sound pressure level at the standard distances of 5-feet and 50-feet for small towers, and measuring the performance at 10-feet, 25-feet, 75-feet and 100-feet for the inlet and casing, and 25-feet for the outlet for test stand erected cross-flow towers. The following tables present some examples of the data collected to note the measured decibel difference due to distance, compared to the predicted decibel difference assuming hemispherical radiation in a free field.

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Cross-Flow	Sound Pressure Level, dBA										
HP	5' Inlet	25' Inlet	50' Inlet	100' Inlet	5' Casing	25' Casing	50' Casing	100' Casing	5' Outlet	25' Outlet	50' Outlet
30	84.0	76.8	69.0	63.2	78.9	72.4	68.6	63.9	88.8	81.9	77.5
Measured dB difference		7.2	7.8	5.8		6.5	3.8	4.7		6.9	4.3
Predicted dB Hemispherical		14.0	6.0	6.0		14.0	6.0	6.0		14.0	6.0

Table 2: Test Stand (Manufacturer A)

Cross-Flow	Sound Pressure Level, dBA									
HP	5' Inlet	10' Inlet	25' Inlet	50' Inlet	100' Inlet	5' Casing	25' Casing	50' Casing	75' Casing	100' Casing
30	81.0	79.7	73.6	66.4	60.2	73.1	67.6	64.3	61.0	59.2
20	75.9	73.3	68.9	62.2	55.9	67.7	62.9	59.2	57.1	55.0
10	71.4	69.4	63.6	57.7	51.4	64.0	58.1	56.4	52.5	53.6
Avg Measured dB difference		2.0	5.4	6.6	6.3		5.4	2.9	3.1	0.9
Predicted dB Hemispherical		6.0	8.0	6.0	6.0		14.0	6.0	3.5	2.5

Table 3: Test Stand (Manufacturer B)

Cross-Flow	Sound Pressure Level, dBA									
HP	5' Inlet	25' Inlet	50' Inlet	100' Inlet	5' Casing	25' Casing	50' Casing	100' Casing	5' Outlet	50' Outlet
60	79.9	75.1	70.3	63.4	70.1	66.5	63.6	60.3	87.5	75.7
50	79.3	74.6	69.7	63.1	69.3	65.8	62.9	59.7	87.1	75.5
40	78.2	73.3	68.4	61.8	68.5	64.7	61.8	58.6	85.7	74.3
30	74.9	70.3	65.2	58.6	64.9	61.0	58.2	55.0	82.0	70.2
20	72.5	67.8	62.7	55.9	63.1	59.0	55.9	52.6	79.2	67.8
15	69.9	64.9	59.8	53.4	60.4	55.7	52.5	50.2	75.1	64.3
Avg Measured dB difference		4.8	5.0	6.7		3.9	3.0	3.1		11.5
Predicted dB Hemispherical		14.0	6.0	6.0		14.0	6.0	6.0		20.0

Table 4: Test Stand (Manufacturer B)

The measured difference between 5-feet and 25-feet was consistently 50% less than the values would be predicted for a free field hemispherical radiation of 6 dB per doubling of distance, though this is not surprising because these are in the near field. The measured difference between 10-feet and 25-feet, which based on hemispherical point source radiation should be 8 dB of reduction, was usually 4 dB to 6 dB for inlet. The measured difference between 25-feet and 50-feet was 4 dB to 7 dB for the inlet and outlet and 3 dB to 4 dB for the casing side.

The distance of 25-feet is greater than half of one wavelength for 50 Hz, the lowest 1/3-octave band currently evaluated as part of the ATC-128 standard. Based on these, using 25-feet as an alternative reference distance is a feasible option for field measurements where background noise is a contributing factor. This distance can also be considered for casing even though the sound decay does not follow the characteristics of a point source in a hemispherical condition. This is likely due to the panel radiated sound from the casing that makes this similar to a plane wave or linear sound source, which could be noted in the future to assist engineers with accurate predictions from casing radiated noise, though in our experience the casing side is generally 6 dB or more quieter than the inlet and discharge of the cross flow cooling towers that were evaluated as part of this analysis.

Conclusion

Based on the results obtained to date, the best ways to use ATC-128 sound data is using the 50-feet sound pressure level data, rather than the sound power data. To ensure reproducible results for ATC-128 users' additional documentation should be considered to provide a best practices guide for using published sound data. Completing accurate estimates of sound emission at receiving properties includes factors associated with distance, topography, and equipment installation conditions. The published sound levels at 5-feet, 50-feet and sound power ratings for all towers do not clearly guide users' on which values will provide the most accurate predictions. In our experience the sound power value measured versus predicted has been as much as 7 dB louder at the property line. This is a major issue that should be considered when using the calculated sound power values for small towers noted in ATC-128. Through testing the feasibility of measuring the radiated noise at 25-feet was compared to 50-feet, which showed reasonable accuracy to be considered an option for field tests completed for locations with higher background noise levels.

Polyvinyl Chloride in Cooling Towers

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Ken Mortensen

Introduction

Polyvinyl Chloride (PVC) is a unique material in cooling tower history. It has been used for many and varied components over a long period of time. This paper is intended primarily as a discussion of the suitability and history of Polyvinyl Chloride material in evaporative cooling systems. What material properties are important to proper application? What are its limitations? These questions will be explored in this paper.

Polyvinyl Chloride, PVC, has been an important evaporative cooling tower material for nearly 50 years. PVC would seem to be well suited to the evaporative cooling environment. It is inert in water and thus resistant to the varied environments presented in a cooling tower: basin immersion, splash zone, and the 100% relative humidity plenum. It has good initial strength and predictable properties in service. “[PVC] is the second most important polymer”(1) in general industry, behind polyethylene, and therefore available at good value to cooling tower manufacturers and owner/operators.

PVC application as fill, both splash and later film, and other components, such as eliminators, piping, and even casing, has been important to the growth of the cooling tower industry. These component’s functional efficiencies and their costs are fundamental to the economics of cooling systems. This paper documents the history of PVC application development and discusses PVC’s important material properties, testing, and application standards for the evaporative cooling tower market.

PVC in Cooling Tower History

During the 1950’s, the development of new chemicals and polymers was a major thrust in the industrial expansion in the United States and Europe. New “plastics” were being synthesized, molded, tested, and applied in many applications. Ideas originated in the 1950’s include, the first plastic Coke bottle, vinyl (PVC) records, polyester fiber for clothing, and the invention of polypropylene (PP) for injection molded parts like spray nozzles.(2)

In 1959, H. H. Branine of Marley, stated in his article “Why Plastics in Cooling Towers?”, that “conventional cooling tower materials undergo continual deterioration in service. The wood is attacked by microbiological organisms. Metals are subject to corrosion…(i)n a constant battle to improve service life economically, cooling tower manufacturers recently have been investigating plastics.”(3)

Some extended excepts from John Nelson’s paper “Plastics and the Marley Cooling Tower Company”,(4) present an inside view of plastic component development in the cooling industry.

> The Marley Cooling Tower Company pioneered the use of plastic components in cooling tower construction. Marley engineers early recognized the unique, useful properties of plastics, particularly as they related to cooling tower environments. [page 1] (4)
>
> GRP [glass reinforced polyester] and polypropylene were the work horses in the plastics area for many years and were the dominant materials until the use of PVC began in earnest around 1970. [page 1] (4)
>
> Polyvinyl chloride became commercially available just prior to World War II. In 1945, world production was 50,000 metric tons and by 1955 the figure had grown to 520,000 metric tons. PVC has been the second most used thermoplastic exceeded only by the polystyrenes. The popularity of PVC (is) the result of low cost, versatility, physical, chemical and weathering properties and inherent fire-retardance. [page 14] (4)
>
> When properly formulated, PVC is eminently suited to most cooling tower applications. [page 14](4)
>
> Through 1986 approximately 78 million pounds of PVC had been used in Marley cooling tower components. Of this quantity 61 million pounds were in sheet products with the remaining 17 million pounds in extrusions. A large percentage of this PVC is still in service. [page 18] (4)

According to the Vinyl Institute, PVC “(c)onsumption in 2007 in the United States and Canada amounted to over 6.4 million metric tons, or almost 14.2 billion pounds.”(5)

Historically, use of PVC in Cooling Tower components started with splashbar in 1968, and later included crossflow film fill in 1970, counterflow film fill in 1979, and eliminators in 1982. (4) Installations containing these components include base-load power, chemical process, refining, metals and mining, pulp and paper, gas separation, agricultural processing, geothermal power, high tech manufacturing, data center, hospital, commercial, and comfort cooling. Tower conditions include exposure to high and low pH, and high temperatures, up to 120 degF (48.9 degC). Other exposures include brackish water, seawater, and sewage effluent applications.(6)

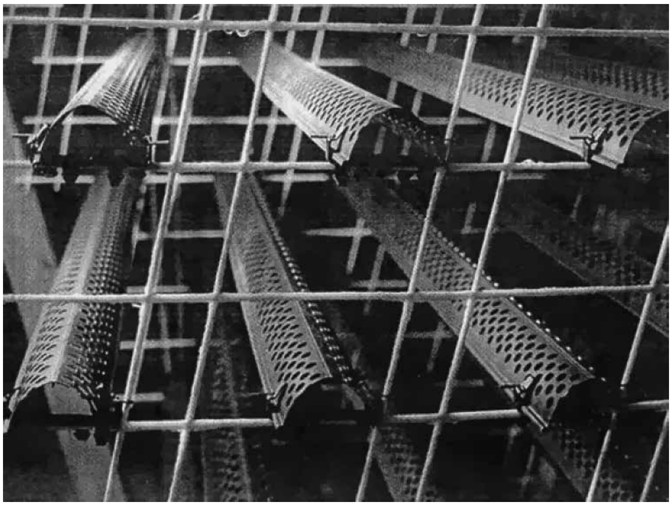


Figure 1: Omega Splashbar(7)

Splashbars were the first cooling tower component made with PVC. Bars were and are extruded in a variety of shapes and profiles, some with perforations and some without. Figure 1 shows Omega Bar, an industry workhorse splashbar. Figure 2, below, is an illustration of V-Bar manufactured and installed in many 70's and 80's era cooling towers. This design was later replaced by designs like Omega Bar.(7)

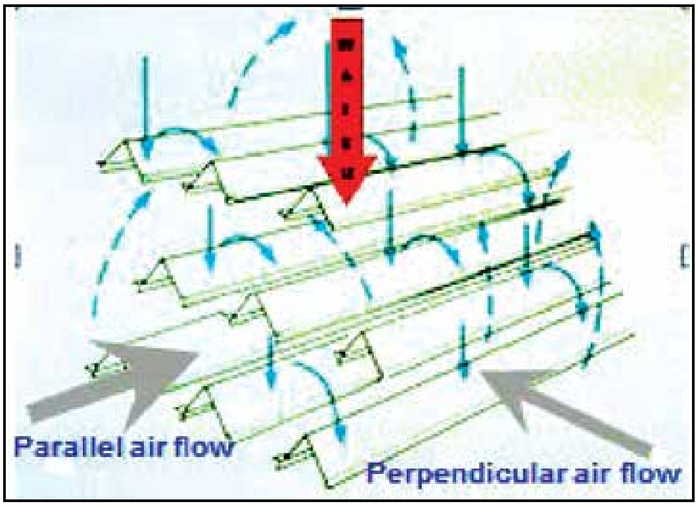


Figure 2: V-bar(7)

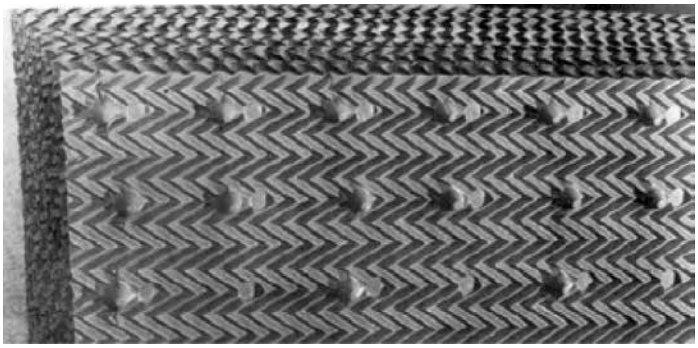


Figure 3: M-106 Crossflow Film Fill(7)

Within a few years, the original crossflow film fills were converted to PVC designs. Figure 3 is an early PVC film fill, M106, from the mid-1970's. PVC in these film fill applications replaced durable resin and fiber sheet products. PVC was well suited to form the intricate original shapes.(7)

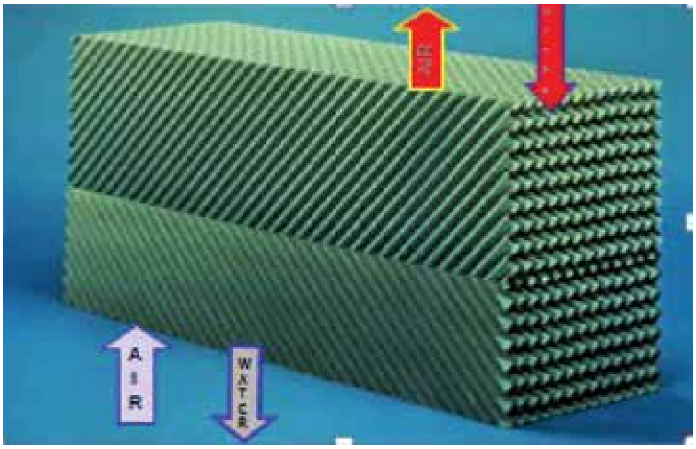


Figure 4: MC67 Counterflow Film Fill(7)

Counterflow film fills were the next component to be designed in PVC in the late 1970's. Figure 4 shows an MC67 pack introduced in 1979. This type of fill was used in many tower installations including the 1981 California tower described later in this paper.(7)

Material Description

PVC chemically is a vinyl, defined as containing the vinyl bond group {CH_2=CH-}. "The factors responsible for the rapid growth of PVC are considered to be: 1) low cost, 2) the ability to be compounded..., 3) good...properties, 4) utility..., and 5) processability..."(1). Several of these material properties of PVC are discussed in more detail below. Properties are grouped into two general categories: Functional and Reference/Mechanical.

Functional PVC Properties

Processability – Properly compounded, PVC is an ideal material for the thermoforming process, one of the main manufacturing processes for cooling tower parts. In a thin film, PVC accepts heat, applied via infrared heaters efficiently, while maintaining its tensile properties for the vacuum-forming of intricate shapes. PVC does not melt at these thermoforming temperatures and therefore processing can be configured to avoid folding, or dragging on mold surfaces. Many of the cooling tower shapes may not be producible by other processes. These large formed PVC parts provide the essential air-water interface for evaporative cooling towers. Controllable stretch is critical to making large parts free of defects. The necessary processing properties of this material are pinpointed using raw material QC evaluations, such as film shrink in the roll length and machine directions, so that acceptable raw stock is consistently provided to the manufacturing process.

Physical Properties – The properties of PVC are a function of PVC viscosity/molecular weight, compounding, and the additives chosen for a specific PVC formulation. Lower melt viscosity PVC "permits intimate mixing, resulting in the development of maximum physical properties and permitting high processing rates."(5) This creates the best results for that lower molecular weight PVC, but use of lower molecular weight PVC and shorter chains, the backbone of the polymer, limits the "best" overall properties available for the mix. High melt flow PVC, on the other hand, can be difficult to process. Balancing molecular weight and processability is the key to PVC use for applications like thermoformed film fill sheets. It is important for the cooling tower manufacturer to have substantial experience and have performed significant qualifying testing for the material in each fill application.

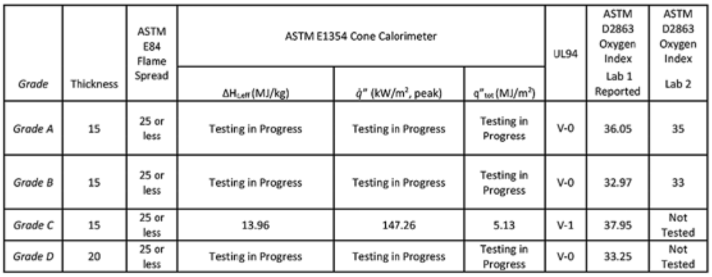
Essential PVC Attributes

Load Bearing – The ability of PVC to withstand the physical load imposed in a fill application is important and reflects several basic reference properties of the material described later in this paper. These include tensile and flexural strength and modulus of elasticity (stiffness). Design properties must first be delineated and then verified by both standardized testing and application testing. Full sized film fill testing for each new application is required, at least initially, to determine the temperature, water loading, and support spacing requirements for a given cooling tower film fill product. Small-scale part exposure at realistic and correlated application conditions can be developed by competent designers. Several acceleration factors, such as high temperature and/or high water loading can be employed to rapidly define long-term film fill behavior at lower operating loads and temperatures. Many of these tests are proprietary to the cooling tower manufacturer.

Impact Strength – Impact strength is a measure of material resistance to rupture or shatter and is an important property in minimizing PVC part damage in service. This parameter will vary widely for different PVC formulations. Impact testing using the Gardner method described in ASTM D-4226, Procedure B, is recommended for verification and monitoring of this property. A specified value of 1.2 inch-pounds/mil of PVC thickness provides excellent long-term durability for cooling tower parts.

Flammability – There are many ways to measure flammability, a number of which are discussed here. Reduced flammability is important to avoid loss of process cooling equipment and tower damage in service. "PVC is inherently non-burning because of the high chlorine content."(1) Its natural fire resistance can be characterized using a number of testing techniques. Customer specifications should include one or more of the test requirements listed below:

1. Flame Spread Index (Tunnel Test), ASTM E84 – This test measures the distance flame travels down a horizontal tunnel loaded with a flat piece of subject plastic. Historically this test has been used often to characterize a particular PVC formulation's flammability. While not specifically designed for testing cooling tower film fill material, if used consistently on standard thickness flat continuous PVC without extraneous support material, it is a very useful gauge of PVC flammability. A long-time standard for PVC materials has been a Flame Spread Index of 25 or less as evaluated by ASTM E84.
2. Oxygen Index (OI), ASTM D2863 – This test measures the minimum oxygen percentage in a nitrogen and oxygen gas stream required to support material combustion in a vertical position. This test seems to be a pure material flammability test. PVC formulation flammability is a component in evaluating the flammability of a tower configuration. Typical OI numbers for PVC formulations often used in cooling tower components need to be developed to characterize the proper range of values for effective cooling system materials.
3. Flammability of Plastic Materials, UL 94 – This test classifies plastics by their burn characteristics in various orientations. Fire retardant materials will generally yield one of the vertical burn ratings. This test combines burn time and drip characteristics of the plastic tested. This test seems to be a combination of a material flammability and a melt characteristic test.
4. Heat and Smoke Release Rates Using an Oxygen Consuption Calorimeter – This test determines the heat contribution of a material to a fire. The test yields multiple results including ignitability, heat release rate, mass loss rate, effective heat of combustion, and smoke generation. Here, $\Delta H_{c,eff}$ = Effective heat of combustion is defined by ASTM as the amount of heat generated per unit mass lost by a material, product or assembly, when exposed to specific fire test conditions; $\dot{q}''$ = Heat release rate per unit area, ASTM defines this as, the heat evolved from the specimen, per unit of time, and q''_{tot} = Total Heat Released, which ASTM defines this as, the complete heat evolved from the specimen over the duration of the test.



Grade	Thickness	ASTM E84 Flame Spread	ASTM E1354 Cone Calorimeter			UL94	ASTM D2863 Oxygen Index Lab 1 Reported	ASTM D2863 Oxygen Index Lab 2
			$\Delta H_{c,eff}$ (MJ/kg)	$\dot{q}''$ (kW/m², peak)	q''_{tot} (MJ/m²)			
Grade A	15	25 or less	Testing in Progress	Testing in Progress	Testing in Progress	V-0	36.05	35
Grade B	15	25 or less	Testing in Progress	Testing in Progress	Testing in Progress	V-0	32.97	33
Grade C	15	25 or less	13.96	147.26	5.13	V-1	37.95	Not Tested
Grade D	20	25 or less	Testing in Progress	Testing in Progress	Testing in Progress	V-0	33.25	Not Tested

Table 1: Flammability Test Results for Cooling Tower PVC's

Values for several of the flammability tests are given in Table 1. The PVC grades that were fire tested for this paper varied, but are grades commonly used in the cooling tower industry. The sample thicknesses varied to a limited degree, but are thicknesses commonly used in cooling tower components. The ASTM E84 Flame Spread test is a commonly known combustion standard in the cooling tower segment. Flame Spread results are given for the four grades of PVC. Cone Calorimeter testing is very complex, results are stated as multiple parameters that vary substantially, and difficult to normalize for different PVC grades. UL94 testing is a rough measure of PVC burn characteristics. ASTM D2863 Oxygen Index seems to focus specifically on the ability of the material grade to support combustion. It is fairly consistent lab to lab. With a properly selected specification requirement this test seems functional. Recommended tests for inclusion in CTI STD-136 are Flame Spread Index at 25 or less for historic reasons and Oxygen Index at 30 minimum.

Ultra Violet Light Resistance – This material attribute is difficult to define, test, and simulate in samples that are representative of a full-sized cooling system component. Cooling Towers are not aesthetic products and testing based on visual criteria is not relevant to the strength/durability properties the customer seeks in cooling systems. The practical effect of UV exposure is impact strength reduction of the plastic. Impact testing described above provides for the customer need - a stable long-term product. Monitoring tower components over time in the installed cooling systems is needed to track component capability. Accelerated testing can be a helpful comparative means of determining the relative UV resistance of a PVC material. Recommended UV operating procedure is ASTM G-154.

Recyclability –Recycling is a characteristic many customers desire in industrial products today. "PVC is one of the most recyclable of polymers…" available.(8) PVC plant extrusion and thermoforming processes produce significant re-usable material. PVC material for cooling tower components can therefore originate as plant offal from these more sensitive and aesthetic processes. Critical to cooling tower use of this recycled material is verification of component function. The properties of this re-use plastic critical for the specific component application must be tested. See Physical Properties Section above. Use of virgin PVC material does not guarantee appropriate properties. Proper compounding, processing, and test standards will ensure suitability.

Cost – Because PVC is in such common use and is highly recyclable, it offers commodity plastic pricing levels for functional cooling tower products. It is simply a good value when one considers the property requirements of the components in cooling towers.

"Life cycle assessment (LCA) and environmental impact – LCA is used in green building to evaluate and compare building materials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and assemblies based on measurable indicators of environmental impact. Since the late 1980s, dozens of life cycle evaluations have been completed on PVC building products, which were found to perform favorably in terms of energy efficiency, thermal insulating value, emissions of greenhouse gases and product durability. Recent life-cycle studies show the health and environmental impacts of vinyl building products generally are comparable to or less than the impacts of alternatives."(8)

"Safety – A substantial volume of research and over 50 years of experience, support the fact that PVC can be safely used even in the most sensitive of applications (such as medical devices)."(1) "Contrary to some popular belief, vinyl does not harm the atmosphere. Once chlorine is processed into vinyl, it is chemically locked into the product more tightly than it was in salt. When vinyl is recycled, landfilled, or disposed of in a modern incinerator, chlorine gas is not released into the atmosphere."(9)

Reference/Mechanical Properties

The following Reference/Mechanical PVC Properties support the Essential PVC Attributes listed in the previous section. They are indicative of good grade PVC material, can be used to compare PVC material grades for relative function, and therefore can be used as a Quality Control proxy by specifiers for more detailed component testing that may be proprietary and not specifiable. Users will find these properties quite useful for insuring tower quality. A description and the current CTI STD-136 value are provided for each category.

- Tensile Strength – Tensile strength is the axial force necessary to pull a coupon apart pulling end-to-end.(10) This is an important indicator of material strength and therefore quality material.
- Flexural Strength – Flexural strength is the force necessary to fail a coupon with a transverse bending force applied between two supports. The bending force creates both tensile stress at the convex surface and compressive stress at the concave surface, as well as internal shear stress.(10) This is an important indicator of material strength and therefore quality material.
- Flexural Modulus – Flexural modulus of elasticity is an important indicator of material stiffness capability and therefore material quality. Modulus "is the ratio of stress to strain below the proportional limit of the material"(10) in a flexural test.
- Heat Deflection Temperature – Heat Deflection Temperature (or Deflection Temperature Under Load) is one of the important indicators of material capability and therefore material quality. It "shows the temperature at which ...deflection occurs under established loads."(10)

Table 2 lists the current Mechanical/Reference values from CTI STD-136 for Tensile Strength, Flexural Strength, Flexural Modulus, and Heat Deflection Temperature. These are important numbers that should be retained in any revised standard.

MINIMUM PROPERTIES	ASTM TEST METHOD	PVC, (MIN. VALUES)
Tensile Strength at yield	D638/D882	5,500 psi (37.9 MPa)
Flexural Strength	D790	10,000 psi (68.9 MPa)
Flexural Modulus	D790	350,000 psi (2413 MPa)
Heat Deflection Temperature at 264 psi (1.82 mPa)	D648 (annealed)	160°F (71°C)

Table 2: Reference/Mechanical Properties from Table CTI STD-136 (10)

PVC Processing

PVC manufacturing processes are sophisticated and have been developed over a long period of time by experienced experts. The most common processes for PVC material used in cooling towers are extrusion for profile and sheet, calendaring for sheet, and thermoforming to create film fill features. Figures 5 and 6 below show processes for manufacturing flat thin sheet, referred to as roll stock, by extrusion and calendaring. Quality checks of the materials, proper feed rate, and thickness control ensures that the roll stock is manufactured "per specification" to be used in the next process, forming.

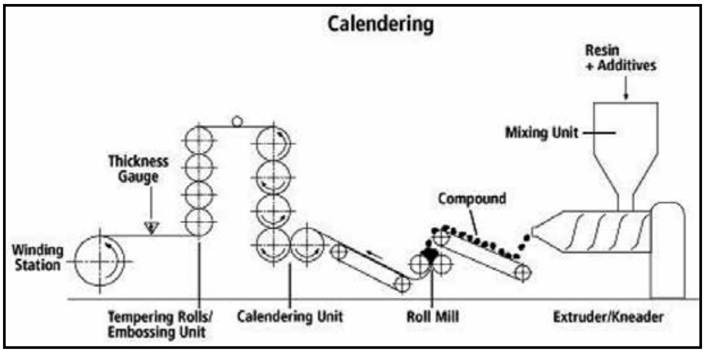

Figure 5: Sheet Extrusion Process Equipment(11)

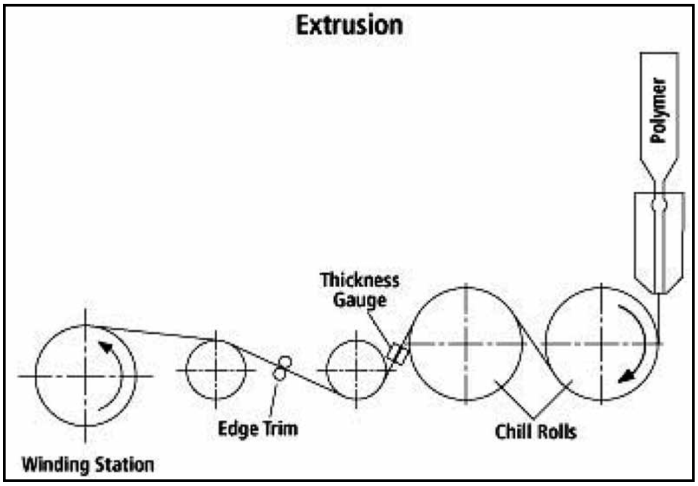

Figure 6: Sheet Calendaring Process Equipment(11)

Figure 7 below shows processes for manufacturing formed thin sheet from flat roll stock, by a process called thermoforming. Quality checks of the materials, proper cooling cycle, and shape design ensures that the part is manufactured "per specification".

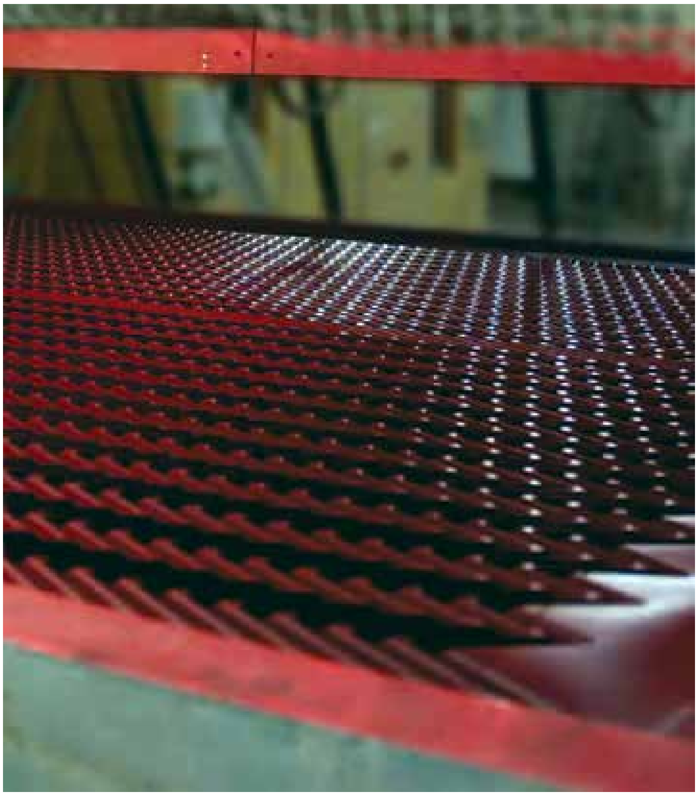

Figure 7: Thermoforming Process[7]

Quality Systems in Manufacturing

PVC material quality and part production should be judged by a number of factors. The appearance of PVC profile or sheet is a good indicator of care taken in manufacture. Observation is a guide in monitoring processes. Further checks may be specified by the customer and provided by the component and/or evaporative cooling tower manufacturer for the customer.

Review of the manufacturer's quality plan, observation of their process, physical properties verification tests, quality procedures, and measurements of the formed part are typically adequate to assure that the parts will perform in cooling towers. These recommendations help the end user feel confident that PVC parts are right for their application. A competent PVC supplier should have in-house testing facilities to ensure specified performance, and an in-plant quality manual, verification, and documentation available for the cooling tower manufacturer and the end user. Figure 8 shows lab Testing of a PVC coupon.

Figure 8: Lab Test, Coupon in Tension[7]

The PVC Standard, CTI STD-136

As PVC use in critical evaporative cooling designs has increased, the need for defined standards became apparent. The Cooling Technology Institute's Engineering Standards and Maintenance committee created Standard CTI STD-136, Thermoplastic Material used for Film Fill, Splash Fill, Louvers, and Drift Eliminators. This document captures the requirements for PVC and other plastics used in critical cooling tower components. As of 2016, this standard is in the revision process. Input during the standard revision process is critical to keeping it significant and relevant for cooling tower users. The CTI standard writing philosophy depends on expertise developed by the evaporative cooling tower manufacturers, component makers, and customers, in consultation with the polymer industry. Design engineering skill is critical in applying PVC for maximum thermal efficiency and longevity at operating conditions. These applied engineering skills are not readily available, but must be sought and retained in the industry.

Critical material qualities that need to be included in CTI STD-136 to insure the proper selection, processing, and application of PVC components are:

1. Tensile Strength
2. Flexural Strength
3. Flexural Modulus
4. Heat Deflection Temperature
5. Impact Strength
6. Flammability

For these specified items, customer should review the discussions of each category in this paper for the reasons these qualities are important and the specific tests that capture the needed material attributes. These categories represent the practical needs for Cooling Tower Internal Components, application strengths and longevity at temperatures.

Case Study

Film Fill History – One of the first counterflow towers in North America with PVC fill/eliminators was at a refinery facility in California. At inspection after 13 years of service, the tower was in very good condition, structurally sound, and operating efficiently. PVC components were inspected closely and found to be functioning well. PVC offers a high strength, corrosion resistance, impact resistance, dimensionally stable, and highly formable material for profiles and shapes with a proven cooling tower track record.

Figures 9 and 10 below show the tower exterior and interior. This installation began as a single cell built in 1981 with some of the earliest PVC counterflow fill and eliminators. Subsequently, three cells were added. These PVC components looked good, without distortion or breakage in these 1994 photos. This original 1981 cell is still in operation, 34 years later. A piece of the eliminator, sun exposed, was pliable and flexible indicating good impact strength. Fill surfaces looked good, without distortion or breakage. Wood structure and FRP connectors also looked good, a testament to wood quality and FRP attributes suitable to the cooling tower environment.

Figure 9: Counterflow Tower constructed in 1981 photographed in 1994

Figure 10: PVC Eliminators from 1981

Problems and Resolutions

Physical problems in PVC components in cooling towers have been rare. By far the most significant problem with PVC film fill has been fouling. Physical property loss due to material capability and/or exposure to excessive loads, high temperatures, and specific chemicals, all of which were envisioned when the first PVC fills were designed, has not generally occurred.

Recommended policy for suppliers is to be responsive in diagnosing any physical problems that may occur, identifying failure mechanisms, and performing warranty repairs for any PVC material related problems, while implementing changes in design and manufacturing requirements that reflect lessons learned.

This paper is focused on the PVC material itself and its capability. PVC components have some qualities that are derived not from the PVC material, but from the component geometry and configuration. These issues are the subject of multiple CTI papers, CTI Guidelines and CTI Standards, and are not dealt with in this paper. These qualities and capabilities include:

1. Film Fill Fouling propensity [planned CTI ESG – 164]
2. Fill Physical Component Capability
    a. Fill pack crush [planned CTI ESG – 164]
    b. Tower fire resistance - FM Testing [CTI Chapter 12]

Conclusions

Substantial testing, application, and operational data indicate that PVC is a material well suited to the cooling tower environment. It is very durable in the varying wet exposure. PVC has been in-use since the 1970's with strong roots in early tower designs. Specific Conclusions:

1. PVC is a material well suited to cooling tower application and very durable in the wet cooling tower environments.
2. CTI STD-136 is the reference for PVC material properties and attributes and should be used as a reference in specifying components.
3. CTI STD-136 should include the following properties:
    a. Tensile Strength
    b. Flexural Strength
    c. Flexural Modulus
    d. Heat Deflection Temperature
    e. Impact Strength
    f. Flammability – Flame Spread Index and Oxygen Index
4. Competent PVC component manufacturers:
    a. have a capable design staff
    b. have quality system in place for review
    c. have field construction procedures providing for proper component handling
    d. stand behind their design, QC, and construction practices
    e. provide a long historic track record of sound component application

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

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

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

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

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

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

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

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

1. The cooling tower vendor shall be a Participating Manufacturer in the Cooling Technology Institute (CTI) STD-202 program for Publication of Custom Tower Thermal Performance Test Results, as validated by listing as such on www.cti.org.
2. The cooling tower shall be subject to acceptance testing conducted by a CTI-Licensed Thermal Performance Testing Agency, according to the latest edition of CTI ATC-105. Testing shall occur within one year of commercial operation of the cooling tower.

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MARLEY®

Participating Manufacturer	Composite Cooling Solutions, L.P.	EvapTech, Inc.	SPX Cooling Technologies
Testing during the Period:	08/12/2013 TO 08/11/2015	06/11/2013 to 09/30/2015	08/12/2013 TO 08/11/2015
Percentage of tests at or above 100% Capabability	NA	100	80
Percentage of tests at or above 95% Capability	NA	100	100
Avg of Test Results below 95%	NA	0	0
Average Water Flow Rate below 50,000 GPM	NA	19,813	20,086
Average Water Flow Rate at or above 50,000 GPM	NA	117,540	116,667

N.A. = At the time of this publication the minimum number of CTI licensed tests required to publish results by STD-202 have not been performed.

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CFD Modeling of Wind Velocity And Direction of Exit Air in Performance of Cooling Tower

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Ram Kumar Jha

Abstract

The induced draft wet cooling tower performance is highly affected due to recirculation of saturated exit air from the cooling tower. The impact of wind velocity and wind direction further degrades the predicted performance of cooling tower. This paper covers the volumetric multi fluid analyses using CFD modeling in 18 back to back cells of 14 meter x 14 meter cooling tower in three different possible orientations like parallel, perpendicular and 45°inclined to the prevailing wind direction.

The quantitative analysis estimates the amount of recirculation and extent of recirculation around the cooling tower and qualitative analysis identify the flow recirculation and flow behavior for different wind direction.

Prediction of recirculation allowances is generally provided by CTI (Cooling Technology Institute, USA) such as PTG-116& PTB-110 Codes

The adopted methodology of fluid volume around the cooling tower is extracted using ANSYSICEM–CFD and used to generate the multi-block hexahedral mesh. The analysis is single phase multi component fluid flow analysis. Turbulence model selected depends upon the physics of the flow quality and quantity of the grids. For the analysis, realizable k-εturbulence model used and second order discrete scheme will be used to solve various associated equations.

The adopted methodology has been duly accepted in "Ansys User Conference, 2011"1

The CFD simulations results enable designer to predict the performance of the counter flow large wet cooling towers, operated over wide range of operating conditions. The results provide sufficient data for thermal performance evaluation, tower performance predictions, refurbishment capability projection and optimization of cooling tower design.

KEYWORDS: Computational Fluid Dynamics, Recirculation, CTI

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INTRODUCTION

A Cooling tower is heat exchanging device that works on the phenomenon of evaporative heat transfer as a dominating process. Warm water carrying heat fall gravitationally though heat transfer fill and fresh air stream induced by Fan or natural flow due to density difference. This heat transfer happens in two ways

- Latent heat transfer of water
- Sensible heat transfer due to fresh air entering to tower

The heat that is transferred from the water stream to the air stream raises the air's temperature and its relative humidity tend to reach 100% and this air is discharged to the atmosphere.

This paper discuss the computational fluid dynamics investigation of various alternatives and options for reducing recirculation effect in different combination of orientation in large back to back cooling tower to improve generating unit performance capabilities .

Selecting tower orientation properly improves cooling tower performance providing enhanced condenser performance which translates to overall improvement of plant performance.

Each of the alternatives presented in the paper will provide varying degrees of recirculation due to orientation of tower & levels of wind velocity, however, some of the combination will provide greater benefits in proportion to the capital required to actualize the benefit.

METHODOLOGY

The development of modern computational fluid dynamics (CFD) begins with the advent of the digital computer in the early 1950's.

The field of computational fluid dynamics has a broad range of application. Independent of the specific application under study, the following sequence of the steps must be generally followed in order to obtain a satisfactory solution. The first step involves the specification of the problem, including the geometry flow conditions, and the requirements of the simulation. The geometry may result from live project dimensions of cooling tower or may be associated with the design study. Alternatively, or a set of objectives and constraint must be specified. Flow conditions might include for example the Reynolds number and the Mach number for the flow over a geometry of the cooling tower. The requirement of the simulation includes such as the level of accuracy needed, the turnaround time required and solution parameters of interest.

Selection of governing equations and boundary conditions -:

Once the problem has been specified, an appropriate set of governing equations and boundary conditions must be selected. It is generally accepted that the phenomenon of importance to the field of computational fluid dynamics are governed by the conservation of mass, momentum and energy. The partial differential equations resulting from these conservative laws are referred to as the Navier –Stokes equations. However, in the interest of efficiency, it is always prudent to consider solving simplified forms of **Navier -Stokes equations** when the simplified retains the physics which are essential to the goals of the simulation. Possible simplified governing equations include the potential-flow equations, the Euler equations and the thin layer Navier- Stokes equations. These may be steady or unsteady and compressible or incompressible. The success of a simulation depends greatly on the engineering insight involved in the selecting the governing equations and the physical model.


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All analysis are single phase multi component, without heat transfer and mass transfer. Operating pressure is considered as atmospheric pressure Fig. 1.1 shows the typical boundary condition used for analysis, except the wind entrance surface (left vertical surface), the outer surface are treated as open to atmosphere. Flow may leave or enter the domain depending upon the flow variables prevailing boundary condition as depicted in table 2.1. There are totally three wind directions for the current analysis, along the length of cooling tower, across the cooling tower and finally at 45˚ to the cooling tower. Effect of wind speed and wind direction is analyzed for three different directions and speed. Similarly there are three exit mass flow rate through the fans of each cooling tower. Hence there would be in the total twenty seven simulations. These details are shown in table 2.2

Fluid Properties

Current analysis is a single phase multi-component fluid analysis. Fluid entering the domain is ambient air at 32˚C hence this air is considered as one of the component of fluid i.e, species A Air properties corresponding to temperature of 32˚C will be used for species A. Fluid exiting from the cooling tower will be saturated air at approximate 40˚C Hence this fluid is considered as species B. Properties of air at this temperature will be used for species B.

Species	Boundary	Temp.
A	Rectangular face of the domain	32 °C
B	Fluid exiting from Cooling Tower	40 °C

Gridding strategy

A strategy and numerical method for dividing the flow domain into cells or elements to be selected. Many different gridding strategies exist, including structured, unstructured, hybrid composite and overlapping grids.

Meshing-: ANSYS ICEM CFD is used to generate the multi block hexahedral mesh. Fine mesh is generated near wall and gradually coarsened towards outer domain.

The objective of the current simulation is to estimate the recirculation at the cooling tower inlet. To estimate the recirculation, the amount of exit air reentering the inlet of the cooling tower. Hence to differentiate the fluids, the analysis is multi-component analysis, by analyzing multi component flow, one can determine the fluid that is reentering the inlet of the cooling tower. This analysis will be a steady state in nature as the boundary conditions at inlet and outlet do not change with respect to time. Pressure based solver with simple algorithm will be used to solve governing equations (Mass, Momentum and species). Turbulence plays a major role in fluid flow upon the physics of the flow, quality (Y plus) and quantity of the grids for the current analysis realization **k-ε** turbulence model is used. Second order upwind discretization scheme will be used to solve u.v and w equations. Energy equation will be switched off as this study does not considering Heat transfer.

Parameter	Setup
Material	Multi –Component or multi-species
Nature of physics	Steady state
Compressibility	Incompressible flow
Solver	Pressure Based
Turbulence model	k-ε realization
Wall Functions	Standard wall treatment
Energy Equation	Off(Single phase , multi-species)
Operating Pressure	I atm

Quantitative Objectives

It has been established that certain factors directly affect the cooling tower recirculation process. Some major factors are as below:

1. Continuous length of the cooling tower.
2. The ratio of prevailing wind speed to plume exhaust speed.
3. The direction of wind speed with respect to cooling tower axis.
4. Orientation of the tower i.e. back to back or inline.

While there have been publications quantifying % recirculation with respect to length of the cooling towers, an effort is made hereby to try and quantify the combined effect of other important parameters, in various combinations using CFD analysis.

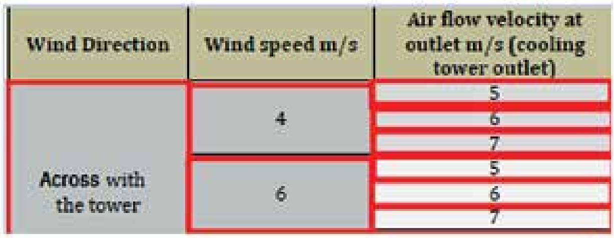
- Estimate the amount of recirculation
  - Percentage of fresh air entering cooling tower at inlet
  - Percentage of re-circulation air entering back to the cooling tower at inlet.
  - Extent of recirculation air movement around the cooling tower
  - The data is required to estimate the location of the next row of cooling tower

Qualitative Object

- Identify the flow recirculation
- Determine the flow behavior for different wind direction

CASE 1

Wind direction across the tower



Wind Direction	Wind speed m/s	Air flow velocity at outlet m/s (cooling tower outlet)
Across with the tower	4	5
		6
		7
	6	5
		6
		7

Simulation results are available in figure no.1.2 & 1.3 which clearly indicates the increase of recirculating volume with increase of wind velocity at lower exit air. Figure 1,4 is a representation of velocity vector. The inaccuracy of result is approximately 4 %.

CASE 2

Wind direction inline to the cooling tower

This simulation is also similar to case 1 for exit air flow and wind speed with addition of 8m/s wind velocity. The results are illustrated in figure no. 1.5, figure 1.6 and figure no.1.7. The mesh is generated in ICEM CFD with multi block hexahedral meshing. The mesh count is around 6 million and wind direction is in line to the cooling tower. Figure 1.8 shows the humid air (exit air mass friction for inline cooling tower and clear indication for higher recirculation at high wind speed.

CASE 3

Wind direction 45˚ to the cooling tower

Similar variable parameter has been considered for 45 degree inclined wind velocity with various combination of wind and exit velocity. The mesh count is 7.8 millions. This has come out as the worst scenario of recirculation at 8 m/s wind velocity and also comparatively higher amongst all the cases.

Conclusion

The maximum recirculation was observed in Case 3 which is approximately 34.4 %. As compared to the wind speed and various combination of exit air velocity, perpendicular to cooling tower and in line with the cooling tower, wind speed at 45˚ has more recirculation for the same combination of governing parameters. In the overall estimation the results are concluded such that the Humid exit air percentage is 3.18 % for INLINE Cooling tower to wind direction, 16.4% for Across the Cooling tower and worse seen has been found in such long back to back cooling tower inclined at 45˚ with wind direction is 32.9% and such orientation must be designed considering the higher recirculation allowance.

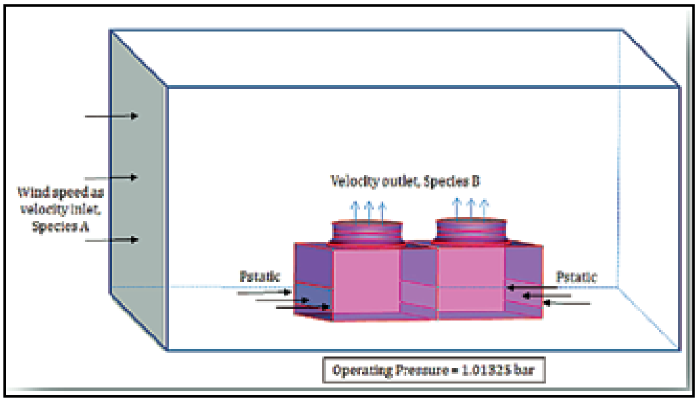
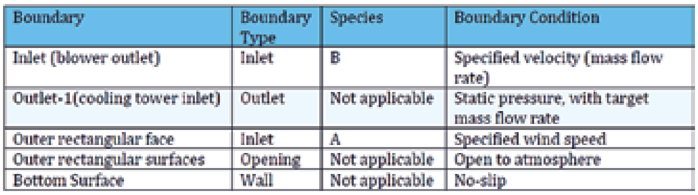
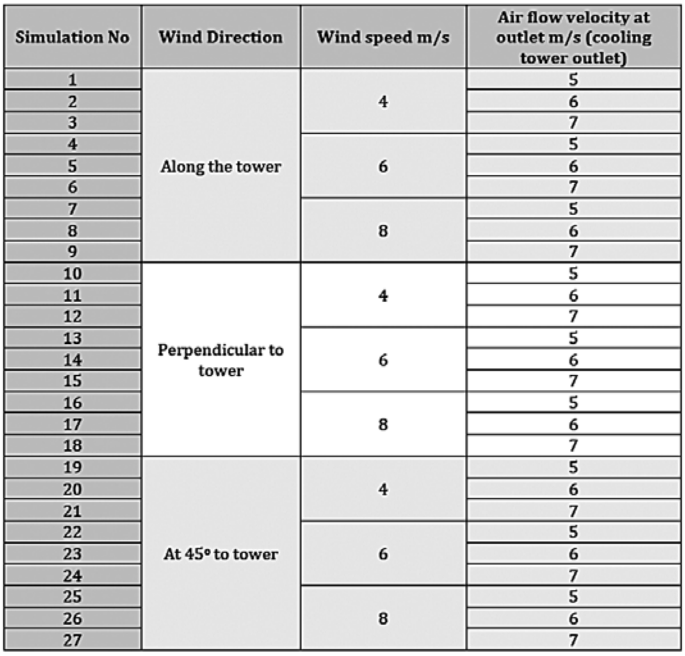


Figure 1.1 Boundary conditions location



Boundary	Boundary Type	Species	Boundary Condition
Inlet (blower outlet)	Inlet	B	Specified velocity (mass flow rate)
Outlet-1(cooling tower inlet)	Outlet	Not applicable	Static pressure, with target mass flow rate
Outer rectangular face	Inlet	A	Specified wind speed
Outer rectangular surfaces	Opening	Not applicable	Open to atmosphere
Bottom Surface	Wall	Not applicable	No-slip

Table 2.1



Simulation No	Wind Direction	Wind speed m/s	Air flow velocity at outlet m/s (cooling tower outlet)
1	Along the tower	4	5
2			6
3			7
4		6	5
5			6
6			7
7		8	5
8			6
9			7
10	Perpendicular to tower	4	5
11			6
12			7
13		6	5
14			6
15			7
16		8	5
17			6
18			7
19	At 45° to tower	4	5
20			6
21			7
22		6	5
23			6
24			7
25		8	5
26			6
27			7

Table 1.2

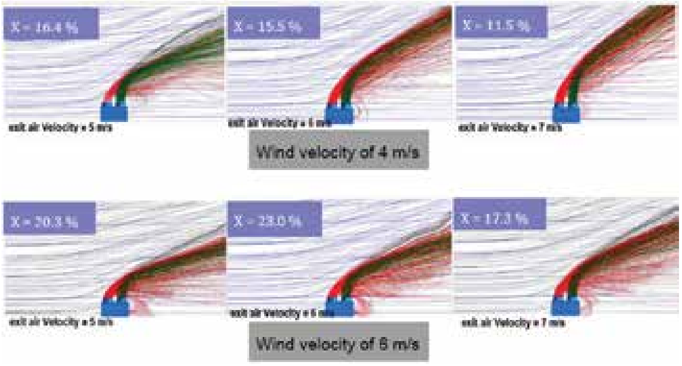


Figure 1.2

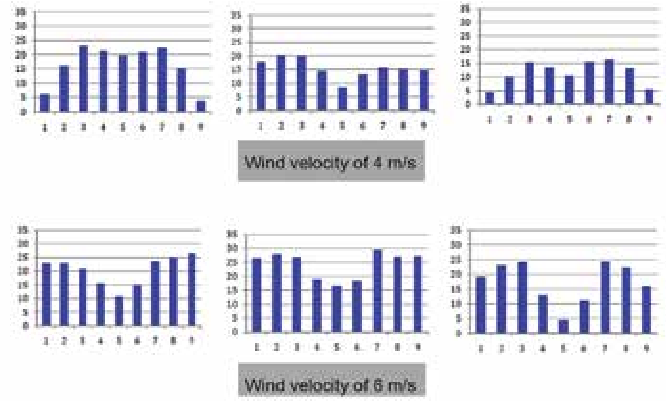


Figure 1.3

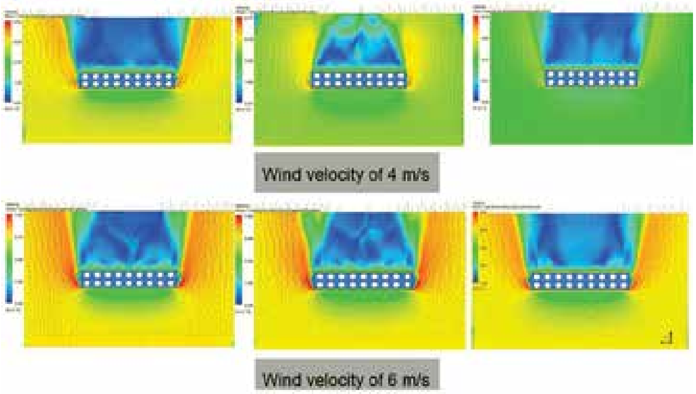


Figure 1.4 (velocity vector)

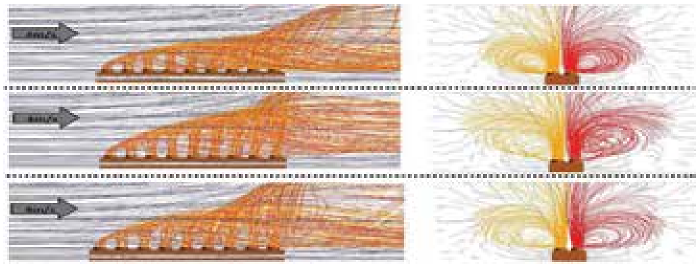


Figure 1.5

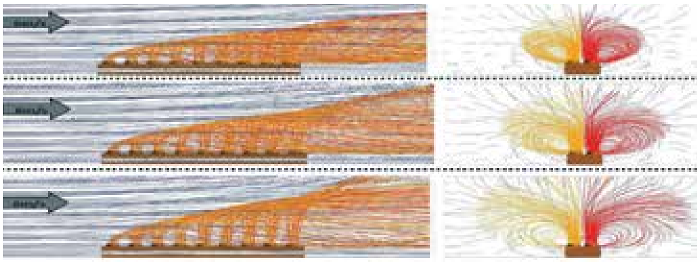


Figure 1.6

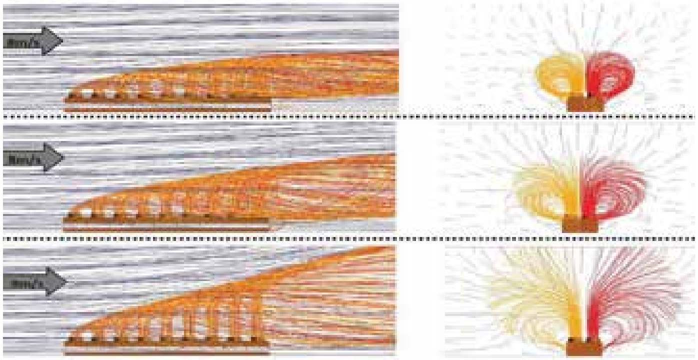


Figure 1.7

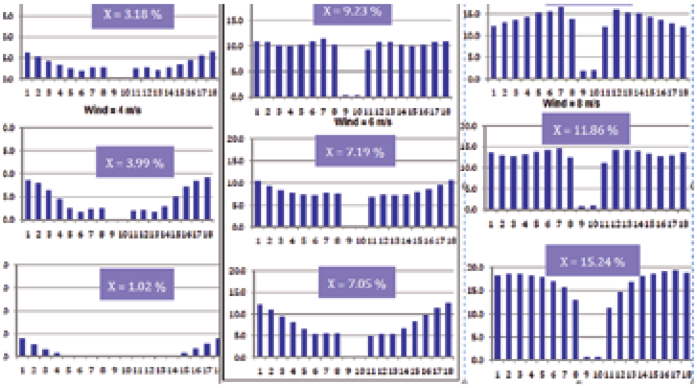


Figure 1.8 (humid air mass friction)

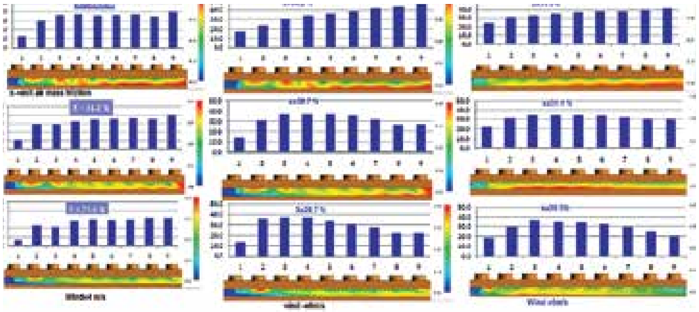
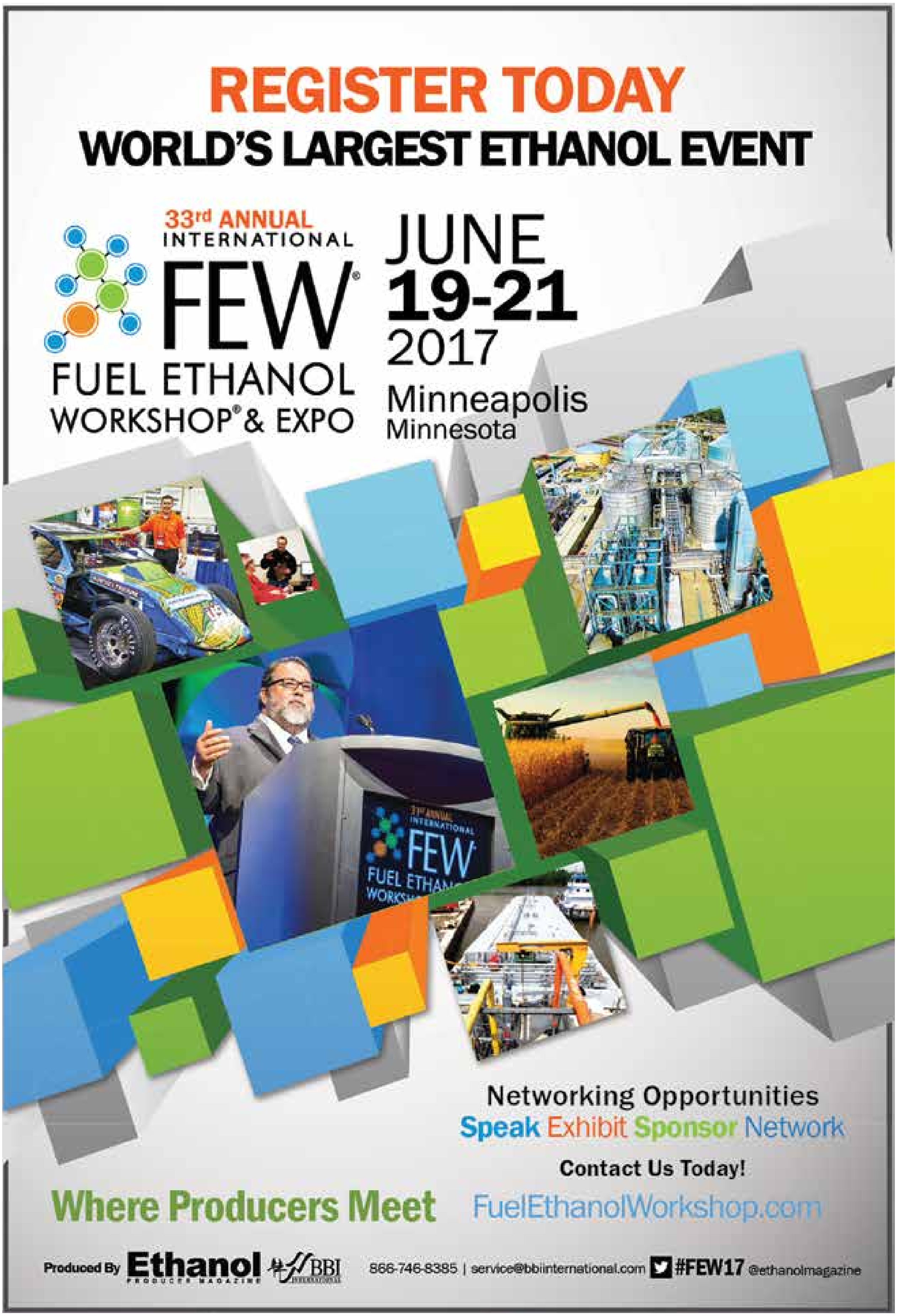


Figure 1.9



Application Of Flow Cytometry To Rapid Microbiological Analysis Of Cooling Water

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Chemtreat Inc.

Kelly Lipps

Abstract

Microbiological growth on cooling towers, heat exchangers and piping cause a multitude of issues including microbiologically-influenced corrosion, reduced heat transfer, fill fouling, increased fluid frictional resistance, and dispersion of airborne pathogens such as Legionella. Rapid and effective microbiological monitoring is the key to ensuring that cooling water systems operate safely and efficiently. Flow cytometry has been used for many years in medical applications that involve cell counting and sorting, particularly in cancer research and diagnostics. The ability of flow cytometry to rapidly identify and enumerate large quantities of nano-scale particles and their fluorescent properties creates vast opportunities for applications in bacteria identification and monitoring. This paper examines the use flow cytometry in conjunction with fluorescent nucleic acid and bacteria stains to rapidly enumerate live and dead bacteria in industrial cooling water samples. Staining methods as a means of identifying particular species, such as Legionella, and cell viability studies using nucleic acid stains are discussed.

Introduction

Determining the microbial populations in industrial water samples is vital when monitoring the performance of an industrial cooling water system. Proper enumeration and speciation of the microbes in the system has the potential to highlight issues before biofouling could appear. The current methods for enumerating microbes (dip slides, Petrifilms3M) are well known and their limitations are understood. The incubation time for these methods (24 – 48 hours) means that the results obtained are already in the past, and not indicative of the real time condition of a system. The development of a rapid method for the determination of viable and nonviable microbial populations in industrial water systems would be a very helpful tool for the water treatment industry.

Flow cytometry is a technology that is used to analyze the physical and chemical characteristics of particles in a fluid stream as that stream passes by a laser. Components of the liquid can be excited by the laser to emit light at varying wavelengths. That fluorescence can be measured to determine various properties (such as size) of single particles. Since cells (both eukaryotic and prokaryotic) can be considered particles when suspended in a liquid medium, Flow Cytometry has found many applications in the biomedical sciences, including those relevant to the healthcare field. The technology has been widely used in the diagnosis of health conditions, particularly diseases of the blood such as leukemia. In recent years the application of flow cytometry to the study of microbiological has increased, and has been used in studies including detection and quantification of viable organisms and those that cannot be cultured [1], enumeration of bacteria both in pure cultures and in aquatic systems [2-4], identification of specific bacterial species [5 – 7], and the assessment of the efficacy of antimicrobials against bacteria [8 – 10].

Our interest in flow cytometry has been driven by the desire to develop a rapid method for the enumeration of viable microbes in industrial water samples. The ability to rapidly determine the microbial population in an industrial water system can be a valuable tool in preventing or remediating a biofouling event in an industrial process water system. The ability to respond quickly to a microbial problem could help prevent problems from developing in the system. Few studies describe the use of the Flow Cytometer to enumerate microbes from industrial systems [11], so we have investigated the use of fluorescent viability stains, in combination with flow cytometry, to develop a rapid and reliable method for the determination of viable microbial populations in industrial water samples. Herein are described those efforts.

Materials and Methods

Fluorescent Stains and Counting Beads.

A membrane-permeable dye which stains live and dead cells (Thiazole orange) and a membrane-impermeable DNA stain for cells with damaged membranes (Propidium Iodide [PI]) were used in these experiments. Thiazole orange (TO) was purchased from Fisher Scientific (50855249) and diluted to a working concentration of 42 μM in DMSO. Propidium Iodide was purchased from Fisher Scientific (AC440300250) and diluted to a working concentration of 4.3 mM in 0.22 μm filtered RO water. Counting beads (Flow Count) were purchased from Beckman Coulter (7547053).

Bacterial Strains and Antibody.

Industrial water samples were used as a source of *Pseudomonas* bacteria for various experiments. One mL of an industrial water sample was pipetted onto Pseudomonas Isolation Agar (Teknova P0144) and the agar plate incubated at 37°C. Colonies of Pseudomonas were scraped off of the agar plate and suspended in to 0.22 μm filtered phosphate buffered saline solution (Butterfield's PBS) then stained with the fluorescent stains according to the protocol described below. A pure lyophilized culture of *Legionella pneumophila* (Philadelphia-1) was purchased from ATCC (33152) and grown out on BCYE agar according to the instructions. The Mono-Fluo Legionella pnuemophila IFA Test used was purchased from Bio-Rad Laboratories (Catalog # 32514). The legionella test kit is a FITC labeled legionella antibody with a maximum emission at 490 nm and a mean emission of 520 nm. It also has a counterstain that fluoresces dark red/dull gold.

Instrument and Settings.

The flow cytometer (Beckman Coulter Gallios) used in this research was equipped with a 10-color, three laser configuration with excitation wavelengths of 488 nm (blue), 638 nm (red) and 405 nm (violet). Before running the stained samples through the flow cytometer, the instrument went through a quality control protocol using Flow-Check Pro Fluorospheres (Beckman Coulter A63493). Once the lasers and filters were aligned, the forward scatter and side scatter signals were calibrated to detect particles ranging in size from 0.5μm and 6μm using sizing beads provided by Beckman Coulter. A noise region was determined by running 0.22μm filtered RO water through the cytometer with no stains or bacteria and a discriminator was set on forward scatter of 2. The laser and filter settings are listed below. A medium flow rate of 30μl/min was used for the bacteria viability protocol. Viable and nonviable regions were set based on a kill study outlined below

Table 1

	FS	SS	FL1	FL3
Voltage	135	200	517	625
Gain	20.0	7.5	1.0	1.0
Discriminator	2	OFF	OFF	OFF
Compensation				
FL1	-	-	0	4.1
FL3	-	-	25	0

Typical Incubation and Staining Procedure.

For pure culture testing, a sample of *Pseudomonas* was grown from an industrial water sample on a *Pseudomonas* isolation agar and incubated at 37°C for 48 hours or until growth was present. The bacteria were scraped from the plate and suspended in 0.22 μm filtered PBS and vortexed until thoroughly mixed. The suspension of bacteria was diluted until there was little to no turbidity in the sample. A 500 μl aliquot of the suspension was transferred to a test tube fitted for the flow cytometer. The 4.3 mM solution of PI was diluted 1:10 in 0.22 μm filtered RO water and then again 1:20 into 0.22 μM filtered RO water to give a final concentration of 21.5 μM. The 500 μl bacteria suspension was stained with 10 μl of 21.5 μM PI and 2.5 μl of 42 μm TO. The stained sample was incubated at room temperature for 5 minutes in the dark. After incubation was complete, 50 μl of BD Liquid Counting beads were added to the stained sample and it was vortexed to mix. The sample was then run on the viability protocol on the flow cytometer.

Industrial water testing was completed as follows. A 10 mL aliquot of an industrial water sample was filtered through a 5μm nylon filter into a 10 mL centrifuge tube to remove any debris. The sample was then centrifuged for 30 minutes at 5,000 rpm as a concentration step. Once centrifuging was complete, the supernatant was discarded and the pellet was resuspended into 100 μl of 0.22 μM filtered PBS. The concentrated bacteria sample was added to 437 μl of 0.22 μm filtered staining buffer in a sample tube fitted for the flow cytometer. Next, 10 μl of 21.5 μM PI and 2.5 μl of 42 μM TO were added and the sample was incubated at room temperature for 5 minutes. After incubation, 50μl of counting beads were added and the sample was vortexed to mix. The sample was then run on the viability protocol on the flow cytometer.

Staining of Legionella pneumophila.

Freeze-dried *Legionella pneuomphila* (*Legionella pneumophila* strain Philadelphia – 1, ATCC® 33152™) was resuspended as directed. The resuspended pellet was cultured on BYCE agar and incubated at 37°C for 48 hours or until growth was present. Using an inoculation loop, one loop full of Legionella was scraped from the plate and suspended into 9 mL of 0.22 μm filtered PBS. Then, 430 μl of stain from the IFA Legionella Test Kit was added to 1 mL of the *legionella* suspension. The stained suspension was incubated in the dark at room temperature for 30 minutes to 1 hour. Once staining was complete, the sample was centrifuged for 5 minutes at 10,000 rpm. The supernatant was then discarded and the pellet was resuspended into fresh 0.22 μm filtered PBS. The sample was centrifuged a second time for 5 minutes at 10,000 rpm. The supernatant was discarded and the pellet was again resuspsended into fresh 0.22 μm filtered PBS. This completed the rinse phase of the legionella staining. The rinsed suspension of stained legionella was run on a *Legionella* protocol on the flow cytometer [12].

Results and Discussion

Validation of Signal (kill study)

A kill study was done to validate the TO (viable) and PI (nonviable) regions of the FL1 v. FL3 dot plot on the flow cytometer. A sample with a known killed population fluorescing in the nonviable (PI) region of the dot plot would validate the PI region and a sample with a known viable population fluorescing in the viable (TO) region of the dot plot would validate the live TO region. The nonviable sample was prepared by adding 70% isopropanol at a 1:1 ratio with a 5μm filtered customer bacteria sample and incubated at room temperature for 30 minutes. The live sample was the same customer sample without the addition of isopropanol also filtered to 5μm. The viable, untreated sample and killed sample were combined in various ratios to validate the regions. (The untreated and killed sample were combined at untreated concentrations of 100%, 75%, 50% 25% and 0%.) The dot plots for the 100% live (untreated), 50% live and 0% live are shown below in Figure 1. Proper compensation was also applied during the kill study to make sure that the signals between TO and PI were not overlapping. Counting beads provided a count of cells in each region in cells/μl to give the data in Table 1. Table 1 shows the count in each region as well as the percent of total cells in that region. The percent total decreased steadily as the percentage of killed bacteria increased. This decrease is represented in Figure 2.

As the concentration of the live population decreased, there was a strong linear correlation to the dead bacteria concentration as shown by an R^2 of 0.965. The cells in these regions accurately reflected the expected proportional change of live to dead cells with each sample. This linear relationship can be represented by $y=0.3303x+0.0268$ for this sample. The process was repeated for 2 other customer samples and gave similar results. This gave us sufficient evidence to conclude that the live region was to be set in the upper left hand corner of the dot plot and the dead region was to be set in the bottom right hand corner of the dot plot. The region to the top right is the injured region where bacteria emit fluorescence from both TO and PI. The bottom left is the unstained region for debris, unstained bacteria and noise. This region is disregarded when enumerating bacteria. With the regions set, research continued and industrial water samples were tested on this protocol with these settings.

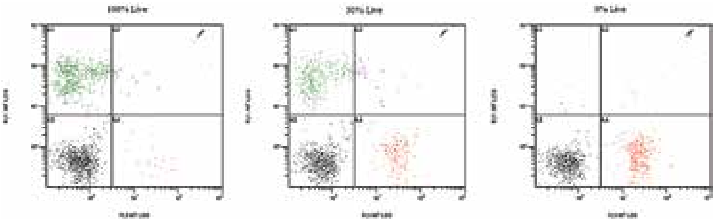
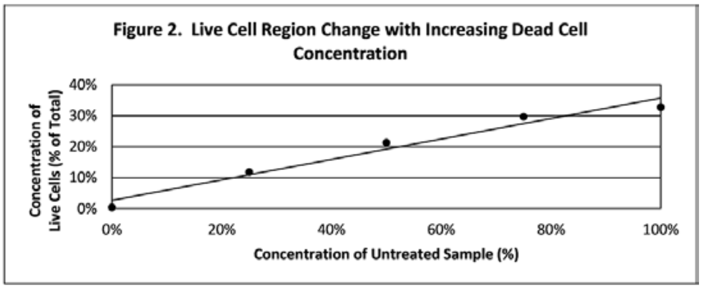


Figure 1. Dot Plots showing Regions Where Viable and Non-Viable Bacteria are Detected

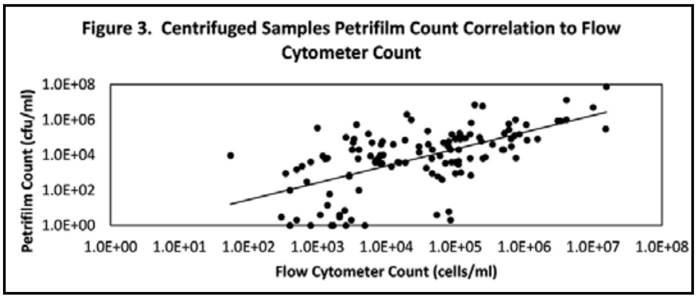
Treatment	Live Region (cells/µl)	% Total	Dead Region (cells/µl)	% Total
100% Live	2411	32.74	102	1.38
75% Live	1793	29.70	432	7.16
50% Live	1251	21.34	716	12.20
25% Live	630	11.82	876	16.44
0% Live	20	0.39%	1196	23.26

Table 2. Data from Kill Study



Correlation of Flow Cytometer Counts to Petri Films Populations.

With the protocol set, industrial water samples were tested using the method explained previously and the live population data from region A1 was collected. The same samples were plated for enumeration on aerobic 3M Petrifilms to determine if a correlation could be seen between the viable bacteria data from the flow cytometer and the traditional testing method of aerobic petrifilms. The count given by the flow cytometer is in cells/µl. To convert this number to get to the actual count the count was multiplied by 10 for the dilution into staining buffer, then divided by 100 for the centrifuging concentration step and lastly multiplied by 1,000 to get it into cell/mL. Due to this conversion step, the lower detection limit of the flow cytometer is 100 cells/mL (10e2 cells/mL). It was found that for the centrifuged samples, there was a correlation of R^2=0.3776. At bacteria concentrations of greater than 10^3 cfu/mL, there was a correlation of R^2=0.4268. It was also found that 58% of the aerobic petrifilm counts fell into a range of +/- 1 log of the flow cytometer viable cell count. It needs to be considered that the aerobic petrifilm only allow us to enumerate aerobic and culturable bacteria while the flow cytometer enumerates all viable and dead bacteria in a sample. While there was not a strong correlation between the aerobic petrifilm count and the viable bacteria count from the flow cytometer, it can be seen that there is a large amount of bacteria that is not being enumerated through the petrifilm method. It was found that 78% of samples tested had a higher count on the flow cytometer which is expected for the reasons just listed.



Results from the Staining of Pure Cultures of Legionella and Deposit Samples.

Pure Legionella cultures were stained as described above. Once the sample was stained, rinsed and resuspended, it was ready to run on the flow cytometer. The control sample that was provided with the IFA test kit was used to set the positive *legionella* region on the flow cytometer. The forward and side scatter settings were the same as the viable bacteria protocol. The filter settings were adjusted as necessary for the FITC stain on the Legionella antibody. The figures below show a sample of *legionella* fluorescing positive with the specific absorbance region being marked on the plot. A sample of *Pseudomonas* fluorescing negative for legionella is also shown and its absorbance is outside of the region where the *Legionella* was detected. Finally, testing was also done on a customer sample to determine if any *Legionella* was present in a customer deposit sample but that result showed negative for *legionella*. This method is a single parameter analysis that serves as a presence/absence type test. We have not determined the limit of detection for this method as that testing is still ongoing. Further, since this test uses an antibody, it detects the presence of any *Legionella* bacteria that might be present, and does not distinguish between viable and nonviable bacteria. These results show that the flow cytometer is excellent tool for testing for the presence of specific strains of bacteria where a fluorescently labeled antibody stain is available [13 – 17].

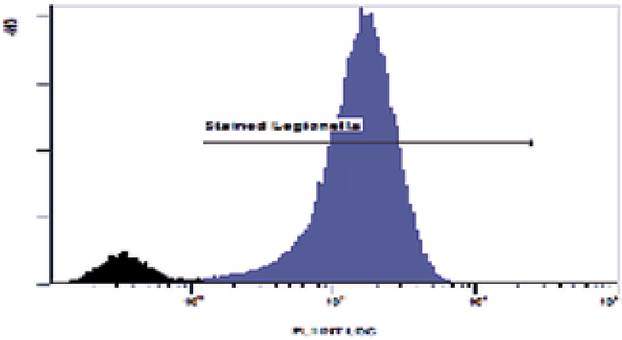


Figure 4. Absorbance and Detection of *Legionella* Stained using MonoFluo IFA Test

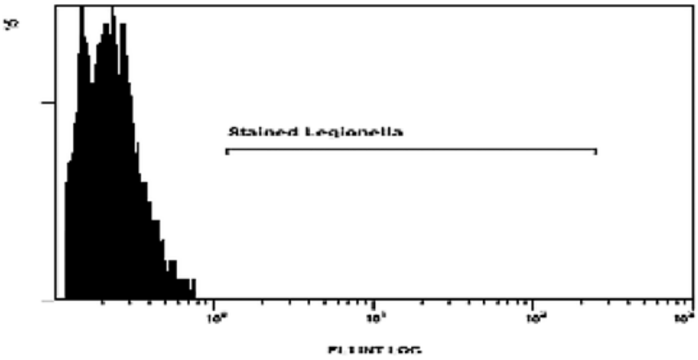


Figure 5. Negative Control (*Pseudomonas*) Stained using MonoFluo IFA Test

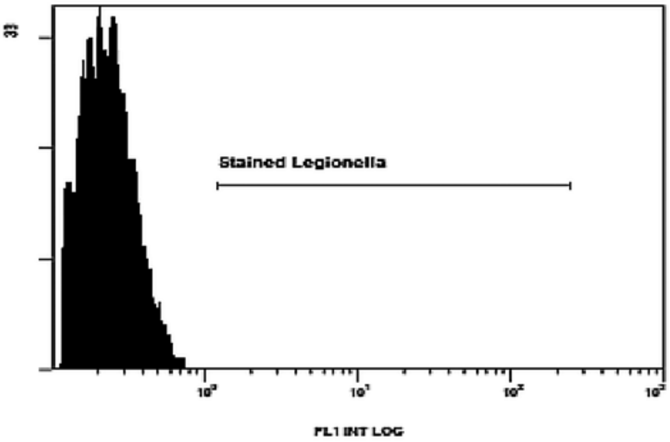


Figure 6. Customer Sample Stained using MonoFluo IFA Test

Conclusion

The lack of reliable and easy to perform rapid microbial enumeration techniques is a frustrating fact of life in the water treatment industry. Whereas several parameters that are monitored in an industrial water system may be performed in real time, a microbiological analysis of the system takes days. The use of the Flow Cytometer, in combination with fluorescent Live/Dead stains, provides an exciting opportunity for the determination of microbial populations in industrial water samples in just minutes rather than days when using traditional methods. It is not surprising that this method would indicate that traditional methods of microbial enumeration likely under-report the true population of microbes present in an industrial water system. Further, the use of fluorescently labeled antibodies, raised to specific types of microbes, opens the possibility for the rapid and reliable determination of the presence or absence of certain problematic bacteria. Taken together, the Flow Cytometer method for microbial detection and enumeration enables the water treatment service company to better serve their customers by reducing the analysis time required to determine microbiological populations in industrial water systems and provide remedial actions if necessary.

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Cooling Technology Institute Licensed Testing Agencies

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

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

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

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

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Thermal Testing

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Fax 865.938.7569
www.cleanair.com / khennon@cleanair.com
Contact: Kenneth (Ken) Hennon

Cooling Tower Technologies Pty Ltd
PO Box N157, Bexley North, NSW 2207
AUSTRALIA
+61.2.9789.5900 / (F) +61.2.9789.5922
coolingtwrtech@bigpond.com
Contact: Ronald Rayner

Cooling Tower Test Associates, Inc.
15325 Melrose Dr., Stanley, KS 66221
913.681.0027 / (F) 913.681.0039
www.cttai.com / cttakc@aol.com
Contact: Thomas E. (Tom) Weast

DMT GmbH & Co. KG
Plant & Product Safety division
Am Technologiepark 1, 45307 Essen, Germany

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

McHale Performance
4700 Coster Rd, Knoxville, TN 37912
856.588.2654 / (F) 865.934.4779
www.mchaleperformance.com
jacob.faulkner@mchleperformnce.com
Contact: Jacob Faulkner

CTI
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Contact: Kenneth (Ken) Hennon

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856.588.2654 / (F) 865.934.4779
www.mchaleperformance.com
jacob.faulkner@machaleperformance.com
Contact: Jacob Faulkner

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

Cooling Technology Institute Sound Testing

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

Licensed CTI SoundTesting Agencies

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Powell, TN 37849
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Fax 865.938.7569
www.cleanair.com
khennon@cleanair.com
Contact: Kenneth (Ken) Hennon

McHale Performance
4700 Coster Rd
Knoxville, TN 37912
865.588.2654
Fax 865.934.4779
www.mchaleperformance.com
jacob.faulkner@mchaleperformance.com
Contact: Jacob Faulkner

Cooling Technology Institute Certification Program
STD-201 for Thermal Performance

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

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

Those Manufacturers who have not yet chosen to certify their product lines are invited to do so at the earliest opportunity. You can contact Virginia A. Manser, Cooling Technology Institute at 281.583.4087, or vmanser.cti.org or PO Box 681807, Houston, TX 77268 for further information

Licensed CTI Thermal Certification Agencies

Agency Name / Address	Contact Person / Website / Email	Telephone / Fax
Clean Air Engineering 7936 Conner Rd Powell, TN 37849	Kenneth (Ken) Hennon www.cleanair.com khennon@cleanair.com	800.208.6162 or 865.938.7555 (F) 865.938.7569
Cooling Tower Test Associates, Inc. 15325 Melrose Dr. Stanley, KS 66221	Thomas E. (Tom) Weast www.cttai.com cttakc@aol.com	913.681.0027 (F) 913.681.0039
Cooling Tower Technologies Pty Ltd PO Box N157 Bexley North NSW 2207 Australia	Ronald Rayner coolingtwrtech@bigpond.com	+61.2.9789.5900 +61.2.9789.5922
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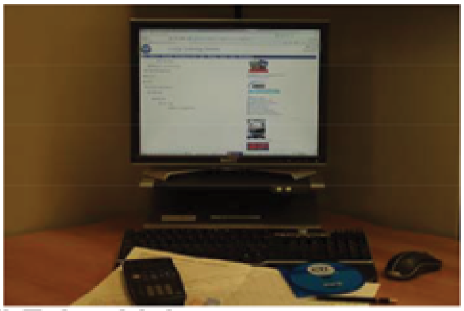

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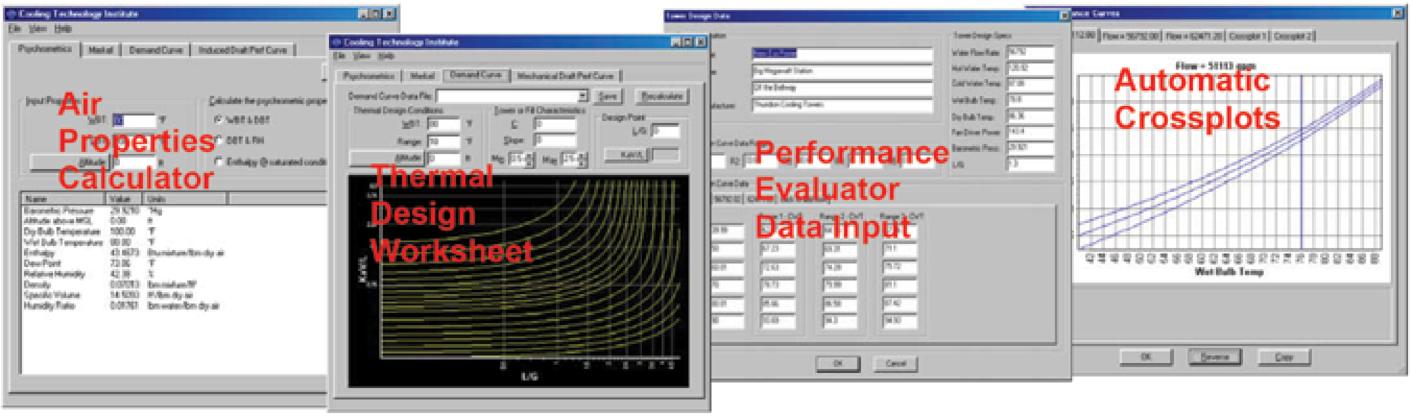

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Cooling Towers Certified by CTI Under STD-201

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

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

**Performance as specified when the circulating water temperature is within acceptable limits and the air supply is ample and unobstructed. CTI Certification under STD-201 is limited to thermal operating conditions with entering wet bulb temperatures between 10°C and 32.2°C (50°F to 90°F), a maximum process fluid temperature of 51.7°C (125°F), a cooling range of 2.2°C (4°F) or greater, and a cooling approach of 2.8°C (5°F) or greater. The manufacturer may set more restrictive limits if desired or publish less restrictive limits if the CTI limits are clearly defined and noted in the publication.*

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

The CTI STD-201 Thermal Performance Certification Program has grown rapidly since its' inception in 1983 (see graphs that follow). A total of 54 cooling tower manufacturers are currently active in the program. In addition, 11 of the manufacturers also market products as private brands through other companies.

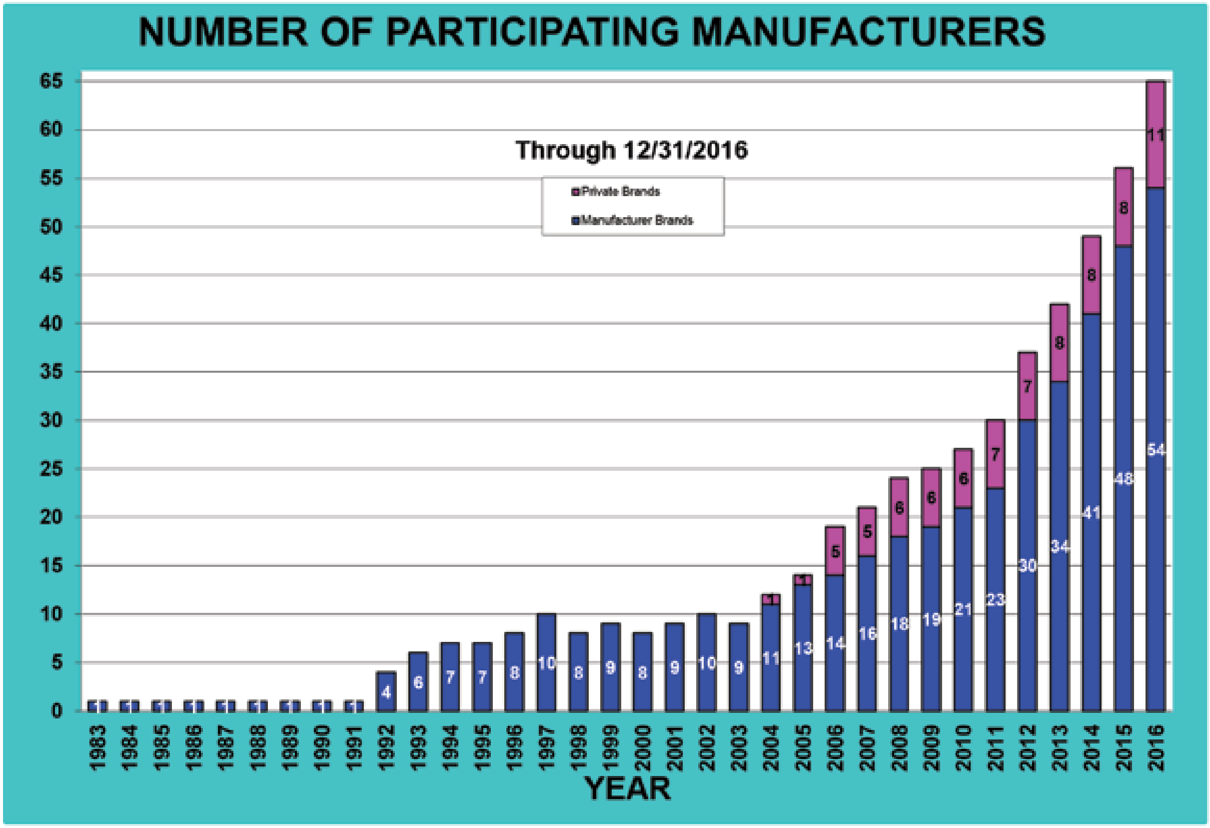
While in competition with each other, these manufacturers benefit from knowing that they each achieve their published performance capability and distinguish themselves by providing the Owner/Operator's required thermal performance. The participating manufacturers currently have 134 certified product lines plus 16 product lines marketed as private brands which result in approximately 29,000 CTI Certified cooling tower models to select from.

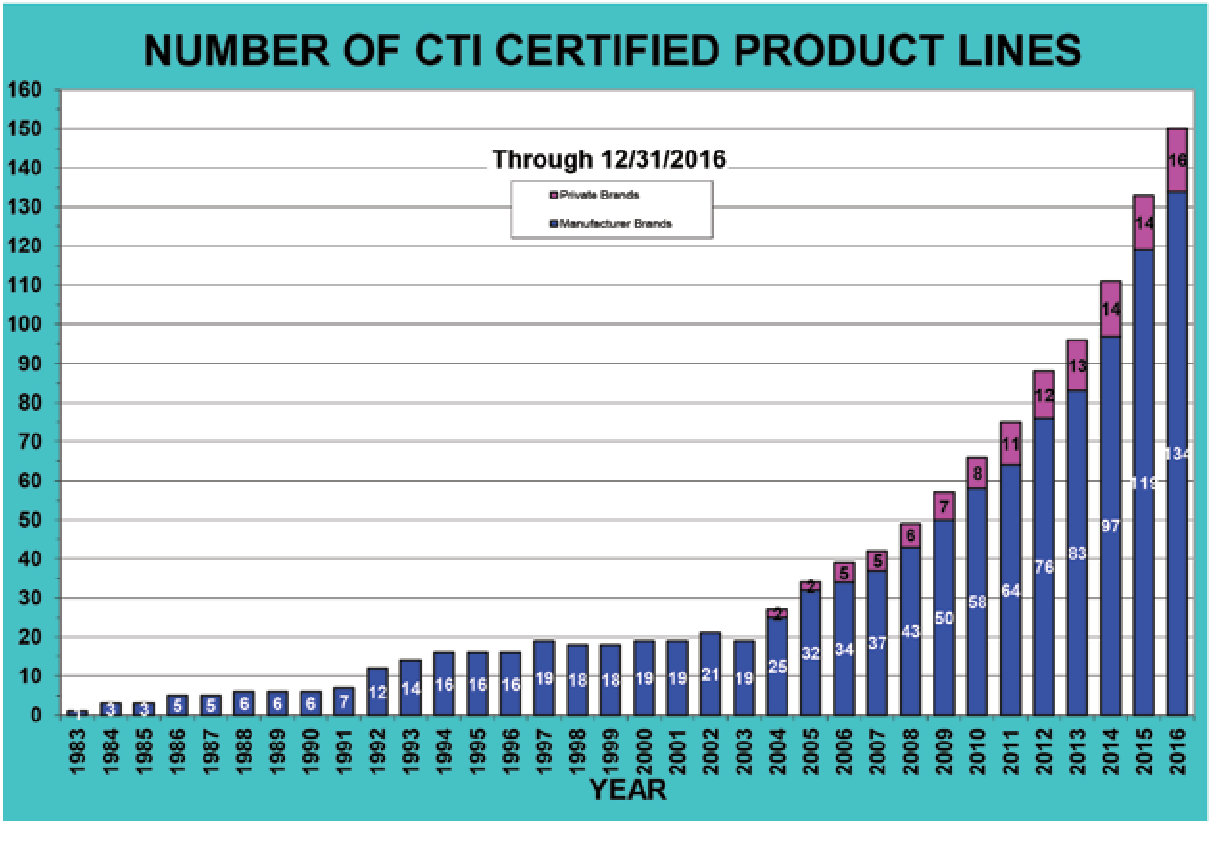
For a complete listing of certified product lines, and listings of all CTI Certified models, please see:

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

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

Thermal Performance Certification Program Participation Through December 31, 2016





Current Program Participants

(as of December 31, 2016)

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:

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

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

A

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

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

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

AONE E&C Corporation, Ltd.
ACT-C Line *Validation No. C28B-09R01*
ACT-R/ACT-RU Line *Validation No. C28A-05R04*

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

Axima (China) Energy Technology Co., Ltd.
EWX Line *Validation No. C72A-15R01*
ACC Line *Validation No. C72B-15R01*

B

Baltimore Aircoil Company, Inc.
FXT Line *Validation No. C11A-92R02*
FXV Line *Validation No. C11J-98R10*
PF Series *Validation No. C11P-12R02*
PT2 & PTE Series *Validation No. C11L-07R04*
Series V Closed VF1 & VFL *Validation No. C11K-00R02*
Series V Open VT0,VT1,VTL &VTL-E
Validation No. C11B-92R06
Series 1500 *Validation No. C11H-94R09*
Series 3000 A,C,D,E & Compass & Smart
Validation No. C11F-92R18

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

C

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

D

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

Decsa
RCC Series *Validation No. C42C-14R00*

DongGuan Ryoden Cooling Equipment Co., Ltd
RT-U Series *Validation No. C71A-15R01*
RTM-L Series *Validation No. C71B-15R00*

E

Elendoo Technology (Beijing) Co., Ltd.
EL Line *Validation No. C50C-15R01*
ELH Line *Validation No. C50A-13R01*
ELOP Line *Validation No. C50B-14R02*

Evapco, Inc.
AT Series *Validation No. C13A-99R18*
ATWB Series *Validation No. C13F-09R07*
AXS Line *Validation No. C13K-15R02*
ESWA & ESWB Series *Validation No. C13E-06R08*
L Series Closed *Validation No. C13G-09R03*
L Series Open *Validation No. C13C-05R03*

G

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

GOHL (E.W.Gohl, GmbH)
DTC-ecoTec Line *Validation No.C92A-14R01*

Guangzhou Laxun Technology Exploit Company, Ltd.
HMK Line *Validation No. C45A-12R04*
LMB Line *Validation No. 12-45-02*
PL Line *Validation No. C45E-16R00*
LC Line *Validation No. C45F-16R00*

H

Hon Ming (Guang Dong) Air Conditioning Equipment Company, Ltd.
MK Series *Validation No. C66A-15R01*

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

HVAC/R International, Inc.
Therflow Series TFC *Validation No. C28B-09R01*
Therflow Series TFW *Validation No. C28A-05R04*

I

Industrial Mexicana
Series 1000 *Validation No. C60A-15R00*
Series 2000 *Validation No. C60B-16R00*
Series 6000 *Validation No. C60C-15R00*

J

Jacir
KS Line *Validation No. 12-46-01*
KSF Line *Validation No. C46B-15R00*

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CTN Line *Validation No. C91A-14R00*
CTH Line *Validation No. C91B-14R00*
CTNX Line *Validation No. C91D-16R00*
CTHX Line *Validation No. C91E-16R00*

K

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

KIMCO (Kyung In Machinery Company, Ltd.)
CKL Line *Validation No. C18B-05R03*
Eco-Dyna Cool Line *Validation No. C18C-09R01*
Endura Cool Line *Validation No. C18A-93R07*

King Sun Industry Company, Ltd.
HKB Line *Validation No. C35A-09R03*
HKD Line *Validation No. C35B-09R03*
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KDI Line *Validation No. C70A-16R01*

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GXC Series *Validation No. C81B-16R00*

L

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Series D-LC *Validation No. C20F-14R01*
Series R-LC *Validation No. C11E-11R02*
Series U-LC *Validation No. C20D-10R04*
Series V-LC *Validation No. C20C-10R01*
TLC Line *Validation No. C20G-16R00*

M

Marley (SPX Cooling Technologies)
Aquatower Series *Validation No. 01-14-05*
AV Series *Validation No. 98-14-04*
MCW Series *Validation No. 06-14-08*
MD Series *Validation No. 08-14-11*
MHF Series *Validation No. C14G-04R07*
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Mesan Cooling Tower, Ltd.
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MFD Series *Validation No. C26J-16R00*
MXC Series *Validation No. C26H-12R01*
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N

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Qingdao VOFAT Air Conditioning Equipment Co., Ltd.
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Ryowo (Holding) Company, Ltd.
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Zhejiang Shangfeng Cooling Tower Co., Ltd.
SFB Line *Validation No. C73A-15R01*

Zhejiang Wanxiang Science and Technology Company, Ltd.
FBH Line *Validation No. C54A-13R02*

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