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For Immediate Release

Contact: Chairman, CTI Multi-Agency Testing Committee  
Houston, Texas, 3-May-2014

The Cooling Technology Institute announces its annual invitation for interested drift testing agencies to apply for potential Licensing as CTI Drift Testing Agencies. CTI provides an independent third party drift testing program to service the industry. Interested agencies are required to declare their interest by July 1, 2014, at the CTI address listed.

Internal Guide & Support System

The “Vari-Flow” Distribution Valve has been designed with a superior internal guide system that supports the stem and disc providing support needed to allow the valve to be used for balancing flow.

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Positive Shutoff

An improved gasket system allows complete (positive) shut-off of the water stream without the persistent leaking associated with conventional valves.

Step up to the “Vari-Flow” Distribution Valve

---

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This will be my last CTI Journal article as president and I have sincerely enjoyed serving our membership over these past two years. CTI is truly the preeminent international organization on all issues related to water cooled evaporative systems.

I just returned from Trinidad, West Indies where I spoke to a series of four day “Lunch and Learn” audiences. One of the primary requested topics was for me to describe the benefits of CTI educational services, including our various standards. The audiences were very interested in learning about cooling tower inspection, disinfection, and which of the various CTI standards were applicable to their specific cooling systems. In addition to appreciative audiences, the weather was also a welcome relief as the daily highs were in the upper 80’s (32 deg C), as compared to (32 degrees F) back in Richmond, Va.

That being noted, it won’t be long before we shall be trying to escape the summer heat and there will be no better way to do so than to attend the 2014 Summer Committee workshop (July 13-16) at the Sheraton Steamboat Springs, Colorado. We have held two previous summer workshops at this hotel and everyone agreed it was an exceptional value and venue.

Although each previous CTI president has mentioned the value of attending the summer workshop, this event is where the CTI committees review and update all documents, as well as form new task groups, as needed, to address evolving issues related to all aspects of evaporative cooling. I therefore urge you to put this event on your calendar to offer your input on topics of your choice.

Congratulations to our new Board members who have now received confirmation ballots form the CTI membership:

Tony DePalma of Tower Performance, Inc., Jon Cohen of H-O-H Technology, Jim Cuchens of Southern Company Services, Inc. and George Zubritsky of Cooling Tower Testing. George was appointed to serve the remaining 1 year term due to Dean Lammering’s passing last month. Dean will be missed for his leadership as Treasurer and his service as Water Treating Committee chairman for many years. We offer our sincere condolences to his family.

Finally, I wish to thank all of the members of the Thermal Certification Committee, and especially Trevor Hegg of Evapco, for their hard work in the selection process of a new Thermal Certification Administrator. Clean Air Engineering of Powell, Tennessee was selected after a rigorous review of all candidates. Frank Michell of American Electric Power, your newly elected CTI President for 2014-2016, will provide details of the Thermal Certification Administrator’s job and introduce Mike Womack and David Wheeler of Clean Air to the CTI membership at the Winter Meeting.

As I pass the President’s gavel to Frank, I once again offer my thanks to the CTI Board, each committee chair and to the general membership for your support over the past two years and I look forward to my new position as Chairman of the Past President’s Council going forward.

Respectfully submitted,
Jack Bland, ChemTreat consultant

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**Dean Lammering - 1949 - 2013 | Obituary**

An executive in water treatment, Dean Lammering passed Dec.12 in Chicago, surrounded by family, after an 18-mo, courageous battle with leukemia. The consensus of his friends and colleagues is that he was a gentleman’s gentleman. Born Apr. 13, 1949 in Chicago, he grew up in Hammond, IN and graduated from Hammond High in 1967. He graduated with a degree in microbiology from Wabash College in Crawfordsville, IN, in 1971, where he was a member of Sigma Chi. He taught briefly at Roosevelt Univ. before starting a 32-year career in product development and marketing at Nalco Chemical Co. In 1988 he was named Marketer of the Year. During the course of his career he won many awards. He was a member of the Cooling Tower Institute, where he was a committee member, treasurer and member of the board of directors. Most recently he led the Cooling Water Product Marketing Team for the Water & Process Services Division of Nalco. He also worked for eight years in marketing for Lonza, of Basel, Switzerland. He traveled around the world for Nalco and family travel took him to Chile, France, Ireland, Mexico, Cambodia, Thailand, Korea and Alaska and Hawaii and many other places in the US. “Lead by example was his mantra,” said his wife of 31 years, Judy Chaffee Lammering. “And he lived it every day. He was modest and didn’t take credit for many of the great things he did, for the company and for his friends and family. He had many loves: family, friends, golf, gardening, movies, da Bears and the Cubs, fishing and camping, and outdoor grilling no matter what the weather was. He was known for his skill in raising dahlias and was active with his children in YMCA Indian Princesses and Indian Guides. He enjoyed a good scotch or a nice Bordeaux. He is survived by his wife, his children, Staci (Bryan Ray), Bailey and Renny, his sister, Randi (late David) Nelson two brothers-in-law, three sisters-in-law, and five nieces and nephews. A celebration of Dean’s life is scheduled for 10:30 am, Fri, Dec. 20 at First Presbyterian Church, 550 N. Main, Glen Ellyn. In lieu of flowers, the family suggests contributions to the Leukemia & Lymphoma Research Society (lls.org) or to CaringBridge (caringbridge.org). Arrangements were handled by Leonard Memorial Home, 565 Duane St., Glen Ellyn 630-469-0032.

Published in Chicago Tribune on Dec. 17, 2013 - See more at: http://www.legacy.com/obituaries/chicagotribune/obituary.aspx?n=DeanLammering&pid=168593640/#sshash.pf7pd9bz.dpuf
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Dear Journal Reader,

2014 is an eventful year for CTI.

After an exhaustive process, an agreement has been reached with CleanAir Engineering to provide Thermal Certification Administrator Services to CTI. This multi-year contract places Mike Womack as the Thermal Certification Administrator going forward, with support services being provided by CleanAir per the contract requirements. The thermal certification program has been growing rapidly, and this arrangement positions us well to accommodate the growth. We are fortunate that Tom Weast, the longtime Certification Administrator has agreed to overlap with Mike Womack to provide as smooth a transition as possible. Tom’s company will also continue to provide the licensed thermal certification testing services. CTI is working to extend the licensed testing program for thermal certification testing to additional existing CTI Licensed Thermal Certification testers. Please take an opportunity to thank Tom Weast for his many years as CTI Thermal Certification Administrator, and also to thank Mike Womack and CleanAir Engineering for coming on with the Thermal Certification Program.

You will also note in this Journal, that the first publication of CTI Licensed Thermal Test results by participant name is included for the three participants in the new CTI STD-202 program. Data for last year’s results are being reported. Next year the results will cover 2 years, and the year after that will begin to report a three year rolling set of results. This is a very significant step for CTI, giving visibility to Owner/Operators and EPC’s to the success of testing results by the participating manufacturers. In the past, CTI has only published the aggregate results of that testing with no identification of manufacturers. This writer is very pleased to congratulate the participants on their willingness to join the program, and I am sure many other CTI members join in that expression. Please check the table of contents for the location of the STD-202 program published results in this Journal.

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

Best wishes for the New Year,

Paul Lindahl, CTI Journal Editor
INDUSTRIAL COOLING SYSTEM BIOFILMS, ISSUES AND REMEDIATION PRACTICES

OVERVIEW

It has been described many times and is well known in the scientific community that biofilms cause problems in industrial cooling systems. They are part of a tricité of compounding issues comprising biological fouling, scale build-up and corrosion which lead to decreased heat exchanger efficiency, increased energy costs and reduced equipment life if not adequately controlled. Ultimately, the consequences of out of control systems may lead to complete system shut-downs, production shut-downs that depend on the cooling system, lost revenue. Additionally, the formation of biofilms in cooling systems provides an ideal environment for the proliferation of Legionella species, the cause of Legionellosis.

In contrast, the control of biofilm promotes system cleanliness which leads to better system performance, lower maintenance costs, asset protection with a possible reduction in health risks. Biofilms are not passive complexes nor are they easy to control however, effective biofilm control is very necessary to ensure system cleanliness and avoid fouling that degrades cooling system performance, promotes corrosion and favors the growth of pathogens. Biofouling control that successfully addresses biofilms will have a positive impact on asset protection, unit reliability, worker safety and profits.

One of the main challenges in treating biofilms is that the organisms in biofilms are better protected than planktonic organisms from disinfectants applied to the bulk water. This is due to the protective film that is formed with polymeric material which does not allow for contact of microbes which lay with in the layers to contact the biocide for adequate killing.

While the protection afforded microbes in the biofilm is not absolute, higher concentrations of disinfectant are required to control organisms in the biofilm. Some researchers have claimed disinfectant levels 10-100x higher than needed to kill planktonic organisms are required to control microbes in biofilms (1).

Historically, biofilm issues have been seen through system performance issues or gross visualizations of bacterial slime on surfaces. Remediation practices have been to add more biocidal product and especially increase the use of non-oxidizing biocides. While this may aid in solving the problem of gross contamination it leads to other concerns, including cost, regulatory discharge issues and safety concerns through the handling a larger footprint of hazardous substances.

Because of differences in susceptibility to disinfectants, assessments of bio-control based solely on bulk water counts can be misleadingly optimistic – at least for a time - as planktonic organisms are readily eliminated by disinfectants applied to the bulk water. However, if these same disinfectant residuals are inadequate for controlling biofilms, fouling can eventually occur and, at some point, biofilm will begin to slough off into the bulk water. When this occurs, bulk water counts will rise quickly (i.e., “over night”) and since organisms within the sloughed biofilm (now a bio-floc) are still protected, disinfectant residuals that previously controlled bulk water populations will no longer be effective. Obviously, biocontrol programs will be better managed by tracking performance against sessile populations and not just bulk water populations.

One approach used to treat biofilm fouling is through the use of biodispersants. Biodispersants are surfactant based products used in the Industrial Water Treatment industry as a methodology to disperse or prevent agglomeration and attachment of planktonic forms of microbial growth on surfaces. They also work as surface acting agents to help open up channels in biofilms to allow for better penetration of biocides. However, they do not exhibit highly efficacious behavior when faced with removal of already established biofilms, especially heavy ones. As stated in the teachings of patent US 7,824,557, the activity of biodispersants has been responsible for only 25 – 30% biomass removal from biofouled surfaces even in conjunction with a biocidal agent”. In addition, due to the non-cidal removal mechanism of biofouling reduction associated with their use, biocide is needed concurrently to fully destroy the living organisms which are contributing to the biofilm. This is imperative due to the risk of “generating tower drift contaminated with live and potentially pathogenic microbes.”(IWC-08-39)

To address the challenges of biofilm penetration, removal and killing, a new methodology has been developed using a Targeted Delivery (TD) system. This technology utilizes a liposomal carrier which encapsulates a biocide in order to deliver the active ingredient to the biofilm surface where, due to its unique properties, fuses with the biofilm releasing the active ingredient within the biofilm itself. This creates a targeted selectivity of the biocide within the biofilm matrix which aids penetration, dispersal and killing of the consortium of microorganisms from inside out of the biofilm.

Due to the targeted delivery mechanism of the Targeted Delivery system, better utilization of the biocide is achieved, which reduces the concentration needed to provide an efficacious effect on biofilm removal which as stated above may be 10 to 100 times the dosage used for planktonic organisms. Furthermore, enhanced removal of biofilm in a system would result in more efficient overall system
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clean-up over time which could lead to lower biocide maintenance dosing in the bulk water due to the decreased organism loading from the biofilm.

**LIPOSOME COMPOSITION AND RELEVENCE**

Liposomes were discovered in the early 1960’s by the late Dr. Alec D. Bangham showing some of the first electron microscopic images of multilamellar phospholipid which helped establish the knowledge that lipid bylayers are the primary barrier of all cell membranes (12,13). Since that time some fifty years ago, liposomes have become an integral part of the delivery of chemicals and biological substances in the medical, cosmetic and health industries. Furthermore, they also have relevance in the delivery of industrial biocides in Water Treatment which is the purpose of this paper.

The word “Liposome” consist of two Greek words- “Lipos” meaning fat and “Soma” meaning body. Liposomes are artificial vesicles of spherical shape that are composed mainly of phospholipids arranged in unilamellar and sometimes multilamellar complexes much like that of a biological membrane. They are spontaneously formed when the phospholipids are exposed to water and orient into small vesicles with agitation with the structure itself is driven by repulsive forces of the the phospholipid molecule which contains a polar, hydrophoric head group and two long fatty-acid non polar chains. The polar end groups consist of phosphoric acid and may contain other functionalities such as alcohol functional groups (esterified). This amphiphilic chemistry drives the physical orientation of the molecules to arrange in bilayer planar sheets which fold over into a spherical arrangement to minimize the repulsive actions of the polar and non-polar components (14).This leads to the formation of an internal hydrophilic core which is capable of encapsulating and protecting a portion of the active ingredient for release upon the vesicle fusing with a biofilm, thus creating the beneficial use in Water Treatment biofilm control.

**TARGETED DELIVERY DEVELOPMENT**

In the development of any product, certain physical and chemical variables must be considered and monitored depending on the nature and features of the product. For the Targeted Delivery biocide development in addition to biofilm efficacy the major factors to be taken into account are:

- Basic proof of concept of liposome encapsulation and formation
- Active ingredient concentration and subsequent stability over time
- Trapping efficiency to determine and monitor the encased biocide in the core of the liposome
- Particle size to ensure the proper and consistent formation of the liposome particle’s physical stability
- Mixing dynamics

**PROOF OF CONCEPT**

Liposome encapsulated fluorescent dye.

The advantage of the Targeted Delivery concept is the ability to penetrate and deliver a biocide directly into the biofilm itself for more targeted and efficient use of the biocide. In an effort to demonstrate such behavior which is created by the liposome, a series of tests were conducted whereby fluorescent dyes were incorporated into a liposome and the penetration of the dye from the liposome into the biofilm was observed.

Liposome encapsulated fluorescent dye samples were mixed with the above mentioned organisms in a formed biofilm for 4 hours at room temperature and followed by removal of liquid in the wells. The Calcein dye alone was used as a control. The fluorescent intensity of the biofilm was then measured by a microplate reader.

**ACTIVE INGREDIENT**

Although the Targeted Delivery system could be utilized for many different biocides, the focus of this paper is to examine that of encapsulated isothiazolone and in particular 5-chloro-2-methyl-4-isothiazolin-3-one and 2-methyl-4-isothiazolin-3-one. This biocide is a highly effective broad spectrum non-oxidizer class of biocide that is used widely in Water Treatment among other industries. It is highly water soluble and was a good candidate for incorporation into the water soluble core inside the void of the liposome.

Established HPLC methods exist for this active ingredient and were used throughout the course of product development. In addition, the product has established greater than 6 month physical stability with one year EPA storage stability studies currently underway.

**TRAPPING EFFICIENCY**

The trapping efficiency of the isothiazolone biocide inside a liposome is determined by measuring conductivity before and after the lysing of the liposome.

Alternatively, a dialysis method may also be used and is a direct measure of the active ingredient itself inside of the liposome. In this procedure, the TD product is run through a dialysis bag to isolate the liposome particles. The liposome particles are then lysed as above and the active ingredient is quantified through HPLC with and without lysing the particles to determine the active contained inside.

Studies on the effect of mixing time and mixing speed during the product development phase were conducted and utilized trapping efficiency as a control parameter. In conjunction with these methods basic microscopic examination was useful in determining formation and dissolution of the liposomal vesicles under testing and storage conditions.

**PARTICLE SIZE**

**Light Microscopy**

The Zeiss microscope was used to visualize the particles and has attached high resolution camera interfaced to a computer. The digital images were captured and processed using Clemex, Inc. Vision image analysis software. There were a total of 30 images scanned for each analysis.

The images were enhanced to delineate the particles and image processing algorithms were utilized that automatically separated touching particles within agglomerates. To ensure that as many particles were measured as possible within an area of interest, some manual measurements were made by touching two points at extremes of the periphery. This was done so as not to bias the measurements towards only particles that did not overlap or would not distinctly separate from large agglomerates.
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EXPERIMENTAL EFFICACY METHOD

Microplate Biofilm Test
A high throughput screening evaluation was carried out using a published protocol by Christensen et al (1985). The purpose of this test was to perform a comparative biofilm removal efficacy evaluation of isothiazolone and the Targeted Delivery product to determine the enhanced benefit of the liposome encapsulation. In this test, adhered microbial cells are exposed to a comparative ladder of biocide treatment concentrations followed by an application of a metabolite redox indicator dye, Resazurin. This dye is used to quantify the presence of biofilm remaining attached to the wells of the plate via the reaction of the indicator dye from resazurin to the reduced form resorufin which gives off a fluorescent red color. The fluorescent intensity may then be read and quantified with a microplate reader.

The data presented in Figure 5 shows both the batch to batch consistency in efficacy as well a significant increase in biofilm efficacy of the Targeted Delivery product over straight isothiazolone alone. The data is a reflection of a summary of tests conducted and it should be noted that the isothiazolone alone was not tested at the 5ppm level in this group of tests and is absent from the data set.

EXPERIMENTAL EFFICACY METHOD

Biofilm Flow-through Method
The Biofilm Flow-through Method is a modification of part of the ASTM Standard Method E2562-07. It is a dynamic flow biofilm generating system which provides an environment for growing biofilm on test surfaces using hollow stainless steel tubing in which media is re-circulated. Biocides are then added to the dynamic biofilm systems and biocidal efficacy is determined following biofilm contact time. The purpose of this test was to perform a comparative biofilm removal efficacy evaluation of isothiazolone and the Targeted Delivery product to determine the enhanced benefit of the liposome encapsulation using the dynamic biofilm reactor system with high shear and continuous flow.

The results, as shown in Figure 7 show, an increase in biofilm efficacy of the Targeted Delivery over isothiazolone alone. The untreated control was shown to maintain or grow slightly throughout the study. The isothiazolone was tested at 2.0, 5.0 and 10.0 ppm active and the Targeted Delivery at 5.0, 1.0 and 2.5 ppm active. The Targeted Delivery showed better efficacy at lower levels with 2.5ppm Novel Biodelivery being equivalent to 10ppm isothiazolone and 0.5 and 1ppm Targeted Delivery having greater efficacy than 5ppm Isothiazolone.

FIELD AND PILOT SCALE BIOFILM TESTING AND EVALUATION

Modified Robbins Device Biocide evaluations are most commonly performed against free-floating (planktonic) populations. In our customer service laboratory, such conventional biocide testing has been expanded and improved to include testing against sessile (attached) organisms – the organisms that comprise a biofilm - as well as planktonic populations.

Biocide testing against sessile bacteria is preferred for several reasons:

1.) In terms of numbers or biomass, microbes in biofilms better represent the microbial population relevant to system fouling and/or corrosion.
2.) The number and species of microbes that predominate in the biofilm may be different from those present in the bulk phase.
3.) Due to the protective action of microbial exopolymers, the susceptibility of sessile microorganisms to antimicrobial agents differs markedly from that of equivalent organisms dispersed in the bulk water phase. (18)

Sessile microbial populations for testing are collected on a sampler known as a modified Robbins Device (mRD). (See Figure 8) The mRD is a side-stream sampling device designed to provide replicate surfaces for studies of microbial attachment and antimicrobial agents. It consists of a manifold supporting two cassettes; each cassette holds an in-line array of 1cm-diameter stainless steel studs. The cassettes position the studs within a U-shaped water channel running through the manifold. (18)

The unit is typically attached to a return cooling water line and supplied with constant water flow for several days so microbes have sufficient time to attach, reproduce and excrete protective, extracellular polymeric substance (EPS) on the sampler studs. Development of a mature and stable biofilm representative of that in the operating system ensures a more rigorous test of antimicrobial agents.

Following biofilm development, the inlet and outlet ports of the sampler are plugged and the device, along with a sample of cooling water from the system, is shipped back to the customer service microbiology lab. Upon receipt, studs are removed from the sampler and placed in test tubes that contain aliquots of system water. This method allows a range of products and concentrations to be screened simultaneously for biocide activity against sessile organisms attached to the studs as well as planktonic organisms in the bulk water. With the exception of control samples, each tube is treated with the appropriate volume of a selected biocide to obtain the desired test concentration. Control tubes receive no biocide.

Following biocide addition, all tubes are gently agitated at room temperature for a period of time. The actual contact time used can be adjusted to reflect cooling system operating conditions or expected biocide dosing practices in the field.

The number of surviving planktonic and sessile organisms in each tube is determined after the allotted contact time has passed. Surviving planktonic bacteria are determined by the heterotrophic plate count (HPC) method. Surviving sessile bacteria are determined by removing each stud from the bulk water and gently rinsing with sterile water to dislodge loosely attached organisms and debris. Rinsed studs are placed in individual dilution water tubes and sonicated to disperse attached cells. Aliquots of the sonicated mixture are serially diluted and plated as per the HPC method. (20)

CFU/mL results are converted to CFU/cm2 (colonies per coupon surface area) using the formula:

\[ \text{CFU/cm}^2 = \frac{\text{CFU/mL} \times \text{ml dilution water volume}}{\text{sample stud surface area}} \]

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Delivery product and “Biocide 2” being a non-oxidizing product combination. Three equivalent concentrations of each biocide were chosen and non-treated samples were included as controls. Each sample concentration was run in triplicate with the results shown being the average of the three samples.

The results show the Targeted Delivery product having an efficacy benefit over the on-encapsulated version at the lower biocide dosage and over a log benefit over both the non-encapsulated version as well as the combination product at the mid and higher dosages (figure 9).

FIELD AND PILOT SCALE BIOFILM TESTING AND EVALUATION

Coupons

A field study was conducted on a Marley 125 ton Cooling Tower with a 900 gallon system volume (Figure 10). In this test, stainless steel coupons were placed in a coupon holder which was positioned in the sump of the tower in a high flow area. Non-oxidizing biocide treatment was suspended during the duration of the biofilm growth period to allow for population of field isolates on the coupons. The coupons were left in place for three weeks after which they were retrieved and tested (Figure 11).

Testing consisted of placing a single coupon in individual centrifuge tubes containing 20mL of sterile phosphate saline buffer. Each biocide treatment consisted of 3 coupons in triplicate.

Coupons were rinsed with sterile water to remove any lose debris, dosed with respective biocides and incubated on a shaker for 24 hours contact time.

Following the contact time, the coupons were removed from the treatment solution and placed in fresh sterile buffer solution. The coupons were then vortexed and living organisms remaining on the coupons were quantified by the heterotrophic plate count (HPC) method mentioned above. Biofilm density (CFU/cm2) is determined based on the appropriate dilution factor and the dimensions of the coupons.

The results yielded increased efficacy in the case of the Targeted Delivery over the conventional non-encapsulated version at each treatment level ranging from 1-2 log difference.

FIELD AND PILOT SCALE BIOFILM TESTING AND EVALUATION

Pilot Cooling Tower Evaluation

The Pilot Cooling Tower (PCT) is a scaled down replica of an actual cooling tower. The towers and sumps reside outside (Figure 13) and the controls such as the conductivity controller, feed chemicals and exchanger are housed inside. The flow rate of the tower is 16g/min, runs on 12 cycles and blow down is approximately 12g/day. Each tower has a system volume of 150L and has attached to it a sessile sampler which includes stainless steel rods (Figure 14).

The pilot cooling towers are treated as a “normal” cooling tower would be and are open to air and environmental conditions, thus creating a natural environment for microbial growth. To address the need for biofilm monitoring, a sessile sampler was installed in-line with the flow of water and allowed to colonize with natural organisms.

The sampler consists of four steel and four plastic ¼” I.D. tubes over two feet in length. The tubes are bundled with gaskets and slipped inside a slightly longer, plastic pipe. PVC hose barbs are attached to each end of the pipe. Tubing that supplies recirculating cooling water is attached to the inlet end of the pipe. Another length of tubing (going to drain) equipped with a Dole valve is attached to the outlet end of the pipe. By selecting a Dole valve with an appropriate gallon per minute flow rating, water velocity through the tubes can be controlled in a desired range.

After a period of time under flow to allow for microbial colonization (baseline development), the tube bundle is removed for sampling. A one inch sample is cut from each plastic and steel tube, and the exterior of each sample is sterilized with an alcohol wipe. After the alcohol evaporates, individual sections are placed in plastic tubes containing 9 mLs of sterile water. Ultrasonication, vortexing, or simple shaking can be used to remove organisms into the water volume for quantitation by any of a variety of methods (e.g., HPC, ATP, SRBs, etc). Because complete removal of all biofilm organisms is not expected, consistent handling is important to ensure the same level of removal and a consistent relative basis for comparison.

Sessile results are calculated for each section using the following formula:

\[
\text{Sessile result/cm}^2 = \frac{\text{Quantitation result/ml} \times 9\text{ml dilution volume}}{5.0671\text{cm}^2}
\]

Average sessile/cm2 results for the four plastic and four steel tube samples are determined and plotted as the Log10 value of the sessile/cm2 count. Assuming a usable working length of 24 inches for all tubes and one sessile sampling per week, the sampler allows about six months of weekly sessile monitoring before a new tube bundle must be installed.

For consistency of conditions, one tower was used for the addition of the two biocidal products, one being the non-encapsulated (Iso) and the other being the Targeted Delivery product (TD). The Pilot Cooling Tower (PCT). The dosing regime was identical for the two biocides. The sessile sampler was allowed to colonize with biofilm of a period of 3 weeks followed by addition of isothiazolone three times a week. This was followed by suspension of biocide and subsequent regrowth of biofilm on the sessile sampler. Next was the addition of the Novel Biodelivery product at the exact frequency as the isothiazolone was added.

Sessile samples were evaluated as mentioned above, with results below in Figure 14. Prior to both biocide additions, the baseline of the microbial counts without the addition of biocide was at least \(1 \times 10^6\text{cfu/cm}^2\) with the baseline level being closer to \(1 \times 10^7\text{cfu/cm}^2\) prior to the addition of the Novel Biodelivery product. Each biocide was added three times a week at a level of 4ppm active ingredient and sampled on Friday of each week for microbial counts.

Initial drop of organism count after the initial dosing period was more pronounced with the Targeted Delivery than with the straight isothiazolone in having more than a 2 log drop verses a half of a log drop. The Targeted Delivery product, although some fluctuation was more pronounced with the Targeted Delivery than with the straight isothiazolone, was able to drop the counts quickly and maintain lower than straight isothiazolone. Ultimately at the end of each doing period the straight isothiazolone had slightly more than a one log drop and the Targeted Delivery had almost a 4 log drop. (Figure 15)
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CONCLUSION

Biofilm formation causes a multitude of issues in water systems including reduced heat transfer efficiency, subsequent increases in energy costs, corrosion, damage to equipment and the potential to harbor disease causing organisms that effect human health.

Effective treatment of biofilms is therefore necessary to reduce such risks and also offers the benefit of more efficient overall system performance and cleanliness and the potential to reduce the eventual biocide feed amount.

The Targeted Delivery product was developed with these benefits in mind, taking already effective biocides and enhancing the efficiency of biofilm penetration and control.

In order to accomplish this task, much development and effort was required to produce a stable and efficacious product which incorporates a biocide into a liposome carrier for targeted delivery to biofilm. Through the development of the product, it was important to obtain data related not only to the efficacy and active ingredient, but also to the physical stability, trapping ability of the liposome and utilize various biofilm growth and monitoring methods.

Through this work, the Targeted Delivery product has demonstrated through laboratory evaluations and also in pilot cooling conditions the proof of concept of increased penetration and incorporation into biofilms leading to a more efficient and throughout clean-up of surfaces.

Acknowledgements

Much gratitude goes to Charles Ascolese who provided much content and guidance for this paper. Also to Gloria Tafel and Robert Semet for endless hours of tedious lab work.

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Figure 14. Sessile Sampler

Figure 15. Comparative Efficacy Results of the Targeted Delivery vs. un-encapsulated biocide
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Air Cooled Steam Condenser Test Laboratory

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Executive Summary
Power plants that incorporate Air Cooled Steam Condensers (ACC’s) offer significant water savings over power plants using traditional evaporative cooling technologies. State-of-the-art ACC’s feature single-row finned tubes installed in an A-frame steel structure. The steam from the turbine exhaust condenses as it is directly cooled by forced convection of the ambient air. Precise knowledge of the heat transfer and pressure drops both on the steam side and air side, are vital to allow the ACC supplier to properly rate the equipment and guarantee its performance.

EVAPCO has designed, built and commissioned a unique wind tunnel to investigate ACC heat exchangers. To best serve our clients, this one of a kind laboratory installation incorporates a full size (up to 35ft tall) heat exchanger test section, required for many client applications. The process loop produces steam under vacuum in conditions typically utilized in power or other process plant applications. The ability to test the heat exchanger with steam under vacuum rather than hot water makes it unique as well, and allows EVAPCO to optimize the Air Cooled Condenser design with unprecedented precision; giving particular attention to phenomena such as freezing, air leakage, impingement, flow accelerated corrosion (FAC) and limiting the high parasitic power losses associated with Air Cooled Condensers. The EVAPCO Dry Cooling test laboratory can not only test first stage (concurrent flow, K or condenser cell) or second stage flow (counter-flow, dephlegmator or reflux cell), in a 100% direct cooling configuration, but can be adapted to also test hybrid / parallel condensing systems.

Outline
This technical paper discusses the application of Air Cooled Steam Condensers (ACC) in power plants and the importance of performance testing the ACC heat exchangers. It also explores the benefits and shortcomings of small scale water testing, small scale steam testing and large scale steam testing. We will finish with product improvements that can be realized through testing.

ACC Background
The current state of the art ACC is constructed with single row finned tube heat exchangers in an A-frame steel structure in a forced draft configuration. The steam from the turbine exhaust condenses in the ACC as it is directly cooled by forced convection of the ambient air. Figure 1 illustrates a typical Air Cooled Condenser installation. The ACC heat exchangers (HX) are configured in an A-frame arrangement. Steam from the turbine exhaust enters the 1st stage heat exchangers through the steam distribution manifold. Axial flow fans mounted at the base of the A-frame force cooling air through the fins of the heat exchangers. The steam condenses as heat is transferred from the steam to the air moving across the fins outside the tubes. The condensate drains from the heat exchangers into a collection manifold which flows into the condensate tank. A pump transfers the condensate from the tank to the boiler system.

Figure 1
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Air Cooled Condensers reduce water consumption in combined cycle power plants by more than 97% when compared with traditional, recirculating wet cooling. They also eliminate the environmental effects of plume, drift, and blow down associated with wet cooling. Lower water usage and environmental impact allows for faster permitting than wet cooling.

ACCs are now present in many countries with over 200 GWe of generation capacity, and the number of new installations with ACC is growing rapidly.

Why test the heat exchangers?
The condensation temperature and pressure of the steam at the turbine exhaust affect the steam turbine efficiency and the power generation therefore thermal performance of the ACC has a direct impact on the power generation. Temperatures and pressures inside the ACC must be predicted accurately to meet or exceed the forecast power generation. ACC are the largest power consumers in a power plant. It is important to find ways to reduce the parasitic power losses due to the ACC.

Heat Transfer Knowledge
Precise knowledge of the heat transfer and pressure drops (steam-side and air-side) is critical to allow the ACC supplier to rate the equipment and guarantee its performance. Heat transfer in the steam HX can be expressed as:

\[ Q = \frac{U_{\text{overall}}}{\text{A}} \times \text{LMTD} \]

where:

\( Q \) = rate of heat transfer,
\( U_{\text{overall}} \) = overall heat transfer coefficient associated with A,
\( A \) = total heat transfer area
\( \text{LMTD} \) = log mean temperature difference.

Computation of Uoverall in the steam HX has 4 main components:
1. Condensation inside the tube.
2. Conduction through the tube wall and the fins.
3. Convection between the fins and the cooling air.
4. De-rate due to fouling.

By definition, the overall heat transfer resistance is equal to the inverse of the overall heat transfer coefficient Uoverall. Expressing these heat transfer components as a sum of resistances, the overall resistance is equal to the internal condensation resistance plus the conduction resistance of the fins and tube walls plus the external convection resistance:

\[ \frac{1}{U_{\text{overall}}} = R_{\text{overall}} = R_{\text{condensation}} + R_{\text{wall}} + R_{\text{convection}} \]

The fouling resistance is not included here since in a test cell it is approximately zero: \( R_{\text{fouling}} \approx 0 \). The conduction resistance of the fins and tube walls is well known.

The resistance of condensation and the resistance of convection are most accurately determined by testing. The resistance of condensation is low relative to air side convection and it varies with operating conditions along the tube length. The resistance of convection on the air-side is the highest; it primarily depends on tube and fin geometry. Precise knowledge of each resistance is required to accurately predict the thermal performance of the ACC.

A relatively quick and easy method to find the air side resistance to heat transfer of an ACC heat exchanger is to perform a small scale test whereby heated water is cooled inside the tubes, rather than condensing steam. Measurements are recorded of the temperatures, flow rates, and pressure drops on both the water side and air side. The water side resistance to heat transfer can be estimated through empirical correlations. The tube wall resistance is well known, the overall resistance is calculated from the test data, and the air side resistance is then found by subtracting the water side and wall resistances from the overall resistance:

\[ R_{\text{conv,air}} = R_{\text{overall}} - R_{\text{conv,water}} - R_{\text{wall}} \]

Small Scale Water Testing
Figure 2 is an illustration of an apparatus that has performed water tests on a small scale ACC heat exchanger. The 6' x 8' heat exchanger is mounted in a horizontal orientation in the vertical section of the tunnel. Blowers mounted on the end of the tunnel force air through a wall of flow nozzles prior to making the turn into vertical section where it flows through the heat exchanger.

Testing with water rather than steam has its shortcomings. In a steam condenser the temperature inside the tube is relatively constant along the length of the tube. In a water test, any heat transferred to the air side results in a decrease in the temperature of the water. The changing water temperature along the length of the tube does not represent ACC conditions. Minimizing the temperature change, or range, of the water side increases the uncertainty in the test analysis. Additionally, water tests provide no information on condensation such as:

- Local heat transfer, rate of condensation, internal pressure drop.
- Optimal balance between 1st and 2nd stage.
- Impact of non-condensable leading to freezing and loss of performance.
- Risk of flooding in two-phase flow.

Small Scale Steam Testing
Small scale steam testing could be considered as an option to overcome some of the shortcomings associated with small scale water testing. However, there are inherent weaknesses in scaling up small scale ACC test data to predict full scale ACC performance. A small scale test would utilize a heat exchanger with shorter tubes than an actual ACC.
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• Shorter tubes have less condensing capacity than longer tubes.
• Less condensing capacity equates to lower liquid and vapor flow rates in the shorter tubes.
• The internal heat transfer coefficient and the pressure drop are dependent upon the liquid and vapor flow rates.
• Small scale testing does not experimentally represent the heat transfer coefficients or the internal pressure drops that occur in full scale tubes.

Large Scale ACC Lab

The most accurate method of testing an ACC heat exchanger is to perform large scale testing that is representative of an actual plant installation. To conduct such tests we set out to construct an ACC test lab with the following design goals:

• Test large scale ACC HX condensing steam.
• A wide range of operating conditions.
• Several different configurations of interest.
• Accurately measure ACC thermal performance.

To reproduce full scale conditions, we have designed a laboratory that can test a full scale heat exchanger up to 2.4 m (8 ft) wide by 11 m (35 ft) long with the ability to generate over 4500 kg/hr (10,000 lb/hr) of saturated steam under vacuum at temperatures up to 65 °C (150 °F).

The lab will accommodate testing over a wide range of operating conditions including inlet air temperatures from -12 to 49 °C (10 to 120 °F) and inlet air velocities up to 4 m/s (800 FPM).

To achieve these conditions we designed a wind tunnel loop capable of blending hot air with cool air to control the inlet temperature to the heat exchanger.

Figure 3

On the steam side the lab is capable of testing condensing pressures from 50 to 260 mbara (1.5 to 7.7 inHgA), condensing temperatures from 33 to 65 °C (91 to 150 °F) and steam loads from 0.13 to 1.3 kg/s (1000 to 10,000 pounds per hour).

Figure 4 shows a simplified steam loop. Basically, water is boiled under vacuum in a kettle boiler. The water on the shell side of the kettle boils as heat is transferred from the hot water on tube side. Since the kettle and ACC bundle are both under vacuum, the temperature of the steam created in the kettle is similar to the condensing temperature in the ACC bundle.

In order to accurately predict the thermal performance of an ACC, it is necessary to accurately predict the performance of the heat exchangers in both 1st stage configuration (Concurrent Flow, K or condenser cell) and 2nd stage configuration (Counter-Flow, dephlegmator or reflux cell). Therefore the lab is designed to directly measure the performance of the heat exchangers in the 1st stage configuration or the 2nd stage configuration separately. Although its performance is measured separately, it is necessary for the 1st stage condenser to be paired with a 2nd stage condenser to simulate its operation and performance in an actual ACC. Varying the capacity of the 2nd stage condenser relative to the 1st stage will allow its impact on the thermal performance of the 1st stage to be studied. It will also allow the performance degradation due to the presence of non-condensable gases in the steam to be studied. Since the steam loop is designed and built to be leak-free, nitrogen gas will be injected in the steam loop at measured controlled rates to study the performance degradation in both 1st and 2nd stage configurations.

The first configuration of interest is to test the heat exchanger in a 1st stage configuration with variable 2nd stage capacity, as shown in Figure 5.

Figure 5
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Figure 6 describes the laboratory flow diagram for testing a 1st stage heat exchanger configuration.

Because the performance of the 1st stage heat exchanger is measured separately, the results are not affected by the type of heat exchanger providing the 2nd stage condensation. For flexibility of operation and space considerations, a water-cooled surface condenser provides the 2nd stage condensation capacity. The 2nd stage condensation rate and vapor velocity through the 1st stage can be controlled by manipulating the cooling water temperature supplied to the surface condenser.

Figure 7 illustrates the 2nd stage bundle configuration with steam entering the bottom, and non-condensable gases evacuated from the top.

Steam is drawn from the bottom of the 1st stage bundles through the condensate manifold into the bottom of the 2nd stage bundles. Figure 7 illustrates the 2nd stage bundle configuration with steam entering the bottom, and non-condensable gases evacuated from the top.

In Figure 8, you see the laboratory flow diagram for testing the ACC bundle in a 2nd stage configuration. Steam from the kettle boiler is piped directly to the bottom manifold of the tube bundle. The top manifold is piped to a vacuum pump.

Another design variable of interest is the effect of the angle of the tube bundle installation.

The bundles in the A-frame are nominally designed at 60 degrees from horizontal. The optimal design for some installations requires manipulation of the angle to control the height or the plan area of the ACC.

To explore the effects of the installation angle on the heat transfer and air flow characteristics the lab is designed to accommodate installation angles from 50 degrees to 70 degrees.

Many variables must be measured and recorded for accurate analysis of the ACC heat exchanger thermal performance. These include:

- Boiler water flow & temperatures.
- Steam temperature and pressure (HX in & out).
- Air temperature and pressure (HX in & out).
- HX condensate flow rate, pressure, and temperature.
- Surface condenser (2nd stage) condensate flow rate, pressure, and temperature.
- Air flow rate and velocity profile.

Redundant instruments take multiple measurements for all flows, pressures, and temperatures used for analyzing thermal performance. The load for each flow loop in the lab is calculated and energy balances are calculated to confirm the validity of the measurements for each loop.
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• Boiler load calculation (total load)
• HX steam side load calculation
• HX air side load calculation
• Surface condenser steam side load calculation (steam vapor velocity at outlet of HX tubes).
• Surface condenser water side load calculation.

Figure 10 is a plan view from the model created during the design of the lab.

The wind tunnel and fluid cooler are located outdoors, while the kettle boiler, propane boilers, surface condenser and other mechanical equipment are located indoors.

Figure 10

Figure 11 is a 3 dimensional view of the model.

Figure 11

Steam Lab Completed
These are photos of the completed wind tunnel. The blowers and air nozzles are located in the short section. The test bundle is installed in the tall section of the tunnel.

Figure 12

In Figure 14 you see the steam kettle boiler and in Figure 15 an ACC bundle in preparation for testing.

Figure 14
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Product Improvements
Full scale testing will facilitate improvements in materials of construction and fin and tube geometries.

The full size steam lab is helpful to test different materials used in ACC. New materials always play important roles in the upgrading of ACC. Potentially new types of fin and tube geometries, high-conductivity fin or tube materials will be evaluated experimentally in the lab.

Full scale testing also allows for optimization of the 1st stage / 2nd stage ratio considering thermal performance, condensation temperature and pressure, and freeze prevention for various air leakage rates. By injecting controlled flow rates of non-condensable gases into the steam loop, their effect on ACC performance can be studied.

ACC flow accelerated corrosion (FAC) has been reported but detailed research or analysis has been limited, in part due to the absence of low pressure high velocity steam in controlled laboratory conditions. A full scale steam lab can reproduce actual operating conditions that have reportedly caused corrosion. Findings may lead to product improvements to limit flow accelerated corrosion.

Conclusions
• Evapco has designed, built and commissioned a unique test lab to investigate ACC heat exchangers.
• One of a kind test lab with ability to test full size heat exchangers condensing steam under vacuum i.e. conditions typically used in power plants.
• Ability to test and analyze multiple configurations.
• Ability to rate ACC heat exchangers with unprecedented precision and to guarantee performance.

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Abstract
Most mechanical draft cooling towers used around the world operate by using standard mechanical air moving equipment such as an axial fan, a gearbox, a drive shaft and a motor. As presented in CTI Journal, Vol. 34, No. 1, a low-speed motor directly coupled to an axial fan [3] can present benefits to the cooling tower industry. This paper describes low-speed motor experiences of one European cooling tower manufacturer.

Keywords:
Low-speed motor, direct drive motor, coupled with axial fan

1. Introduction
Direct drive motors for cooling tower applications aren’t something new. As soon as the very first thermal power stations were built early in the last century, cooling towers were the weakest point. First cooling towers were very simple - natural draught type with simple wooden cooling fill.

Cooling efficiency was low and incremental gains in performance could be reached partly by cooling fill improvement and partly by increased air flow. These requirements are rather in conflict. Dense cooling fill increases air flow resistance, but decreases air draught. The tower height is limited by construction limitations or economic reasons, thus the only way to increase air flow through the tower is by means of a powered fan. Discrepancy between required fan speed and much higher motor speed has been solved by use of mechanical transmission, (rubber or leather) belts at first, and a gearbox reducer at later stages. In spite of indisputable technical progress, each solution also brought its own disadvantages. Unreliability and short service life is typical for belts; oil leakage and heavy construction, or necessity of oil cooling is typical for gearbox reducers. The idea of low-speed motor coupled directly with axial fans has been born.

2. Low-speed motors development
The first motors, as known to us intended for direct driving of cooling tower fans were produced in the Soviet Union in the early 60’s. These low-speed motors, known as VASO type motors were robust, rigid-welded frame motors providing power output 75 and 90kW with the speed of 220 RPM. These motors were mainly used in the Russian market.

First prototypes were developed in Czechoslovakia 20 years later, but systematic development and first commercial “in operation” activity was accomplished at the beginning of the 1990’s. First evolutionary induction motors in Czechoslovakia were already two-speed with switchable DAHLANDER windings. Typical motor performances are given in the following Table 01:

Note: DAHLANDER winding means pole-changing winding in a ratio of 2:1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
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<td>Output power</td>
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<td>IP 44</td>
<td>IP 44</td>
</tr>
<tr>
<td>Insulation class</td>
<td></td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Cooling</td>
<td></td>
<td>IC 418</td>
<td>IC 418</td>
</tr>
<tr>
<td>Mass</td>
<td>kg</td>
<td>2450</td>
<td>3280</td>
</tr>
</tbody>
</table>

Table 01: First induction motors

Figure 01: Gearbox application installed in Lukoil refinery, Bourgas, Bulgaria

Regularity low-speed motors could be offered as two-speed induction motors as well as single-speed motors or motors intended for power supply from frequency inverters.

Synchronous motors with permanent magnets installed on the rotor are another item being successfully produced.

In comparison with the same power-asynchronous motors, these are significantly smaller and continuously controllable. The size
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difference is caused by significantly improved power factor of the synchronous motor.

In order to protect winding against moisture condensation, all well engineered motors are fitted with heating elements, which are switched on during long-term shut-down periods, e.g. during winter season.

3. Motor monitoring

In order to record temperature during operation, all motors are equipped with several protecting sensors. There are two sets of three PTC thermistors embedded in the motor winding and two Pt100 resistance thermometers for both bearings. This is the monitoring equipment of regular low-speed motor.

*Note:* PTC thermistors yield very steep resistance-temperature characteristic, suitable for ON-OFF control.

Customized motors may contain two-stage winding thermal protection by means of PTC 130 and PTC 145 sensors. Another option could be KTY instead of PTC, or Pt100 thermometers. Vibration transducers become almost standard monitoring equipment of low-speed motors. Output signals of all sensors can be continuously recorded by monitoring apparatus.

*Note:* KTY is silicon-semiconductor based thermometer with quadratic resistance-temperature characteristic. In comparison to PT100 thermometer, KTY is cheaper however, less accurate.

By continuously measuring all parameters such as winding temperature, bearing temperature and vibration level, it provides protection of driver and fan. All emergency situations could be signaled or stopped in emergency.

<table>
<thead>
<tr>
<th>Emergency situation</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding temperature rising</td>
<td>Winding failure</td>
</tr>
<tr>
<td>Bearing temperature rising</td>
<td>Motor overloading</td>
</tr>
<tr>
<td>Bearing temperature rising</td>
<td>Insufficient greasing</td>
</tr>
<tr>
<td>Vibration level increasing</td>
<td>Motor mechanical disorder</td>
</tr>
<tr>
<td></td>
<td>Fan impeller damage</td>
</tr>
<tr>
<td></td>
<td>Loose hinges</td>
</tr>
</tbody>
</table>

Table 02: Emergency situation

Monitoring unit can work separately or could be linked by means of any standard interface to the control system, e.g. local monitoring system or plant control system.

Because of the 8-10 m/s air speed inside the fan stack at motor level the motor is cooled sufficiently enough by its own ribs. Moreover, as described above, low-speed motors are equipped with several protection elements.

4. Low-speed motor meets nuclear power plant safety requirements

Like other equipment used in nuclear power plants, direct drives must meet very strict safety rules and severe service conditions.
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Power supply from two different mains and high ambient temperature are occasionally specified but is an unusual requirement.

Due to the safety reasons, low-speed motors should run both in regular-operation conditions and in emergency-operation conditions of the nuclear power plant. That is the reason why a supply from two independent mains is important.

Therefore it is not possible to use the motor with two-speed (pole-changing winding), in spite of speed ratio 2:1 and output power ratio 8:1, being demanded.

That is the reason why a nuclear grade motor has got a 40 - pole high voltage winding and an 80 - pole low voltage winding, both embedded in the same slots.

Another technical challenge is to place a direct driver into cooling towers in chemical plants, especially petroleum refineries. These explosion-proof motors must match the rating Exd IIB+H2 (certificates IECEx and ATEX) according to international standards IEC and EN.

Note: Ex…explosion proof – generally; d…flameproof; IIB+H2…motor intended for explosive gas atmosphere except acetylene and carbon-disulphide; T4 … motor surface temperature up to 135°C; IECEx scheme as per IEC Standard; ATEX scheme as per EN Standard.

5. Low-speed motor experience

During 20 years of positive experience, low-speed drives have replaced standard gear-box reducer based mechanical drive units, which had held a dominant position in this field for over the past 60 years. During this time period, more than 700 direct drives, primarily in Central and Eastern Europe, have been put into the operation As seen from the table below, there are many low-speed motor advantages, compared with gear-box reducer installation.

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple mechanical construction</td>
<td>Only two greaseless bearings</td>
</tr>
<tr>
<td>Long service life of whole set</td>
<td>Much lower vibration than gear-box application</td>
</tr>
<tr>
<td>No damaged bearings during shut-down period</td>
<td>Slow movement of fan impeller due to natural draught</td>
</tr>
<tr>
<td>Maintenance free</td>
<td>Without oil lubrication system</td>
</tr>
<tr>
<td>Energy saving</td>
<td>Gear-box losses eliminated</td>
</tr>
<tr>
<td>De-freezing application</td>
<td>Fan impeller reverse direction</td>
</tr>
</tbody>
</table>

Table 04: Low-speed motor benefits

Two important environmental aspects of these drives cannot be omitted, such as low noise and no oil leakage. On the other hand, low-speed motor has got its own disadvantages. As described by Figure 10 below, low-speed motor weight is significantly more than weight of regular motor. This could be reason,
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why low-speed motor solution may not be recommended for cooling tower refurbishment. Structural adjustment could be technically or economically unacceptable.

Another important disadvantage could be initial cost. As could be noted from Figure 11, initial costs difference of low power motors is more than cost difference of bigger ones.

6. Conclusion
Direct fan drives in induced draught cooling towers have many benefits as outlined above. Which is the result of an interaction between motor, fan, cooling fill, water distribution and tower construction development. The best advantages of a low-speed motor are its own simplicity, reliability, energy savings, low noise and low maintenance. These characteristics along with corrosion-proof materials, high-quality coatings and low vibration levels are the main reasons for this motor’s long service life. 15 years’ service interval between motor’s bearing replacements in such an aggressive cooling tower environment is sufficiently self-explanatory. These are valuable aspects for economic evaluation, often neglected by economists.

Note: 130 000 hours of bearings service interval could be reached by correct grease maintenance. As clearly stated in low-speed motor manual, old grease should be replaced by new one, after seven years in operation.

References
[1] List, Paměti, ČES 1992
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- Used regularly, DTEA II maintains maximum operating efficiency by keeping surfaces clean.
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- Maintaining a system with DTEA II allows peace of mind that the system is continually kept clean, with a proven chemistry, and increases customer satisfaction.

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Microbial Corrosion on Metallic Surfaces

Karoline Bohlen, Colorado School of Mines

Introduction

In the last decades extensive studies on microbial corrosion on metals have been pursued. The underlying conclusion to these studies is that it is a complex subject, and still not yet well understood. The studies yield ever more results, widening the areas of detail to further research. It’s been found that many bacterial species can be part of the corrosion process. Likewise, different metal surfaces show different progressions of corrosion; the environment plays a big part of the process; and microbes can even inhibit corrosion of the metals. As such, there is not even a consensus as to the role microbes play – it is quoted from varying sources that microbial induced corrosion is involved in the range of 2% to 90% of the problem. This paper summarizes the process and proposes yet another, more general research approach.

Corrosion Chemistry

Corrosion of metals is broadly defined as an anodic reaction that occurs at the surface of a metal, where the metal is the reactant subjected to oxidation (Lewandowski and Beyenal, 2008). On these metals, anodic reactions (oxidation) are coupled with cathodic reactions (reductions), creating a reduction and oxidation (redox) situation. Water is the host solution found in most corrosive environments, even if not visibly present. In aerobic environments the primary cathodic reaction is reduction of dissolved oxygen from water molecules. In anaerobic environments, the cathodic reaction reduces protons, typically again from water. While many metals can be involved, the most studied corrosive metal is iron. Table 1 presents some general corrosion equations for iron (Fe).

<table>
<thead>
<tr>
<th>Anodic</th>
<th>Cathodic</th>
<th>Net</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe → Fe^{2+} + 2e^-</td>
<td>2H_{2}O → O_{2} + 4e^- + 4H^{+}</td>
<td>=&gt;</td>
</tr>
</tbody>
</table>

Table 1. Empirical iron corrosion equations in aqueous solutions (Lewandowski and Beyenal, 2008)

In using thermodynamic principles and the empirical equations, established redox potentials for standard pairs and known concentration of ions, one can apply the Nernst equation to find reaction potentials. For some Nernst equations, data on partial pressure and pH is also required. An example thermodynamic set of equations is provided below.

\[ Fe^{2+} + 2e^- \rightarrow Fe \]  \[ E^o = -0.44 \text{ V}_{\text{SHE}} \]  \[ E = E^o - 0.059/n * \log(1/[Fe^{2+}]) \]  \[ E = -0.44 + (0.059/2) * \log [Fe^{2+}] \]  \[ if [Fe^{2+}] = 10^{-6}M, E = -0.62 \text{ V}_{\text{SHE}} \]

However, even knowing all these variables, thermodynamic principles can only be used when reaction rates are at equilibrium. Corrosion reactions are not at equilibrium, and so corrosion potentials are not easily predicted. Thermodynamics can, however, predict the directions in which corrosion reactions will occur.

Typically the metal surface is the primary location of redox reactions. Metals can act as sources or sinks of electrons, allowing for more than one redox reaction taking place on the surface at any one time. Each of these reactions strives to reach its own equilibrium potential, creating a mixed potential at the surface. Kinetic computations can determine individual directions of the reactions, determining whether the system polarizations are primarily cathodic or anodic (system overpotential). The Butler-Volmer equation can provide the magnitude of the net current of the system using the overpotential and system exchange current density. This can help predict the rate of corrosion (Lewandowski and Beyenal, 2008).

Passive metals and alloys, the best known of which is stainless steel, show different corrosion mechanisms than active metals such as raw iron. While stainless steel corrosion reactions are the same as those for iron, the alloy components within form dense layers of oxides when oxidized. Known as the passive layer, this oxidized layer prevents further corrosion, but only to a certain extent. Passive metals undergo corrosion steps initially as iron until the passivation potential is reached. At this point, the alloy components are oxidized and form the dense passive layers on the surface, considerably slowing down the corrosion process. No corrosion can occur until the pitting potential is reached. When the pitting potential is exceeded, the corrosion current increases at the site, generally in small localized areas. These then become focused anodic sites, leading to pitting. This localized damage can progress faster than general total surface corrosion (Lewandowski and Beyenal, 2008).

The most well-known corrosion of iron is in rust formation on steel when in contact with oxygen and water (Konhauser, 2007). Anoxic corrosion of steel occurs because of other electron acceptor (as there is no oxygen) availability. Protons themselves can be reduced due to the very negative electrode potential of elemental iron. In anoxic corrosion, in addition to the anodic equation found in Table 1, Equation 5 may also be occurring:

\[ Fe^{0} + 2H^{+} \rightarrow Fe^{2+} + H_{2} \]  \[ [5] \]
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In anoxic waters, Equation 5 leads to H2 adsorption on the surface, forming a passive layer of protection (Konhauser, 2007). In essence, this initially slows the corrosion rate.

**Microbially Induced Corrosion**

With the several reactions involved in metal corrosion, myriad intermediate products are produced. Microorganisms can be substantial contributors to metal corrosion by increasing the rates of these reactions by their consumption of these products. Microbes can also generate their own reactions, adding to the possible corrosion reactions already listed. It’s been found that microbes can stimulate metallic corrosion through production of organic acids, CO2, and sulfur species, primarily through oxidation of hydrogen and reduction of iron (Duncan et al, 2009).

While not a requirement, microbes prefer to be attached to surfaces that can provide nutrients or energy sources. These surface attachments can be in the form of pili, nanowires, EPS (extracellular polymeric substances), etc. As more layers of microorganisms utilize the surface, biofilms are created. Within these biofilms, several types of microorganisms are usually found; rarely is a single species seen in a biofilm.

Chemolithoautotrophs (microbes that acquire energy from chemical reactions of inorganic electron donors and inorganic carbon sources) are serious corrosive agents of stone and minerals (e.g. concrete sewers), but they can also play a role in steel corrosion. While a galvanic corrosion site may slow due to limiting Fe(OH)3 production, Fe(II)-oxidizing bacteria also form Fe(OH)3, ensuring a continual supply of it as a cathode. In addition, this cycle attracts chloride anions (ubiquitous in soil and water), which can form extremely corrosive heavy metal chlorides. The heterogeneity of this environment induces pitting of the metal surface. Figure 1 gives a general schematic of these processes.

Chemoheterotrophs are also implicated in metallic corrosion, especially the sulfate-reducing bacteria (SRB). SRB can indirectly promote corrosion by forming an iron sulfide layer on the metal surface (Equation 6 below), and then directly cause corrosion by utilizing hydrogenase to accept the H2 from the indirect equation activity, releasing protons. The protons directly attack the metal surface, releasing more H2 and Fe(II), seen in Equation 7.

Figure 2. SRB reactions with steel surface, where 1) is cathodic production, 2) is anodic depolarization, 3) is H2S production, and 4) is an indirect supply of H+ (Konhauser, 2007).

Sulfate is reduced by the SRB, creating H2S, which then reacts with the Fe2+ to form FeS and more protons. The many reactions of SRB are depicted in Figure 2.

- Fe2+ + H2S → FeS + H2
- Fe2+ + 2H+ → Fe3+ + H2
- 4H2 + SO4$^{2-}$ → H2S + 2H2O + 2OH⁻
- Fe2+ + H2S → FeS + 2H⁺

Fungi, not in the Bacteria family but rather the Eucarya, can also corrode metals. Most often this corrosion is in the form of organic acid production that corrodes aircraft fuel tanks (Konhauser, 2007). Few studies have been performed on these microorganisms and their metallic corrosion activity. Most of the fungal corrosion research is focused on cement corrosion, including nuclear repositories.

**Microbial Inhibition of Corrosion**

Corrosion inhibition is a retardation of corrosion reactions, usually performed by the addition of substances to an environment (e.g. alloys in iron). As noted above, this electrochemical reaction usually occurs by forming a protective film based on initial reactions between the surface and the environment. This film development is reversible, and a supply of the inhibitor must be available to maintain this protective film as alluded to in the previous section. The presence of bacteria often erodes the film faster than it can be produced. However, bacteria can also act as inhibitors themselves, including production of a protective H2 layer as mentioned above. Some work has been done to research the viability of using microbes as corrosion inhibitors. An excellent paper on microbial inhibition was written by Videla and Herrera in 2009, and much of this section references that publication.

Just as microbial corrosion cannot be simply defined, microbial inhibition can not be defined as a single, universal mechanism. Biofilm constituents, the metal surface, the corrosion products and reactants, and localized environments must all be considered when trying to understand corrosion and inhibition. Just as a corrosive environment will change due to ongoing reactions therein, so will an inhibition environment.
Two primary areas of microbial inhibition have been explored. The first is in neutralizing the effects of the corrosive metabolites often produced by microorganisms. Encouraging microbial activity that directly or indirectly counteracts the metabolite effects could inhibit corrosion. This can be accomplished by providing an optimal environment to promote growth of these beneficial bacteria. The second area of focus has been to form or stabilize the protective films on the metal surface. In particular, SRB activity can be monitored by controlling the amount of free sulfide and soluble iron. The absence or presence of biofilm layer constituents can determine if the layers are protective or corrosive to the metal.

A large problem for inhibition research is the heterogeneities that often prevail with microbes and biofilm production, inducing pitting. Even a single, localized area can reverse from inhibitory to corrosive by bacteria within the biofilm. Much research and collaboration between the fields of corrosion engineering, metallurgy, and molecular biology is needed to further the progress of microbial corrosion inhibition.

**Microbial Induced Corrosion Studies**

As more evidence of microbial corrosion is surfacing, considerable research is being performed to determine the effects of microbial induced corrosion (MIC) and how abiotic corrosion can be enhanced by microbial influence. Different laboratory studies on measuring corrosion potentials have produced different results, exacerbating the non-consensus as to the microbial effect on corrosion. The variety of laboratory environments makes it difficult to produce normalized results. Some examples are provided.

R.G.J. Edyvean and colleagues found that a biological biofilm in seawater, compared to an abiotic film, slowed down hydrogen embrittlement and subsequent crack growth on metal immersed in seawater (Videla and Herrera, 2009).

In studying the concept of nanowires in bacteria, Mehanna et al monitored electrochemical behavior of stainless steel in the presence of \textit{G. sulfurreducens}. Potentials were recorded from -100 mV before bacterial inoculation to over +350 mV after inoculation. Ennoblement (increase in corrosion potential) was produced by a 443 mV increase of free potential in one run. In contrast, pitting potentials were increased from 840 mV without bacteria to 1009 mV, with the dense biofilms acting as inhibitors. However, deep pits formed under the dense biofilms once the pitting potential was exceeded, and scattered microbial settle - ments (very thin or no biofilms) created no pitting. It was also found that several \textit{Geobacter} species were able to achieve direct electron transfer, implicating these species as primary corrosion contributors (Mehanna et al, 2009b).

In another study by Mehanna et al, several alloys of steel were used to study the influence of \textit{G. sulfurreducens} on corrosion. In all cases, bacteria enhanced the rate of corrosion, although
it was noted that the amount of bacteria present affected the rate of potential ennoblement, which was increased by around 350 mV on all steel alloys. The areas of corrosion and pitting were not general, but localized into bacterial-determined zones (Mehanna et al, 2009a).

There are few studies on MIC on cooling towers, but it has been determined that MIC is the most common reason for corrosion of this equipment. Specifically, the zinc used in galvanized steel, the metal commonly used in construction of cooling towers, is found to be toxic to SRB strains and several other microorganisms. However, in structural failures due to pitting, high SRB and heterotrophic bacteria counts have been found. It is theorized that this is possible in these high zinc environments due to biofilm development entailing a dynamic bacterial consortium (Ilhan-Sungur and Çotuk, 2010).

While Geobacter sulfurreducens are often used in laboratory environments, Dinh et al found that Desulfo bacterium-like bacteria isolates, and Methanobacterium-like archeon isolates reduced sulphate and produced methane, respectively, from iron much faster than conventional species (Dinh et al, 2004). It is now presumed this is from the production of nanowires in microorganisms as a means to exchange electrons between the donors and acceptors. While this paper was focused on understanding the hydrogen consumption rate change due to unique microbes, the authors knew to use iron as the metal because of the anaerobic corrosion potential of microorganisms.

MIC in metal oil and gas pipelines has been realized for some time. The majority of research has previously been on targeting SRB a mesophilic species. However, corrosion is also common in the oilfields of Alaska, showing that other microbes must be involved as well. Duncan et al (2009) show that there is a large microbial community, including archaea, found in all equipment of an oil field, with subsequent biocorrosion implications.

**Biotic and Abiotic Process Comparison**

As can be seen by the above studies, it appears most MIC research is focused on singular aspects to further understand the processes. Recent work on nanowires has cultivated some naysayers as to their existence due to lack of reproducibility of some works. The results from measurement of microbial activities have been deemed to be subjective, saying there is no way to separate the abiotic and biotic processes. Even the above selection of studies does not show consistency on comparing the MIC to abiotic processes. While metal corrosion can occur abiotically, especially in oxic environments, it is rare that an operating system is completely free of microorganisms outside the laboratory. It is suggested that an encompassing project be undertaken to provide detailed information on a larger boundary of tasks, in a highly controlled and repeatable environment.

The simple premise of this project is to take repeated self-potential measurements of samples, with intermittent samples from the separate environments to determine and track microbial consortia. An interdisciplinary team should be assembled to perform in their respective areas of expertise. Identical metal electrodes, perhaps cut from a single large sheet, will be cut in identical lengths and sterilized. Each isolated environment will consist of 3 areas: a control electrode in no media but ambient air, an electrode ½ submerged in a sterile abiotic medium, and an electrode ½ submerged in a biotic medium. A general setup is shown in Figure 3.

There will be several of these setups, each with one different variable. The medium (soil, seawater, sand, types of each) or microorganisms (single species, consortia, etc.) will differ between setups. All readings and sampling should be taken every 15 minutes in the beginning, and then every 1 hour, then every 6 hours, until no further changes are noted, or until a predetermined time. For this, sufficient space and personnel need be available so that the timing readings are recorded at like times. This setup and experiment can be repeated with different metal alloys as deemed useful.

The results of this simple but expansive project should definitively define the differences between biotic and abiotic corrosion rates and the microbes involved in the changes. This work would be published and presented in pertinent venues. It is hoped that some continuity to understanding MIC and microbial inhibition could be resolved and further open avenues for future research.

**Summary**

A literature review has shown that there is little cohesiveness to current research on microbial induced corrosion. However, the complexity increases in the topic as study continues, and where some understanding is increasing, there is much research to be pursued. Previous research has shown that microorganisms may also promote inhibition of corrosion to a limited extent, adding more to the complexity. The known consortium of microbes involved is ever growing, even within same environments. A simple project is proposed to consolidate results in a controlled environment to allow a base understanding of microbial effects and participants.

**References**


Research on Reducing Recirculation Influence of Warm and Saturated Air Discharged From Cooling Towers

Liu Zhenyan, Biao Bingguo
Jiangsu Seagull Cooling Tower Co., Ltd.,
Changzhou, China

Abstract
For mechanical draft cooling tower group, warm, saturated air discharged from cooling towers can produce recirculation, so as to increase temperature and moisture of air entering into cooling tower. The researches show that the recirculation ratio is related to length of cooling tower row, the distance between tower rows, tower structure and wind velocity and the angle between long axis of tower row and wind direction. Based on present formulas for calculating cooling tower recirculation ratio, a new formula for the warm and saturated air recirculation ratio is presented through simulative experiments and running test on site for different cooling tower groups. According to the new formula, the calculated results are in accordance with test values on site. The related factors will be adjusted based on the new formula, so as to obtain the minimum recirculation ratio. The formula can be used to calculate practical recirculation ratio of cooling tower group correctly and optimize layout of cooling tower group.

Introduction
The height of mechanical-draft cooling tower body is much lower and tower number of cooling tower group is more than that of natural draft cooling tower, so recirculation influence of warm and saturated air discharged from cooling towers is more. Wind velocity, wind direction around cooling towers and structure of cooling tower, length of cooling tower row, distance between cooling tower rows etc. will affect the recirculation. Ambient air entering into the cooling tower will be mixed with the part warm and saturated air, so as to increase temperature and moisture of air entering into towers. Recirculation of the warm and saturated air is known to reduce the performance of rows of cooling tower units or cells according to CTI Bulletin PFM-110 and the British Standards Institution Code BS4485(1). So the improvement of cooling tower structure on one hand can reduce warm, saturated air recirculation(2); on another hand the relationship between the recirculation ratio and the related factors were studied. At present, there are several calculated formulas for the recirculation of cooling tower. The formulas are the following:

1. Formula which is currently accepted from CTI Bulletin PFM-110 for calculating recirculation ratio is
   \[ R = \frac{0.24 \times L}{1 + 0.013 \times L} \]  (1)
   Where
   L is ratio of length of cooling tower row to 1 meter and unit of length of cooling tower row is m.

2. (BS-4485) of Britain Standard considered that maximum percent of air recirculation on downwind side of cooling tower is 20% of total air flow volume discharged from cooling tower. And recommendation for design of cooling tower is 60% of the maximum recirculation ratio.

3. Another formula analogous to formula (1) which is also currently accepted for calculating recirculation ratio (3) is
   \[ R = \frac{0.22 \times L}{1 + 0.012 \times L} \]  (2)
   Where
   L is ratio of length of cooling tower row to 1 meter

4. Institute of Feed Water, Water Discharge, Hydraulic Structures and Hydro-geological Engineering Sciences of Russia put out the formula for calculating air inlet wet-bulb temperature change caused by the recirculation(3).
   \[ \Delta \tau = 0.2B[1 + K(N-1)\sin a] \]  (3)
   Where
   \( \tau \) is wet bulb temperature of the inlet air °C
   B is impact factor of cooling tower row’s length which is not more than 100m
   K is impact factor of distance between tower and tower which distance scope is 20-40 m
   N is ordinal number of cooling tower row
   \( a \) is angle between long axis of cooling tower row and wind direction

Formula (1) and Formula (2) are only related to length of cooling tower row, whereas distance between tower rows, wind speed, wind direction and air inlet height etc. are not taken into account. So the calculated values of the recirculation ratio are often much more than the actual values. Formula (3) had considered cooling tower row length, distance between tower rows and angle between wind direction and long axis of cooling tower row. But wind velocity and height of air inlet etc. were not yet considered. The value of the recirculation ratio obtained by wet bulb temperature of the inlet air calculated based on formula (3) is obviously lower than that of the testing. The formula could not be used to large cooling tower groups, because they are beyond the use scope of the formula. In addition, the recirculation ratio of the cooling tower is related to structure of cooling tower, too.

Calculation modeling of thermal performance of cooling tower for recirculation of warm, saturated air
Due to the warm, saturated air recirculation, the inlet air enthalpy of cooling tower is calculated by
   \[ G_{h_i} = G_{h_{out}} + (G - G_i)h_{a_{in}} \]  (4)
   From Eq.(4)
   \[ h_{a_{in}} = h_{a_{out}} + (G/G_i)(h_{out} - h_{a_{in}}) \]  (5)
   For moisture of the air
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\[ Gx_{in} = Gx_{out} + (G - Gr)x_{atm} \]  \hspace{1cm} (6)
From Eq. (6)
\[ X_{in} = x_{atm} + (G/G)(x_{out} - x_{atm}) \]  \hspace{1cm} (7)

Where

\( G \) is inlet tower airflow rate, kg/h
\( Gr \) is flow rate of recirculation air, kg/h
\( h_{atm} \) is specific enthalpy of ambient air, kj/kg
\( x_{atm} \) is moisture content of ambient air, kg/kg dry air
\( h_{out} \) is specific enthalpy of outlet air of cooling tower, kj/kg
\( x_{out} \) is moisture content of outlet air of cooling tower, kg/kg dry air
\( h_{in} \) is specific enthalpy of inlet tower air mixed with recirculation air, kj/kg
\( x_{in} \) is moisture content of inlet tower air mixed with recirculation air, kg/kg dry air.

\( Gr/G = r \)
Where \( r \) is recirculation ratio, %

The energy balance equation between water and air in cooling tower is
\[ G(h_{out} - h_{in}) = Q c_{p}(t_1 - t_2) + Qe c_{p} t_2 \]  \hspace{1cm} (8)
\[ Qe = 0.00085Q (t_1 - t_2) / 1 \]  \hspace{1cm} (9)

Where

\( Q \) is cooling water flow rate, kg/h
\( t_1 \) is temperature of Inlet water, °C
\( t_2 \) is temperature of outlet water, °C
\( Q_e \) is water evaporative rate, kg/h
\( c_{p} \) is specific heat of water, kj/kg*°C
\( T_{a1} \) is ambient temperature °C.

Substitution Eq.(5) and Eq.(9) into Eq.(8):
\[ h_{in} = h_{atm} + [r/(1-r)](Q/G)c_{p}(t_1 - t_2)(1+0.00085 t_2/1) \]  \hspace{1cm} (10)
where
\( G/Q = \lambda \), it is ratio of inlet air mass to inlet water mass, \( Q/G = 1/\lambda \).

From \( Q_e = G (x_{out} - x_{in}) \), Eq.(7) and Eq.(9)
\[ X_{in} = x_{atm} + 0.00085 [r/(1-r)](Q/G)(t_1 - t_2) / 1 \]  \hspace{1cm} (11)

Recirculation ratio of cooling tower can be obtained by
\[ G 
\[ h_{in} = (1-r)G h_{atm} + rG h_{out} \]  \hspace{1cm} (12)
From Eq.(12)
\[ r = (h_{in} - h_{atm}) / (h_{out} - h_{atm}) \]  \hspace{1cm} (13)
From Eq. (8)
\[ h_{out} = (Q / G) c_{p} (t_1 - t_2) + (Q / G)c_{p} t_2 + h_{in} \]  \hspace{1cm} (14)

Where
\( h_{in} \) is enthalpy of inlet air of cooling tower, it can be calculated according to inlet air state including dry bulb temperature, wet bulb temperature and atmosphere pressure
\( h_{atm} \) is Ambient air enthalpy, it can be calculated according to ambient air state including dry bulb temperature, wet bulb temperature and atmosphere pressure
\( h_{out} \) is enthalpy of outlet air of cooling tower
\( r \) is recirculation ratio, %.

The above impacting factors for recirculation ratio can be gained by measuring. Considering the warm, saturated air recirculation, the enthalpy and moisture content of the inlet air can be gained by Eq. (10) and Eq. (11) and the dry bulb temperature \( t_1 \) of the inlet air can be calculated by
\[ h_{in} = 4.187 \times [0.2401 + (595 + 0.4701)x_{in}] \]  \hspace{1cm} (15)
The wet bulb temperature of the inlet air can be determined using the values of \( t_1 \) and \( h_{in} \) by air enthalpy-psychrometric chart. Then the revised inlet air parameters in the recirculation case will be put into normal cooling tower design procedure for calculating thermal performance of cooling tower.

Research of factors impacting on warm, saturated air recirculation for cooling tower group

The following factors which affect warm, saturated air recirculation were analyzed:

1. The longer length of the tower row is, the more the recirculation ratio of the cooling towers is.
2. The higher the inlet air velocity is, the more chance of warm and saturated air recirculation for cooling tower is.
3. When wind direction does not parallel to long axis of cooling tower row, distance between rows will affect the recirculation ratio. The larger angle between the wind direction and the long axis of cooling tower row is, the bigger the recirculation ratio is.
4. Distance between cooling tower rows is related to air intake height of the cooling tower for the recirculation.
5. Wind speeds will have an impact on the recirculation for cooling tower.

To reduce the recirculation influence of the warm and saturated air, simulating tests were carried out on cooling tower group layout and running conditions etc. The major research process is as follows:
The experiments on the recirculation ratio were studied in a variety of wind velocities and different angles ranged from 0° to 90° between wind direction and long axis of cooling tower row by simulation of different tower group in wind tunnel

By operation of actual cooling tower group on site thermal tests were carried out on different ambient air temperature and humidity, wind speed, wind direction, and different layout of cooling tower group.

From a large number of simulating experimental data and site tests for Seagull cooling tower operation a new formula of the recirculation ratio was presented which included the above relevant factors. A

Fig. 1 photo of simulative cooling tower group
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reasonable layout of cooling tower group can be achieved as much as possible to reduce the recirculation ratio of the tower group.

**Simulating test for cooling tower group**

Simulation experimental models of cooling tower group were made of plastics in accordance with proportional factor of 1:150 and analogy between actual cooling towers and the models which fans equipped with frequency converters so that air flow volume can be adjusted as shown in Figure 1. Air as working medium is the same as actual cooling towers. The simulative tower group was placed in visual experimental segment of a standard wind tunnel with 2 m diameter and 21 m long which could simulate ambient wind speeds from 0 to 10 m/s as shown in Figure 2. The location and direction of the simulation tower group could be regulated according to the experimental needs. A thermal insulating container was installed in the packed bed location of the simulative tower and replaced the original packed beds. The bottom of the container was uniformly perforated and dry ice (solid state CO\(_2\)) was put into the container. The test methods and principles are as follows:

At first the fan of the wind tunnel started. After the stable running, fans of the simulative towers in the wind tunnel were operated. Air entered into the towers under the action of induced draft fans flew through the dry ice layer and the dry ice was heated to sublimate. Gasification of dry ice carried heat from the air flowing through the layer, the air was rapidly cooled and became saturated air, then vapor of the air was condensed into tiny water droplets and formed white mist on the exit of the simulative towers, which could be observed in the tunnel. The sensors were installed at the side B and side C of the entrance and exit A of the cooling tower respectively for measuring the inlet air temperature, humidity and flow velocity as shown in Fig. 3. The average recirculation ratio could be calculated based on these data of the tower group. The auxiliary inspection of the recirculation ratio was CO detectors. Carbon monoxide was released by a nozzle installed in the middle of the tower. CO concentration detected from the inlet and outlet air was used to determine its recirculation ratio as shown in Figure 3.

The experiments simulated different wind speeds from 0 to 7 m/s and different angles included between wind direction and the long axis of the tower row which scope was 0° to 90°. The plume photos of the tower group are shown in Figure 4. They show plumes exhausted from the simulative cooling tower flow down significantly and the decline accelerates as wind speed increases.

**Results of simulating test**

The experimental study in analogy to actual cooling tower and the site test of cooling tower groups were made. The analysis based on the test data expressed in terms of the recirculation ratio it considered not only the effect of the length of cooling tower row and distance between the rows but effects of wind speed, angle between the wind direction and the long axis of cooling tower row and air inlet height of cooling tower. On the analytic basis of the above, the following results were gained:

1. The relation between the recirculation ratio and the tower row length is shown in Fig. 5. As the length of the tower row increases, the recirculation ratio increases but the increasing rate progressively decreases.
2. When distance between the tower rows is less than 4 times the air inlet height, the recirculation ratio reduces quickly as the distance increasing. As the distance between the
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tower rows is more than 5 times the air inlet height, the recirculation ratio slowly reduces as the distance increasing continuously as shown in Figure 6.

3. The recirculation ratio linearly increases proximately as wind speed increases as shown in Figure 7.

4. The recirculation ratio changes with sina which angle is included between the wind direction and the tower row long axis as shown in Figure 8.

In the basis of the above analysis and referring to Formula (1) and Formula (3), a new formula L-H for calculating the average recirculation ratio \( r \) was presented as follow:

\[
r = F \left[ \frac{AL}{1+BL} + \frac{L}{C} \sin a \frac{1}{D(L^4/H)^2} \right] (1+EV_1), \%
\]  

Where

- \( L \) is ratio of length of cooling tower row to 1 meter
- \( a \) is angle between tower row and wind direction, degree
- \( L_1 \) is distance between two near cooling tower rows, m
- \( H \) is height of air intake of cooling tower, m
- \( V_1 \) is ambient wind speed, m/s
- \( A, B, C, D \) and \( E \) are experimental constants respectively
- \( F \) is correlation coefficient of cooling tower structure.

Many large and medium sized cooling tower groups installed and produced by Jiangsu Seagull Cooling Tower Co. Ltd. were measured on site. Combine the site tests of the cooling tower operation and simulative experiments, experimental constants in formula (16) were taken as:

\[
A=0.12, B=0.013, C=40, D=0.51, E=0.056 \ \text{s/m}.
\]

For cooling towers, the recirculation extent of which depends primarily upon the entering and exiting air velocities and their relationship to each other. Higher entering velocities increase the potential for recirculation, while higher exiting velocities decrease its opportunity. \(^4\) \( F \) in formula (16) is taken as 1 or less than 1 according to different structures and air flow volume of cooling towers.

Recirculation ratio calculated by formula L-H compared with test values of cooling towers on site.

In order to verify the correctness of the recirculation ratio calculated by formula L-H, three cooling tower groups with different arranging ways were measured on site. The test values were compared with the values calculated by formula (1), formula (2) and formula L-H.

1. Test of cooling towers of Jiawang Power Plant in Xuzhou, China

    a. The plane layout diagram is shown in Fig.9.
Fig. 9 Plane layout of Cooling Tower Group of Jiawang Power Plant, mm

b. Test data of Jiawang cooling towers are given in Table 1.

Table 1 Test data of cooling towers of Jiawang Power Plant on site

Based on the test data, ambient air enthalpy was found out by the ambient air dry-bulb temperature and wet-bulb temperatures on an enthalpy- psychrometric chart, $h_{atm}=82.3 \text{kJ/kg}$, the inlet air enthalpy was found out by the inlet air dry-bulb temperature and wet-bulb temperatures on an enthalpy- psychrometric chart, $h_{in}=87.5 \text{kJ/kg}$. The outlet air enthalpy was calculated by Formula (14), $h_{out}=157.6 \text{kJ/kg}$. To substitute $h_{atm}$, $h_{in}$ and $h_{out}$ into Formula (13), the recirculation ratio $r$ was calculated as 6.91%. The recirculation ratio was calculated as 6.72% by Formula L-H. The deviation between the both was -2.75%.

2. Test of cooling towers of YZBF Company in Nanjing, China
   a. The plane layout diagram is shown in Fig.10.
   b. Test data of cooling towers of YZBF Company are given in Table 2.

Fig. 10: Plane layout of cooling tower group of YZBF Company, mm

Fig. 11: Plane layout of cooling tower group of CSPC South Sea Petrochemical Project A-8304/5, mm

2. Test of cooling towers of YZBF Company in Nanjing, China
   a. The plane layout diagram is shown in Fig.10.
   b. Test data of cooling towers of YZBF Company are given in Table 2.

Based on the test data, ambient air enthalpy was found out by the ambient air dry-bulb temperature and wet-bulb temperatures on a psychrometric chart, $h_{atm}=80.0 \text{kJ/kg}$, the inlet air enthalpy was found out by the inlet air dry-bulb temperature and wet-bulb temperatures on a psychrometric chart, $h_{in}=86.3 \text{kJ/kg}$. The outlet air enthalpy was calculated by Formula (14), $h_{out}=163.7 \text{kJ/kg}$. To substitute $h_{atm}$, $h_{in}$ and $h_{out}$ into Formula (13), the recirculation ratio $r$ was calculated as 7.53%. The recirculation ratio calculated by Formula L-H was 8.07%. The deviation between the both was +7.17%.

3. Test of cooling towers of CSPC south sea petrochemical project A-8304/5 in Huizhou, China
   a. The plane layout diagram of CSPC project is shown in Fig.11.

Table 2 Test data of cooling towers of YZBF Company on site

Based on the test data, ambient air enthalpy was found out by the ambient air dry-bulb temperature and wet-bulb temperatures on a psychrometric chart, $h_{atm}=80.0 \text{kJ/kg}$, the inlet air enthalpy was found out by the inlet air dry-bulb temperature and wet-bulb temperatures on a psychrometric chart, $h_{in}=86.3 \text{kJ/kg}$. The outlet air enthalpy was calculated by Formula (14), $h_{out}=163.7 \text{kJ/kg}$. To substitute $h_{atm}$, $h_{in}$ and $h_{out}$ into Formula (13), the recirculation ratio $r$ was calculated as 7.53%. The recirculation ratio calculated by Formula L-H was 8.07%. The deviation between the both was +7.17%.
b. Test data of cooling tower group of CSPC South Sea Petrochemical Project A-8304/5 are given in Table 3.

<table>
<thead>
<tr>
<th>Project name</th>
<th>Design value</th>
<th>Test value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water volume for single Tower, n/m³/h</td>
<td>4500</td>
<td>4480</td>
<td>Calculation based on the test value</td>
</tr>
<tr>
<td>size of single tower plane for spray, m</td>
<td>18.4 × 17.6</td>
<td>18.4 × 17.6</td>
<td></td>
</tr>
<tr>
<td>Inlet air flow volume, n/m³/h</td>
<td>3190000</td>
<td>3950000</td>
<td>Calculation based on the test value</td>
</tr>
<tr>
<td>Ambient wind velocity, m/s</td>
<td>2.0</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Angle included between wind direction and long axis of the Tower row</td>
<td>45°</td>
<td>45°</td>
<td></td>
</tr>
<tr>
<td>Ambient air dry bulb temperature, °C</td>
<td>28.0</td>
<td>28.0</td>
<td></td>
</tr>
<tr>
<td>Ambient air wet bulb temperature, °C</td>
<td>28.0</td>
<td>28.0</td>
<td></td>
</tr>
<tr>
<td>Inlet air wet bulb temperature, °C</td>
<td>28.0</td>
<td>28.0</td>
<td></td>
</tr>
<tr>
<td>Atmosphere pressure, kPa</td>
<td>100.5</td>
<td>100.5</td>
<td></td>
</tr>
<tr>
<td>Inlet water temperature, °C</td>
<td>42</td>
<td>43.5</td>
<td></td>
</tr>
<tr>
<td>Outlet water temperature, °C</td>
<td>32</td>
<td>32.8</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Test data of cooling tower group of CSPC South Sea Petrochemical Project A-8304/5

Based on the test data, ambient air enthalpy was found out by the ambient air dry-bulb temperature and wet-bulb temperatures on a enthalpy- psychrometric chart, hatm = 92.0 kJ/kg, the inlet air enthalpy was found out by the inlet air dry-bulb temperature and wet-bulb temperatures on a enthalpy- psychrometric chart, hin = 94.8 kJ/kg. The outlet air enthalpy was calculated by Formula (14), hout = 150.7 kJ/kg.

To substitute hatm, hin and hout into Formula (13), the recirculation ratio r was calculated as 4.77%. The recirculation ratio calculated by Formula L-H was 4.75% and coincided with the test value. The deviation between the both was 0.42%.

Optimizing layout of cooling tower group

The above analyses express that in order to reduce the recirculation ratio of the warm, saturated air, it’s very important to layout of cooling tower group. The following optimization steps are recommended:

1. Because of hot and humid climate in summer, cooling effect of cooling tower is poorer than that in other seasons, so it’s necessary to take the tower row long axis along the direction of summer monsoon, the angle θ is as small as possible in order to reducing the recirculation ratio.
2. Due to the length of the tower row is the main influence factor for the recirculation ratio, it is necessary to shorten the length.
3. The distance between the rows is suggested 4 times to 5 times air intake height of cooling tower. It is economic and effective for decreasing the recirculation ratio.
4. According to the site case, multivariate optimum calculation carried out by formula L-H can arrange layout of cooling tower group so as to obtain the minimum recirculation ratio of cooling towers.
5. The inlet air parameters of the cooling towers can be determined after the recirculation ratio is calculated by formula L-H, then design parameters of cooling tower will be determined so as to ensure the good cooling performance.

Conclusions

To reduce recirculation ratio of warn, saturated air discharged from cooling tower is the multiple-factor calculation process. Optimization layout of cooling tower group can obviously decrease the recirculation ratio. The experimental study in analogy to actual cooling tower and the site test of cooling tower groups were made. The analysis based on the experimental data and test data expressed the recirculation ratio is not only related to length of cooling tower row and distance between the rows but related to wind speed, angle included between wind direction and long axis of cooling tower row and structure of cooling tower. A new formula has been presented for calculating the practical recirculation ratio. Recirculation ratios calculated by Formula L-H can coincide with test values on site. Multivariate calculation carried out by formula L-H can optimize layout of cooling tower group so as to reduce the recirculation of cooling towers.

References

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Appendix: Reference photos

1. Photo of Cooling Tower Group of Jiawang Power Plant

2. Photo of cooling tower group of YZBF Company

3. Photo of cooling tower group of CSPC South Sea Petrochemical Project A-8304/5

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The purpose of this paper is to outline effective cleaning techniques for galvanized and stainless steel cooling tower fill and heat exchanger surfaces. Modern water treatment programs often require maximizing the cycles of concentration. Sulfuric acid is commonly employed to help maximize the cycles, but many systems cannot use this option due to safety or logistical limitations. This is particularly true with smaller systems typically seen in commercial and institutional facilities. Higher cycles of concentration combined with high efficiency fill leave little room for program forgiveness and often result in fouling because of scaling, evaporation salts, airborne contaminants and biological matter. Hardness salts can result due to the point of evaporation at the fill being supersaturated as compared with the bulk water or because of inadequate water flow over the fill. Galvanized and stainless steel towers are susceptible to corrosion by inhibited hydrochloric acids, elevated free chlorine levels and proprietary acid blends that are traditionally used to mitigate these issues.

This paper will discuss the following cleaning categories:

- In service cleaning to remove scale from the tower and heat exchangers.
- In service cleaning to remove biological or organic fouling from the tower and heat exchangers.

In each case listed above, the cleaner has to identify the safety concerns, potential impact on the environment, system metallurgy, impact on discharge regulations, and how to deal with waste materials. These issues must all be clearly identified and managed before proceeding with any cleaning.

### In-Service Cleaning Techniques to Remove Scale from the Tower and Heat Exchangers

Three effective methods were developed to remove scale from cooling tower and evaporative condenser systems while in service. The first process employs a proprietary surfactant, with the normal inhibitor program for 120 – 180 days. The surfactant penetrates the scale, and allows it to detach from the fill and release from heat exchanger surfaces and disperse with the water treatment program. This program is never 100% effective, but will often result in removal of up to 80% of the fouling minerals. This is also a great program to use prior to more extreme processes. The surfactant is also effective when used off line by spraying a 5:1 dilution on the fill and rinsing with a pressure washer with a fan nozzle so as not to damage the integrity of the film fill.

Before and after photos of the supplemental surfactant process on the tower fill can be found in Figure 1.

The second process requires the operator to drop the tower pH to a negative Langelier Saturation Index (LSI) while maintaining adequate corrosion inhibitors and higher scale inhibitor levels for 7 – 14 days or longer. The surfactant can be used to supplement this process. In summary the pH is lowered near the discharge limits and additional corrosion inhibitors and polymers are used to facilitate dissolution while preventing excess corrosion. Since the cycles are lowered and the inhibitor levels are typically tripled the cleaning is monitored by approach temperatures and ion balance and halted as soon as desired results are obtained. This method has the least negative impact on galvanized towers and condensers and discharge permits. This method has been used on numerous occasions where flow is not impeded to the critical heat exchangers. When flow is significantly impeded due to blocked tubes off-line mechanical cleaning is required. Where phosphate is a concern in the discharge alternate corrosion inhibitors may be employed. Laboratory spinner bath tests have produced copper corrosion rates of less than 0.2 mpy and mild steel corrosion rates of less than 1.5 mpy using Richmond, Virginia water cycled 5 times and Lake Michigan water cycled 5 times. This was comparable to results seen with alkaline programs on the same water.

### Table 1: Suggested Parameters for Negative LSI In-Service Scale Removal

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycles</td>
<td>Drop by 20 – 50%</td>
</tr>
<tr>
<td>pH (maintain permit limits)</td>
<td>6.0 – 6.5</td>
</tr>
<tr>
<td>Surfactant</td>
<td>60 – 80 ppm</td>
</tr>
<tr>
<td>Phosphonate as PBTC</td>
<td>8 – 12 ppm</td>
</tr>
<tr>
<td>Ortho-phosphate</td>
<td>18 – 22 ppm</td>
</tr>
<tr>
<td>Azole</td>
<td>&gt; 3 ppm</td>
</tr>
<tr>
<td>Polymeric Dispersants</td>
<td>15 – 28 ppm</td>
</tr>
</tbody>
</table>

The third process requires the operator to drop the tower pH below 3 using a specialty inhibited sulfamic acid and surfactant package and drop system cycles by 50% to reduce dissolved solids prior to initiating the cleaning. Local discharge permits may require neutralization of the cleaning solution, so a neutralization tank may be necessary. This process requires the operator to drop the pH to approximately 2.5 using a 0.5 – 1.0% by volume concentration of...
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inhibited sulfamic acid and readjust the pH below 3 every 30-60 minutes with another 0.5% charge of inhibited sulfamic acid. If the system requires more than a total of 4% by volume of sulfamic acid then the system should be flushed and neutralized and the process restarted.

Most systems are successfully cleaned with the initial 2.5% dose of sulfamic acid if they are addressed prior to severe fouling. This process is typically completed within 6 hours of initiation and can be completed in service or off line. A typical cleaning pH profile is provided in Figure 2. Following any low pH cleaning, high levels of azole and corrosion inhibitors are recommended for the first 48 hours. At a cleaning in Georgia the cleaning raised the calcium in the water from 237 mg/L to 23,321 ppm as calcium carbonate with the pH buffered to 5.76 and the corrosion loss on a new galvanized coupon was 0.015 mils after circulating overnight.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycles</td>
<td>Drop by 50% to reduce total dissolved solids</td>
</tr>
<tr>
<td>pH (discharge may require</td>
<td>2.2 – 3.0 during cleaning</td>
</tr>
<tr>
<td>neutralization)</td>
<td></td>
</tr>
<tr>
<td>Inhibited Sulfamic Acid</td>
<td>0.5-4.0% by weight</td>
</tr>
<tr>
<td>Post cleaning azole and inhibitor</td>
<td>250 - 300% of normal</td>
</tr>
<tr>
<td>levels for the first 48 hours</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Low pH Cleaning Parameters

In-Service Cleaning to Remove Biological and Organic Fouling from Towers and Heat Exchangers.

There are several effective methods to remove biological material from cooling tower fill and systems. Hyperhalogenation is a widely accepted method, but the damage to the system components is a concern. The methods outlined in the table below are contrasted with hyperhalogenation. Success can be achieved with any of these methods, but the peroxide and chlorine dioxide methods have produced the most dramatic results. One cleaning at a power plant in Southern California resulted in an increase from 79% cooling tower efficiency to 87% efficiency and a 0.5 megaWatt gain in production.

<table>
<thead>
<tr>
<th>Method</th>
<th>Concerns</th>
<th>Benefits</th>
<th>Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperhalogenation with a 5-10 ppm</td>
<td>Damage to metals</td>
<td>Low Cost and easy to implement</td>
<td>Efficient, but not affective at removing organics and will create chlorinated hydrocarbons</td>
</tr>
<tr>
<td>residual for 6 hours with surfactant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine Dioxide</td>
<td>Difficult to mobile</td>
<td>Doesn't react with many organics</td>
<td>Very Effective</td>
</tr>
<tr>
<td></td>
<td>Capital Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Requires several applications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid Chlorine Dioxide and surfactants</td>
<td></td>
<td>Doesn't react with many organics</td>
<td>Very Effective</td>
</tr>
<tr>
<td></td>
<td>Requires multiple applications</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peroxide and surfactants</td>
<td>500 - 3000 ppm as acetic peroxide is required</td>
<td>Great environmental profile</td>
<td>Very Effective</td>
</tr>
<tr>
<td></td>
<td>Need peroxide handling</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Knowledge and ability to shock the system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Comparison of Biofilm Removal Methods

Summary

Descaling and cooling tower fill and basin cleaning are becoming more and more necessary to meet performance and safety expectations. ASHRE standards and the CTI guidelines for Legionella control both suggest regular cleaning as a control and response method and have highlighted the need for effective cleaning processes. The purpose of this paper was to outline effective methods that have been employed by the author and provide methods to manage system upsets.
Figure 4: Before and After Hydrogen Peroxide Cleanings
James L. Baker, Composite Cooling Solutions, LLC

There is a misconception throughout the Power, Process, and HVAC industries that cooling towers are basically resistant to fire because they are by nature wet. This technical paper will explain in detail the facts about fires in cooling towers. It will address and clarify terminology, such as fire retardant vs. flame spread, and other misconceptions and misinterpretations.

After terminology is defined, this paper will address Factory Mutual (FM) Approval and the costs and advantages of this program. We will define FM and present the strict program that has to be completed to gain this accreditation. In addition, the paper will discuss how FM Approval results in savings in insurance premiums.

Sprinkler systems have been used for many years on both wood and FRP cooling towers. The paper will point out the advantages and disadvantages of the systems and how they can be misused without the addition of firewalls.

And finally, we will review the many standards that govern all types of fire protection systems and testing procedures. Some of these standards are: ASTM E-119, Testing Procedures; NFPA-13, Sprinkler Installations; NFPA-214, Sprinkler/Firewalls; CTI Chapter 12, Fire Protection; and NFPA 251 - Testing of Materials Procedures.

There are many different misleading interpretations of the requirements and methods of fire protection. At the close of this paper, we believe a clear understanding of fire protection in cooling towers will be presented.

INTRODUCTION


DEFINITIONS AND TERMINOLOGY

1. Fire Protection

The prevention and reduction of hazards associated with fires. This process includes the study of fire behavior, suppression, and investigation of the fire as well as the research and development, production, testing, and application of mitigating systems.

2. Combustible Material

A material under design conditions will ignite and burn and does not meet the definition of Non-Combustible or Limited-Combustible.

3. Limited-Combustible Material

Either a noncombustible material with a surfacing of no more than 1/8” that has a flame spread rating of 50 or less or self-extinguishing materials with a flame spread rating of 25 or less.

4. Non-Combustible Material

A material that under design conditions will not ignite, burn, support combustion, or release flammable vapors. All materials which have passed ASTM E-136 are non-combustible.

5. Fire Resistance

The property of a material or an assembly designed to withstand fire or provide protection from a fire.

6. Fire Resistant Wall

A tight, continuous wall that is suitable for use in a cooling tower environment that has a fire resistance rating of twenty minutes or more. The partition must extend from one foot below the operating water level of the cold water basin to the underside of the fan deck and/or distribution basin. The test for the wall must be performed in accordance with NFPA 251. Examples of walls that meet this requirement include: 12.7 mm (1/2 in) cement board, and 19.1 mm (3/4 in) tongue and grooved FRP material that are installed on both sides of wood studs or FRP structural members and tested in accordance with NFPA 251. Plywood walls have not been proven to be considered as a fire resistant wall in cooling towers.

7. Fire Resistance Rating

The fire resistance rating is the time that materials or assemblies have withstood a standard fire exposure. The rating should be determined in accordance with the NFPA 251 and NFPA 221, 2000 edition.

8. Self-Extinguishing

The ability of a material to cease burning once the igniting flame source is removed.

9. Fire Wall Test Specimen per NFPA 251

The test specimen must be a true representation of the construction for which the fire resistance rating is to be determined with respect to materials, workmanship, and details such as dimension of parts. The wall must be built under conditions representative of those properties that are applied in actual tower construction and operation.

10. Twenty Minute Fire Wall

The wall assembly must have withstood the fire endurance test without passage of flame or gases hot enough to ignite cotton waste for a period of time equal to twenty minutes. Note: The fire resistance wall is an assembly test of materials as the materials would be in an actual installation. The twenty minute fire wall is a NFPA 251 code.

11. Thirty Minute Fire Wall

The wall assembly must have withstood the fire endurance test without passage of flame or gases hot enough to ignite cotton waste for a period of time equal to thirty minutes. Note: The fire wall is an assembly test of materials as would be in an actual installation. The thirty minute fire wall is a NFPA 251 code.

12. Sprinkler System

A system of piping and nozzles designed to control or extinguish fires. The system includes a network of piping and sprinklers which are interconnected. The system also includes one or more automatic water supplies.

Note: Whether a tower has 20 minute firewalls installed per NFPA 251 determines the amount of water and locations that a sprinkler system must deliver in case of a fire. Generally speaking a cooling tower with non fire wall rated partition walls will require twice the amount of water distribution of the sprinkler system.

13. Wet Pipe System

A sprinkler system employing automatic sprinklers attached to a piping system containing water and connecting to a water supply so that water discharges immediately from sprinklers opened by heat in a fire.

14. Dry Pipe System

A sprinkler system employing automatic sprinklers attached to a piping system containing air or nitrogen under pressure, the release of which permits the water pressure to open a valve known as a dry pipe valve. The water then flows into the piping system and out the opened sprinklers.
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15. Pre-Action System
A sprinkler system employing automatic sprinklers attached to a piping system containing air that may or may not be under pressure, with a supplemental detection system installed in the same areas as the sprinklers. Actuating of the detection system opens a valve that permits water to flow into the sprinkler piping system and to be discharged from any sprinklers that may have opened.

16. Deluge System
A sprinkler system employing open sprinklers attached to a piping system connected to a water supply through a valve that is opened by the operation of a detection system installed in the same areas as the sprinklers. When the valve opens, water flows into the piping system and discharges from all sprinklers attached thereto.

17. FACTORY MUTUAL (FM) Tower
A cooling tower and all its components examined from a fire prevention standpoint and then evaluated for the quantity of combustible products. The cooling tower and components which have been tested, evaluated, and found to be a low fire hazard, not requiring an automatic sprinkler system when installed. This cooling tower must utilize only the materials and components that were tested as a system and approved by Factory Mutual.

18. Flame Spread Rating (Surface Burning Characteristics Rating)
The numerical rating of a material calculated from the results of a tunnel test. The rating indicates the relative rate at which flame will spread over the surface of the material as compared with flame spread on asbestos-cement board which is rated 0 and on red oak which is rated 100.

19. Test Method (Tunnel Test)
The test used to obtain results from which a rating is calculated. It is commonly referred to as the tunnel test as the testing equipment is a twenty-five foot tunnel.

20. ASTM E-119 (Assembly Test)
This is a fire wall assembly test not a product test. This is the test method used for fire resistance wall assemblies. The test exposes a wall assembly to standard fire conditions controlled to achieve specified temperatures throughout a specified time period. The fire exposures are typically followed by a standard hose stream test which subjects the specimen to impact erosion and cooling effect of water stream.

Cooling Tower Fire Hazards
Field erected cooling towers that are constructed completely, or in part, of combustible materials can support proliferating internal fires. overheating of the fan motor can start a fire. All electrical peripheral equipment is a potential for fire hazards.

Depending on the material, the fill media may be another fire hazard present in most cooling towers. Wood fill is combustible, polypropylene and polyethylene plastics are combustible even with fire retardants. PVC material is self-extinguishing but still has limited combustibility.

Human error is also a major contributing factor. Smoking, hot-work such as welding or cutting that was not appropriately managed, and overloading electrical circuits can be potential sources. Then there are the outside the cooling tower sources of fire hazards such as incinerators, smokestacks, or lightning.

The wet environment created by cooling tower operation does not negate the associated fire hazards. Fires can spread internally within a cooling tower during periods of operation as well as periods of maintenance or construction when the cell is not in operation.

Some types of cooling towers are even more susceptible to fire hazards because of the dry areas within the cooling tower. FRP towers are less suitable to fires than wood but not totally exempt.

Fire Risk Analysis
Before fire protection can be determined for a FRP cooling tower, a fire risk analysis should be performed. This will allow the cooling tower owner to rank the importance of the cooling tower remaining in operation at all times.

The following are some of the factors that should be considered when determining the method of fire protection for the cooling tower.

1. Importance of Continuous Operation
Does the cooling tower need to be in operation most of the time in order to meet cooling requirements set by the tower owner?
If not, what will be the duration and frequency of inactivity?

2. Location of Cooling Tower
Is the cooling tower located next to another structure or building?
Does the cooling tower have limited access, because of where it is located, that would hinder fighting a fire?

3. Water Supply
Is there an adequate water supply with which to fight a fire?

4. Climate
Are there extreme temperatures that would affect fighting a fire?

5. Construction Materials
No fire protection is required if the cooling tower’s structure, fan deck, distribution deck, louvers, and fill materials are non-combustible.

6. The Type of Tower
Is the tower a cross-flow or counter-flow? It is more difficult to provide fire protection for a cross-flow cooling tower because the tower configuration makes it much more difficult to contain.

7. Value of the Tower
This is an owner judgment. How important is this tower to the jobsite?

Fire Protection Options
Now that the fire risk analysis has been completed by the cooling tower owner, the materials necessary to achieve the degree of desired fire resistance for the cooling tower can be determined. Once the degree of fire resistance is determined, then fire prevention options are selected.

Options to be considered for fire protection:

1. Structural framework
   • Concrete Structural; considered non-combustible
   • Steel Structural; considered non-combustible
   • FRP Pultruded Structural; Fire-retardant, self-extinguishing with a flame spread rating of 25 or less per ASTM E84 Flame Spread Test

2. Exterior and Partition Walls
   • Concrete; considered non-combustible
   • Steel; considered non-combustible
   • FRP; Fire-retardant, self-extinguishing with a flame spread rating of 25 or less per ASTM E84 Flame Spread Test
   Note: 20 minute fire wall per NFPA 251 30 minute fire wall per NFPA 251
   • Wood; considered combustible

Note: Douglas Fir ½” plywood has a spread rating of 130 to 150 per ASTM E84 Flame Spread Test. This material does not qualify for a 20-minute Fire Wall.

3. Fan Deck
   • Concrete; considered non-combustible
   • Steel; considered non-combustible
   • FRP; Fire-retardant, self-extinguishing with a flame spread rating of 25 or less per ASTM E84 Flame Spread Test
   • Wood; considered combustible

4. Fill Media
   • Ceramic; considered non-combustible
   • PVC; Fire-retardant, self-extinguishing with a flame spread rating of 25 or less per ASTM E84 Flame Spread Test
   • Wood; considered combustible
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spread rating of 15 or less per ASTM E84 Flame Spread Test
- Wood Lath; considered combustible
5. Distribution Header
- FRP; Fire-retardant, self-extinguishing with a flame spread rating of 25 or less per ASTM E84 Flame Spread Test
6. Fill Material & Drift Eliminators
- Ceramic/Metal; considered non-combustible
- PVC; Fire-retardant, self-extinguishing with a flame spread rating of 15 or less per ASTM E84 Flame Spread Test
7. Fan Stack
- Concrete; considered non-combustible
- FRP; Fire-retardant, self-extinguishing with a flame spread rating of 25 or less per ASTM E84 Flame Spread Test

Design and Material Choices
Note: The following examples of fire protection are a sample of the fire protection combinations available in the market. The examples are listed in order from the least fire protection choice to the greatest fire protection choice.

1. Fire-retardant, self-extinguishing FRP structure with fire retardant, self-extinguishing internals and fire walls per NFPA 251.
   Note: Fire resistant wall is a constructed wall that has passed an assemble test not just the materials being used.
2. FRP fire retardant self-extinguishing structure with fire retardant self-extinguishing internals and fire resistant wall per NFPA 251 and Deluge sprinkler system per NFPA 13. This combination will provide a higher degree of protection where water supplies are adequate.

STANDARDS AND CODES FOR FIRE PROTECTION SYSTEMS

ASTM-E-119
The Standard Test Methods used for Fire Test of Building Construction and Materials such as firewalls.

NFPA-251
The Standard Test Methods used for fire resistance of building construction and materials. These methods require a true representation of the construction for which the fire resistance rating is to be determined with respect to materials, workmanship, and details such as dimension of parts.

NFPA-13
This standard governs the installation of all types of sprinkler systems.

NFPA-214
This standard governs the installation of fire protection on Cooling Towers.

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CTI-Chapter 12
This CTI code addresses fire protection in general in cooling towers.

CONCLUSION
Choosing the proper fire protection for a field erected FRP Tower can be challenging. There are many publications available which have addressed the subject. We have summarized the best guideline in Chapter 12 of the CTI Manual for choosing the proper protection and materials to be used to fit the owner’s fire protection demands. It is a must for cooling tower owners to understand the NFPA standards as well as the benefit Factory Mutual Approval brings to the industry. Hopefully we have presented this valuable information in a manner which can be beneficial to both cooling tower owners as well as purchasers of new cooling tower installations.
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1.0 BACKGROUND

Every year the CTI Multi-Agency Testing Chair provides a review of the previous year’s custom tower test results. Such reviews have shown that more than half of the custom cooling tower acceptance tests are at less than 100% thermal capacity. CTI has developed this Standard to encourage custom tower capacity equal to or greater than 100%. It is CTI’s intent to foster and promote the benefits of thermal performance acceptance testing of water cooling towers to the owner/operator of the equipment. It is not a certification program like that governed by CTI STD-201. The success of this program depends on a high percentage of custom cooling towers being field tested for thermal performance and the results published in accordance with this Standard. CTI will take action under the provisions of this Standard against participating manufacturers who imply that participation in this program is certification of the performance of their products, or against participating manufacturers who otherwise discourage testing of their products.

2.0 PURPOSE

This Standard sets forth a voluntary program wherein CTI will publish measurements of the thermal performance test history of participating tower manufacturers (PM) by utilizing field-testing of custom cooling towers within its licensed thermal testing program.

The results for each participating manufacturer are published in this summary. Manufacturers are required to have an average of at least 3 tests in a flow band per year for their results for that band to be published. If there is a number for a category, for example no tests reported below 95% capacity, then N.A. is shown in the table. If there are less than 3 tests in a category, N.A. will also be shown for that category.

The results reflect one year of testing for this first year of the program. Next year the results will reflect 2 years of testing. The third year and thereafter, the results will reflect the last 3 years of testing.

### Cooling Technology Institute Test Results

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As stated in its opening paragraph, CTI Standard 201... "sets forth a program whereby the Cooling Technology Institute will certify that all models of a line of water cooling towers offered for sale by a specific Manufacturer will perform thermally in accordance with the Manufacturer’s published ratings..." By the purchase of a “certified” model, the Owner/Operator has assurance that the tower will perform as specified, provided that its circulating water is within acceptable limits and that its air supply is ample and unobstructed. Either that model, or one of its close design family members, will have been thoroughly tested by the single CTI-licensed testing agency for Certification and found to perform as claimed by the Manufacturer.

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

The history of the CTI STD-201 Thermal Performance Certification Program since 1983 is shown in the following graphs. A total of 34 cooling tower manufacturers are currently active in the program. In addition, 8 of the manufacturers also market products as private brands through other companies. While in competition with each other, these manufacturers benefit from knowing that they each achieve their published performance capability and distinguish themselves by providing the Owner/ Operator’s required thermal performance. The participating manufacturers currently have 83 product lines plus 13 product lines marketed as private brands which result in more than 16,000 cooling tower models with CTI STD-201 Thermal Performance Certification for cooling tower Owner/ Operator’s to select from. The following table lists the currently active cooling tower manufacturers, their products with CTI STD-201 Thermal Performance Certification, and a brief description of the product lines.

Those Manufacturers who have not yet chosen to certify their product lines are invited to do so at the earliest opportunity. You can contact Virginia A. Manser, Cooling Technology Institute, PO Box 73383, Houston, TX 77273 for further information.
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<tr>
<th>Manufacturer</th>
<th>Product Line</th>
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<th>Revision Number</th>
<th>Date</th>
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## Cooling Towers Certified by the CTI under STD-201

Internet links for the Manufacturers, their specific product lines, and the selection information for each product line can be found at: [http://www.cti.org/certification.shtml](http://www.cti.org/certification.shtml)

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<td>TYH</td>
<td>14-40-91</td>
<td>2</td>
<td>December 23, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Tower Tech, Inc.</td>
<td>TTXL</td>
<td>08-17-96</td>
<td>3</td>
<td>December 7, 2011</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td>Towwater Cooling Towers, Inc.</td>
<td>EC-S Series</td>
<td>12-41-91</td>
<td>2</td>
<td>December 31, 2013</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>EX-S Series</td>
<td>12-41-02</td>
<td>2</td>
<td>December 31, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>VKS</td>
<td>13-41-03</td>
<td>0</td>
<td>July 18, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
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<tr>
<td>Watco Systems</td>
<td>WGI</td>
<td>09-36-91</td>
<td>0</td>
<td>August 31, 2009</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
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<tr>
<td>Yanta Ebara Air Conditioning Equipment Company, Ltd.</td>
<td>COW</td>
<td>13-33-91</td>
<td>0</td>
<td>August 27, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>York (By Johnson Controls)</td>
<td>AT Series</td>
<td>95-13-91</td>
<td>15</td>
<td>December 10, 2013</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>ESWAB &amp; ESWB</td>
<td>06-13-96</td>
<td>7</td>
<td>September 26, 2013</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>LSTE</td>
<td>05-13-03</td>
<td>3</td>
<td>April 17, 2012</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td>Zhejiang Jieling Refrigeration Engineering Company, Ltd.</td>
<td>JNC Series</td>
<td>09-29-02</td>
<td>1</td>
<td>December 27, 2013</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
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<tr>
<td></td>
<td>JNT Series</td>
<td>05-28-91</td>
<td>2</td>
<td>January 29, 2016</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Zhejiang Wansheng Science and Technology Company, Ltd.</td>
<td>FSIB</td>
<td>13-34-91</td>
<td>0</td>
<td>September 8, 2013</td>
<td>Closed Circuit</td>
<td>Combined</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Participating CTI Certified Manufacturers</th>
<th>CTI Certified Product Lines</th>
<th>CTI Certified Tower Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>FSIB</td>
<td>19,443</td>
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Cooling Technology Institute
Licensed Testing Agencies

For nearly thirty years, the Cooling Technology Institute has provided a truly independent, third party, thermal performance testing service to the cooling tower industry. In 1995, the CTI also began providing an independent, third party, drift performance testing service as well. Both these services are administered through the CTI Multi-Agency Tower Performance Test Program and provide comparisons of the actual operating performance of a specific tower installation to the design performance. By providing such information on a specific tower installation, the CTI Multi-Agency Testing Program stands in contrast to the CTI Cooling Tower Certification Program which certifies all models of a specific manufacturer's line of cooling towers perform in accordance with their published thermal ratings. To be licensed as a CTI Cooling Tower Performance Test Agency, the agency must pass a rigorous screening process and demonstrate a high level of technical expertise. Additionally, it must have a sufficient number of test instruments, all meeting rigid requirements for accuracy and calibration.

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

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

### Licensed CTI Thermal Testing Agencies

<table>
<thead>
<tr>
<th>License Type*</th>
<th>Agency Name</th>
<th>Contact Person</th>
<th>Telephone</th>
<th>Fax</th>
</tr>
</thead>
<tbody>
<tr>
<td>A,B</td>
<td>Clean Air Engineering</td>
<td>Kenneth Hennon</td>
<td>800.208.6162</td>
<td>865.938.7569</td>
</tr>
<tr>
<td></td>
<td>7936 Conner Rd</td>
<td><a href="http://www.cleanair.com">www.cleanair.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Powell, TN 37849</td>
<td><a href="mailto:khennon@cleanair.com">khennon@cleanair.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A, B</td>
<td>Cooling Tower Technologies Pty Ltd</td>
<td>Ronald Rayner</td>
<td>61 2 9789 5900</td>
<td>61 2 9789 5922</td>
</tr>
<tr>
<td></td>
<td>PO Box N157</td>
<td><a href="mailto:coolingwvtech@bigpond.com">coolingwvtech@bigpond.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bexley North, NSW 2207</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AUSTRALIA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A,B</td>
<td>Cooling Tower Test Associates, Inc.</td>
<td>Thomas E. Weast</td>
<td>913.681.0027</td>
<td>913.681.0039</td>
</tr>
<tr>
<td></td>
<td>15325 Melrose Dr.</td>
<td><a href="http://www.cttaic.com">www.cttaic.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stanley, KS 66221-9720</td>
<td><a href="mailto:cttai@ael.com">cttai@ael.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4700 Coster Road</td>
<td><a href="http://www.mchale.org">www.mchale.org</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Knoxville, TN 37912</td>
<td><a href="mailto:tom.wheelock@mchale.org">tom.wheelock@mchale.org</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 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.

### Licensed CTI Drift Testing Agencies

<table>
<thead>
<tr>
<th>Agency Name</th>
<th>Contact Person</th>
<th>Telephone</th>
<th>Fax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Air Engineering</td>
<td>Kenneth Hennon</td>
<td>809.208.6162</td>
<td>865.938.7569</td>
</tr>
<tr>
<td>7936 Conner Rd</td>
<td><a href="http://www.cleanair.com">www.cleanair.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Powell, TN 37849</td>
<td><a href="mailto:khennon@cleanair.com">khennon@cleanair.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4700 Coster Road</td>
<td><a href="http://www.mchale.org">www.mchale.org</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knoxville, TN 37912</td>
<td><a href="mailto:tom.wheelock@mchale.org">tom.wheelock@mchale.org</a></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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Photo rendering of new Freedom Tower and NYC skyline by dmv, courtesy of Silverstein Properties.
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