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*The Official Publication of the Cooling Technology Institute*



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Volume 38, No. 2

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

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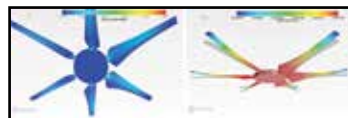
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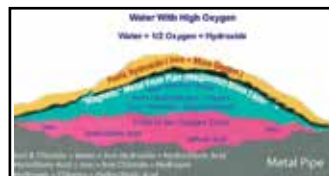
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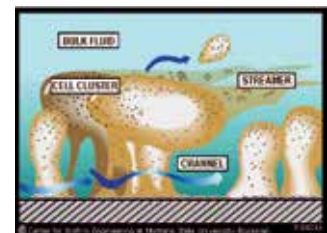
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## For Immediate Release Contact: Chairman, CTI Multi-Agency Testing Committee Houston, Texas 2-December-2017

Cooling Technology Institute, PO Box 681807, Houston, Texas 77268 – The Cooling Technology Institute announces its annual invitation for interested thermal testing agencies to apply for potential Licensing as CTI Thermal Testing Agencies. CTI provides an independent third party thermal testing program to service the industry. Interested agencies are required to declare their interest by August 1, 2017, at the CTI address listed.

## Future Meeting Dates

### Annual Conference

February 4-8, 2018  
Hilton Houston North  
Houston, TX

February 5-9, 2019  
Sheraton New Orleans  
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### Committee Workshop

July 15-18, 2018  
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# View From The Tower

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



• Technical information exchange  
I hope that sounds familiar because it should, it comes right from CTI's website and is our mission statement. We come together at our summer and winter meetings to see friends, to share stories, to learn from one another, to join forces to better our industry and to have fun doing it all because that my friends, is what life is all about. Having a passion for what you do, getting others involved in what you do and joining them in what they do is what makes CTI so successful, it revolves around good people, around committed people, around passionate people who truly care about our industry about one another and about our planet. So here's to you CTI participants, you are what make CTI great!

Sincerely and respectfully,  
Bill W. Howard, P.E.  
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# Editor's Corner

Dear Journal Reader,

The nomination process has started for the incoming CTI President from the Supplier membership category for February, 2018. Bill Howard of CTD, Inc., has started the second year of his two-year term as President of CTI last February.

Here's an update on some external influences on CTI:

**DOE Fan Rule:** My last Editor's Corner made CTI Members aware that a Department of Energy rule-making was in progress with regard to fans, which could include any of the products of interest to CTI that move air with a fan or blower. The change in leadership in the White House has caused this rulemaking to be delayed for review, with no certainty of whether it will proceed. CTI had asked for exemption of heat rejection equipment from the rule, and we had been successful in gaining the exemption in the term sheet agreed upon by the working group. CTI members who produce or embed fans in equipment for any purpose should be aware that they could be affected by this rulemaking, which will set minimum fan efficiencies by fan and equipment types. For more information, contact Larry Burdick, Frank Morrison, or me.

**California Title 20 Fan Rule:** With the change in DOE posture, California has taken up the fan rule and is moving ahead fairly quickly. The SITF working group is working on adapting the DOE documents for the CEC as quickly as possible.

**Legionnaires Disease:** The CDC has published an update to their nicely done Toolkit to supplement ASHRAE STD-188 (2015) Legionella: Risk Management for Building Water Systems. CTP's GDL-159 and an updated ASHRAE Guideline 12 are expected to be a useful tool with this standard when completed, hopefully, this



year. The CDC toolkit and the ASHRAE standard are available on their websites. An Alliance to Prevent Legionnaires disease has been formed, and has a website, [www.preventlegionnaires.org](http://www.preventlegionnaires.org), that should be of interest to those associated with our industry.

Some new CTI activities are updated below:

**CTI Research Update:** CleanAir will be presenting the results of the completed Pitot project in a technical paper as I understand it. Other projects are under consideration, and new ones may be proposed within the standing technical committees at any time.

For those of you who are cooling tower history buffs, here's a tidbit just discovered:

**Oldest Known Cooling Towers in the World:** After being told for some time they existed, I finally was able to find some old Fluor materials. Fluor had purchased Sante Fe Tank & Tower, which was an older company than Fluor. Sante Fe was reported to have started in 1890 making tall atmospheric (wind airflow) wood structures with refrigerant condenser coils at the bottom of a recirculating water loop with internal fill decks. The towers with refrigerant coils initially served large ice making plants in the Los Angeles area. A photo was found of a large one that was started up in 1900 and was still operating when published in 1951 in a Lufkin gearbox newsletter showcasing their relationship with Sante Fe (for gearboxes on their later towers with mechanical draft fans). Balcke started atmospheric towers in 1894.

Respectfully,

Paul Lindahl, CTI Journal Editor

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# Biofouling Control In Industrial Water Systems

Brian Corbin  
The Dow Chemical Company

## ABSTRACT

Failure to control biofouling in industrial water systems can lead to reduced system efficiency, microbiologically influenced corrosion, and increased downtime. Water treatment programs that include a combination of oxidizing and non-oxidizing biocides provide a broad-based approach to microbial control to minimize the negative impact of biofouling. In this paper, we will discuss the value of non-oxidizing biocides and industry best practices to control biofouling in cooling systems. The paper will discuss recent innovations in solid biocides and the numerous advantages over their liquid counterparts. Synergy between oxidizing and non-oxidizing biocides will also be discussed and treatment recommendations presented.

## INTRODUCTION

Biofouling is a frequent and persistent problem in industrial water systems. The range of temperature and pH, aeration, and abundance of nutrients in these systems provides an excellent environment for growth of several biological species. Problems associated with microbial growth can include decreased heat transfer, microbially influenced corrosion, blockage of filters and screens, increased downtime, and potential health concerns. Various groups of microorganisms are well recognized as major causes of these problems. These include aerobic and anaerobic bacteria, fungi, algae, and protozoa. The most diverse group of these organisms is bacteria, which include general slime-forming organisms (*Pseudomonas*, *Enterobacter*, *Klebsiella*), health-related species (*Legionella pneumophila*), sulfate reducers (*Desulfovibrio*), acid-producers (*Clostridium*), and filamentous types (*Sphaerotilus*, *Leptothrix*). The cyanobacteria (formerly known as blue-green algae) are also common to cooling tower waters and include *Phormidium*, *Anabaena*, *Oscillatoria*, and *Anacystis*. Green algae in cooling water systems include *Chlorella*, *Scenedesmus*, *Chlorococcum*, *Ulothrix*, and *Spirogyra*. Fungal contaminants (*Aspergillus*, *Saccharomyces*, *Rhodotorula*) occur less frequently, but are still considered problematic in air washer applications and papermaking.

An effective water treatment program must control microorganisms in planktonic (free-swimming) and biofilm states. Biofilms are aggregates of microorganisms attached to surfaces and encased in a self-secreted extracellular polymeric substance (EPS), often referred to as glycocalyx or slime. The extracellular polymeric substance is predominantly water (up to 95%) but contains other major classes of macromolecules including polysaccharides (1-2%), proteins (<1-2%), and nucleic acids (<1-2%) [1]. Biofilms are ubiquitous in nature and their formation is a defense strategy for survival in hostile environments. Biofilm formation helps cells react and adapt to changing environmental conditions. Cells within biofilms can more readily communicate with each other, exchange genetic material and share resources. In addition, biofilm formation protects cells from desiccation, and reduces sensitivity to antimicrobials.

Biocides have been widely used in the water treatment industry for decades [2] and are a critical component of a successful water treatment program to control microbial fouling. In general, biocides fall



Brian Corbin

into two broad categories, oxidizing and non-oxidizing biocides. Oxidizing biocides include chlorine, bromine, ozone, chlorine dioxide, and peracetic acid, while non-oxidizing biocides, include isothiazolones (CMIT, MIT, CMIT/MIT), quaternary phosphonium compounds (THPS), Polyquat (WSCP), dibromonitropropionamide (DBNPA), bromonitropropanediol (bronopol) and glutaraldehyde. Each of these biocides has limitations as well as advantages under particular conditions. As a result, many microbiological control programs combine various oxidizing and non-oxidizing biocides to more effectively use the attributes of each type of chemical [3].

## OXIDIZING BIOCIDES

Oxidizing biocides are commonly used for cooling water treatment due to their effectiveness, low cost to treat, and rapid biodegradation to non-toxic molecules [4-6]. They demonstrate broad-spectrum activity against bacteria, fungi, and algae and are capable of killing microorganisms within a matter of seconds. The mechanism of action is through chemical oxidation of the cellular structure and subsequent cell lysis. In addition, oxidizing agents can readily pass through the cell membrane and react with cellular components, leading to apoptotic and necrotic cell death [7]. Although effective at killing microorganisms in water, oxidizing biocides are poor at penetrating biofilms and dispersing anaerobic infestations [3]. The limited diffusion of oxidizing biocides into biofilms is due to the high reactivity with EPS matrix components [8]. For example, a study using chlorine demonstrated that >20% of a biofilm failed to reach the concentration of the oxidizer in the bulk fluid [9]. Similar findings were observed by Lu et al. upon analyzing hydrogen peroxide penetration into mixed microbial biofilm communities [10].

Researchers have also demonstrated that bacteria adopting a sessile lifestyle undergo differentiated gene expression and have an altered protein expression profile [11, 12]. In general, 1-15% of genes have been found to be differentially expressed in biofilm cells [13]. Genes that show increased expression include those involved in adhesion and auto-aggregation, motility, metabolism, and oxidative defense [12]. As such, biofilm bacteria have developed defense strategies to protect against oxidants at low levels. For instance, concurrent expression of superoxide dismutase and catalase enzymes by sessile bacteria can convert toxic superoxide radicals and hydrogen peroxide into molecular oxygen. In one study, slight resistance toward chlorine was observed in a 30-generation experiment with *E. coli* exposed to low oxidant levels (0.2 ppm) during short exposure times (1 min) [14]. At higher concentrations, however, defense mechanisms become overwhelmed, with significant intracellular and surface damage occurring [7]. It is estimated that cells existing within biofilms are between 10-1,000 times more resistant to antimicrobials [8]. Additional limitations of oxidizers can include corrosion at use levels, incompatibility with system components (corrosion and scale packages), and an uncontrolled increase of the cooling water pH.

## NON-OXIDIZING BIOCIDES

To overcome the limitations of oxidizing biocides, non-oxidizing biocides are often used as a supplement to provide a more balanced



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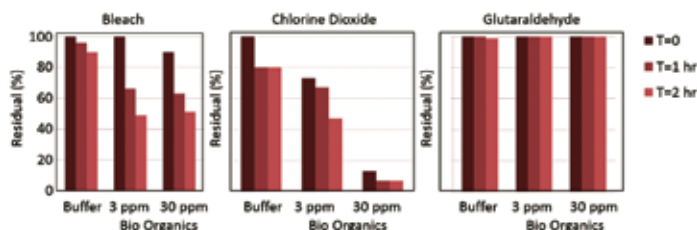
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and robust water treatment program [3]. The key features of oxidizing and non-oxidizing biocides are summarized in **Table 1**.

Feature	Oxidizers	Non-Oxidizers
Speed of Kill	Faster	Slower
Use-Level Corrosion	More Potential	Less Potential
Reactivity with Additives	More Potential	Less Potential
Biofilm Control	Limited	Effective

**Table 1. Key features of oxidizing and non-oxidizing biocides used for industrial water treatment.**

Non-oxidizing biocides have proven more efficacious than oxidizing biocides at controlling microorganisms, including bacteria, fungi, and algae growing in biofilms due to their greater persistence. They are less reactive and subsequently less prone to transport limitations in biofilms compared to oxidizing biocides (Figure 1) [15]. Although non-oxidizing biocides tend to be more expensive on a per-pound basis, non-oxidizing biocides are less likely to cause corrosion and are more compatible with other water treatment additives. Under some circumstances, a scale and corrosion package may need to be increased by 25-30% when solely using oxidizing biocides. Also, by supplementing the use of oxidizers in your system with non-oxidizing biocides, you can minimize corrosion and protect valuable assets.



**Figure 1: Organic matter compatibility with biocides.**

Non-oxidizing biocides inhibit microbial growth by different mechanisms other than oxidation, including interference with cell metabolism and structure [16]. For example, electrophilic agents such as formaldehyde and isothiazolones react covalently with cellular nucleophiles to inactivate enzymes [17] and initiate the formation of intracellular free radicals, which contribute to cell death [18] [19]. Alternatively, cationic membrane active biocides such as quaternary ammonium and phosphonium compounds (THPS) destabilize membranes leading to rapid cell lysis. Non-oxidizing biocides are capable of killing microorganisms within minutes to hours after contact. Some of the most commonly used non-oxidizing biocides are shown in Table 2 and are further described below.

Biocide	Speed of Kill	Efficacy	pH Range	Temperature
CMIT/MIT	Slow	Broad spectrum /biofilm	pH 2.0-9.0	< 40°C
MIT	Slow	Bacteria	pH 2.0-11	> 40°C
Glutaraldehyde	Moderate	Bacteria, SRB	pH 3.0-9.5	< 40°C
DBNPA	Fast	Bacteria	pH 3.0-9.0	< 40°C
THPS	Moderate	Bacteria, SRB, Algae	pH 5.0-9.0	< 40°C
Bronopol	Moderate	Bacteria, SRB	pH 3.0-8.0	< 40°C

**Table 2. Non-oxidizing biocide selection guide.**

Kill Time  
 Slow=6-24 hours  
 Moderate= 2-6 hours  
 Fast = <2 hours

### Isothiazolones

Isothiazolone biocides are frequently used in a variety of industrial water treatment applications to control microbial growth and biofouling [20]. The most frequently used product is a 3:1 ratio of 5-chloro-2-methyl-4-isothiazolin-3-one (CMIT) and 2-methyl-

4-isothiazolin-3-one (MIT), and is often recognized as the industry standard. CMIT/MIT has broad spectrum efficacy versus bacteria, algae, and fungi over a wide pH range [3]. CMIT/MIT inhibits microorganisms utilizing a two-step mechanism involving rapid binding (association) to cells and inhibition of growth and metabolism (within minutes), followed by irreversible cell damage resulting in loss of viability (within hours). Cells are inhibited by disruption of critical metabolic pathways involving selected (thiol-containing) dehydrogenase enzymes. Critical physiological functions are rapidly inhibited in microbes, including growth (cell numbers and protein synthesis), respiration (oxygen consumption), and energy generation (ATP synthesis). Cell death results from the destruction of protein thiols and production of free radicals. This unique mechanism results in a broad spectrum of activity at low use levels and difficulty in attaining resistance. Products containing MIT as the sole active are also available for industrial water treatment that is effective against bacteria in long-term, high pH and temperature preservative applications. The limitations of isothiazolones include a slow speed of kill and its classification as a skin sensitizer.

### Glutaraldehyde

Glutaraldehyde (1,5-pentanedial) is an effective microbicide used to prevent the growth of bacteria in industrial water treatment operations. This includes anaerobic bacteria, notably sulfate reducing bacteria, since it is not inactivated by sulfide. It functions by cross-linking amino groups (R-NH<sub>2</sub>) of outer membrane proteins, disrupting their tertiary structure and function, ultimately preventing cell permeability. Glutaraldehyde can also react to a certain extent with thiol (R-SH) and hydroxy groups (R-OH). Glutaraldehyde is effective across a wide pH range and has a moderate kill time, with cell death typically observed between 3-4 hours. Its effectiveness against algae and fungi is limited.

### DBNPA

DBNPA (2,2-dibromo-3-nitropropionamide) is a broad-spectrum microbicide frequently used in industrial and commercial cooling water systems. It can also be safely and effectively used as part of an off-line, biofouling control program for RO systems as it is compatible with the modern thin film composite polyamide (TCFPA) membranes. It is effective against bacteria and fungi at low concentrations and is capable of killing within minutes. It functions as an electrophilic agent due to the presence of two bromine atoms at the C-2 position and rapidly reacts with protein thiols (R-SH) on the cell surface. The reaction is irreversible, disrupting the function of critical enzymes, culminating in cell death. Decomposition is rapid with a half-life less than 30 minutes depending on system conditions. In general, the half-life decreases rapidly in systems with higher pH and temperature. The instantaneous antimicrobial activity of DBNPA, combined with rapid chemical breakdown, presents one of the most cost-effective ways of eliminating microbiological contamination with diminished environmental concern and effect on the final product. DBNPA is available in both liquid and solid forms. The major limitation of DBNPA is the lack of effectiveness against algae.

### THPS

THPS is a water soluble, quaternary phosphonium compound with broad-spectrum antimicrobial efficacy. THPS effectively kills microorganisms by causing extensive damage to cell membranes and inhibiting cell respiration and sulfate reduction [21]. It functions across the pH range of cooling systems and is effective against sulfate-reducing bacteria. THPS is cationic and may be incompatible with other water treatment additives including polyacrylates and phosphonates [3].



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## BIOCIDES OPTIMIZATION

Optimizing the use of biocides is critical for maintaining effective microbial control in industrial water treatment applications. The optimization of biocide programs provides the most efficient use of the products, the highest degree of performance and manages overall treatment costs. A robust water treatment program typically uses an oxidizing biocide supplemented with a non-oxidizing biocide to effectively use the attributes of each type of chemical. Under specific conditions, however, only one type of biocide may be used, due to either cost, environmental, or other factors. Alternatively, other systems may employ a rotation or combination of non-oxidizing biocides. In a majority of applications, a low residual oxidant is used to significantly reduce the planktonic population in a system and assist in destroying the biofilm EPS layer, whereas a non-oxidizing biocide is used to effectively penetrate and destroy biofilm bacteria.

Non-oxidizing biocides bring additional value to a water treatment program as they can be synergistic when used in combination with other oxidizing and non-oxidizing biocides. Synergy is achieved when the effect of two biocides is greater than the sum of the activity of both products alone. This results in enhanced efficacy and improved microbiological control. Numerous examples of synergistic combinations of biocides have been described for industrial water treatment applications. These include various combinations of biocides including: chlorine, bromine, peroxides, isothiazolones, glutaraldehyde, bronopol, DBNPA, quats, peracetic acid, and chlorine dioxide.

Synergy amongst biocides is often a result of two separate mechanisms of action attacking the cell, which overpowers its ability to grow and divide. Thus, biocides that act directly on the membrane components and cell structure (quats, aldehydes) would be good candidates for a synergistic effect with biocides that function by interfering with the cells metabolic activity (isothiazolones, bronopol, DBNPA). In addition, oxidizing biocides, which are fast acting, are good candidates for combinations with many non-oxidizers, which kill at a slower rate. Examples of synergy observed among biocides used in industrial water treatment are given below.

Synergy between CMIT/MIT and hypochlorite is shown in Table 3 [22]. In this example, bacterial growth was inhibited with either 1.5 ppm CMIT/MIT or 0.5 ppm free chlorine alone, whereas effective control was achieved with the combination of 0.5 ppm CMIT/MIT biocide plus 0.25 ppm free chlorine. This yielded a synergy index value of 0.83, indicating moderate synergism for the combination.

Biocide	Effective Biocide Concentration (ppm active)		Ratio (Combo/Alone)
	Combination	Alone	
CMIT/MIT	0.5	1.5	0.33
Hypochlorite	0.25	0.5	0.50
<b>Synergy Index</b>			<b>0.83</b>

Table 3. Synergy Values and Calculations for CMIT/MIT and Hypochlorite Combinations versus Mixed Cooling Water Bacteria.

Synergy has also been reported for CMIT/MIT and Bronopol versus a pure culture of *Klebsiella* (Table 4) [22]. In this example, CMIT/MIT was reduced two-fold and the Bronopol concentration was reduced eight-fold in the synergistic combination.

Biocide	Effective Biocide Concentration (ppm active)		Ratio (Combo/Alone)
	Combination	Alone	
CMIT/MIT	1.1	2.4	0.46
Bronopol	5.0	40	0.13
<b>Synergy Index</b>			<b>0.59</b>

Table 4. Synergy Values and Calculations for CMIT/MIT and Bronopol Biocide

## Combinations versus *Klebsiella pneumoniae*.

A synergistic effect is typically the preferred result when using a specific biocide combination. This is because the combination is more effective versus either compound alone, but synergy may not always be observed with all species or strains of organisms, and the effect may vary by dose levels and biocide ratios. However, an additive response of using two biocides together (where the synergy index is 1.0) is still a very effective and beneficial treatment program because it can improve the spectrum of activity of each biocide, provide different modes of action, and may prevent resistance from either biocide alone.

Additional strategies to control biofilm formation and development often include the use of a surface active compound (surfactant) in combination with biocide treatment. Biocides, under some conditions, may not be effective in biofilm removal, leaving biomass on a surface that may contribute to microbial recovery and biofilm regrowth. Surfactants function as penetrants that loosen the complex matrix of biofilms allowing biocides to reach the organisms more effectively. As the surface tension is decreased, microbial attachment to surfaces is prevented and microorganisms detach from the adhesion surface [23]. Surfactants can be classified as anionic, cationic, nonionic, or amphoteric depending on the charge of the polar head group. Anionic surfactants include the carboxylates, sulphates, sulphonates, and phosphates. These are the least expensive and some of the oldest known surfactants. Non-ionic surfactants include the alkylphenol ethoxylates and the ethylene oxide/propylene oxide copolymers (EO/PO). Non-ionic surfactants are often used in industrial water treatment due to their effectiveness and lower foaming potential compared to the anionic surfactants. The ideal surfactant would have the following main characteristics: low foaming, biodegradable, low ecotoxicology, high water solubility, stability under acidic conditions, and compatibility with common corrosion and scale inhibitors.

The efficacy of a single-drum combination product formulation containing CMIT/MIT mixed with a non-ionic surfactant is shown in Table 5. In this study, a mature biofilm was grown to a cell density of 6.9 log<sub>10</sub> CFU/cm<sup>2</sup> in 24-48 hr. Exposure to CMIT/MIT for 24 hours led to 2.2 log reduction in cell density compared to the untreated control. In contrast, no viable cells were recovered when treating the biofilm with the CMIT/MIT surfactant blend. Foaming was not an issue during field evaluations of the CMIT/MIT surfactant blend (Figure 2).

## SOLID BIOCIDES

Non-oxidizing biocides are widely used in industrial water treatment systems and are typically formulated as liquid products. However, there is a growing trend towards the use of solid biocides for dos-

Treatment	Sample Time	Biofilm Log Growth Cells/cm <sup>2</sup>	Log Reduction vs Untreated Control
Untreated Control	24 hour	6.9	0
1.5 ppm active CMIT/MIT	24 hour	4.7	2.2
1.5 ppm active CMIT/MIT +5 ppm active Surfactant	24 hour	1.8*	>5.1

\*Limit of detection = no viable cells recovered

Table 5: Biofilm stability after 24 h exposure to CMIT/MIT or CMIT/MIT + surfactant.



Figure 2: CMIT/MIT surfactant blend causes minimal foaming during field trial testing.

ing small to medium sized systems. Several towers are located on the roofs of buildings and gaining access to the tower to dose the biocide can prove to be problematic. In some cases, the biocide must be carried up a narrow set of stairs or transported on elevators with pedestrians. The liquid biocide formulations can be heavy and opportunities for hazardous spills and splashes exist. Solid biocides generally have higher percentage active levels than their liquid counterparts. As such, this reduces the total weight of biocide needed to adequately treat the cooling tower. In addition, the higher active levels results in reduced shipping costs and lower overall chemical usage. An additional benefit of solid biocides is that in an event of a spill, the product is less likely to enter a drain or waste stream. Together, these features make solid biocides a more sustainable option as compared to liquid formulations. Solid biocides can be dosed using feeder systems that provide either a slug dose or continuous release of product over an extended period of time without the need for chemical pumps. Chemical pumps can be expensive and are also subject to failure. The few solid, non-oxidizing biocide options that currently exist on the market include DBNPA (dibromonitropropionamide), bronopol (bromonitropropanediol) and MBT-TCMTB (Methylene bithiocyanate + Thiocyanomethylthiobenzothiazole). In addition, a novel solid isothiazolone formulation containing the actives CMIT and MIT was granted US EPA registration in 2015 [24]. CMIT/MIT and DBNPA are discussed in more detail below.

## CMIT/MIT

The solid isothiazolone biocide is a 3:1 ratio of CMIT and MIT with a total active ingredient of 7%. The material is currently packaged in canisters for use in specialized feeder devices. The solid isothiazolone is designed to be dosed to provide the same range of active ingredient levels as are listed on the EPA labels for the current liquid products (0.5-13 ppm total active). The standard dosing frequency is 1-2 times per week, or as needed. As with liquid biocide dosing, higher solid biocide dose amounts are needed for sys-

tems which are more heavily fouled and those for which greater kill or greater length of control is needed. Heavily fouled systems need to be cleaned before treating with biocide. Dissolution of the solid isothiazolone is rapid and increases with elevated temperatures. Efficacy studies indicate that the 7% CMIT/MIT solid is an effective antimicrobial agent against bacteria, fungi and algae at low active ingredient use levels. Also, minimum inhibitory concentration (MIC) studies have revealed no significant differences in efficacy between liquid and solid CMIT/MIT formulations.

## DBNPA

Solid DBNPA is available in several forms for use in small to medium sized cooling towers. A 40% active, 200 gram tablet is available to continuously treat 500-1,000 gal (1892-3785 L) of cooling water for up to three weeks. The solid tablets are individually packaged with a protective water-soluble wrapping of polyvinyl alcohol (PVA). Each tablet is non-dusting, fully dissolvable, and non-retrievable. The tablets are dosed using a suspended plastic mesh bag in the basin of a tower or placed in a side stream feeder. It is imperative that the tablet is placed in a position of moderate flow. If the tablets are placed in a very high or low flow environment, the DBNPA release will either be expedited or slowed respectively. Once a place of optimum flow has been established in the tower, the 40% DBNPA tablets offer a simple solution for small to medium sized water cooling towers that leave no residual.

Bypass feeders are often a convenient way to dose biocides to a cooling tower. As such, solid DBNPA is available packaged into canisters that easily fit into a bypass feeder and offer up to four weeks of microbial control. Each of these canisters has a specially designed membrane that allows water from the bypass feeder to enter the canister. The water then dissolves a portion of the solid DBNPA. The dissolved DBNPA slowly diffuses across the membrane and into the tower water flowing past the canister membrane. This is an attractive option for towers with basins that are difficult to access. No additional electricity is required to run the bypass feeder system. After the solid DBNPA has been fully dissolved from the canister, the canister can be triple rinsed and disposed of or recycled according to local regulations. This eliminates the need for costly waste disposal of large drums or containers. Additionally, the four weeks of control provided by the solid DBNPA in the bypass feeder canisters allows service engineers to only visit the cooling towers once a month.

## SUMMARY

Significant knowledge has been gained over the past few decades to optimize biocide performance in water treatment systems, and many approaches have been utilized. It is widely accepted that using a combination of oxidizing and non-oxidizing biocides for industrial water treatment has several advantages. First, dual biocide use provides both quick kill and extended control against microorganisms. Second, a reduction in the overall level of oxidizers in a system can minimize corrosion and could extend asset life. Next, the use of non-oxidizing biocides provides enhanced efficacy against biofilms as they are less volatile and don't readily react with biofilm matrix components. In addition, the enhanced performance of a dual biocide program limits system downtime needed due to cleaning and minimizes microbially influenced corrosion and potential health concerns. Synergistic interactions between additives have been discovered and provide enhanced efficacy during treatment. Combinations frequently used in process water systems include CMIT/MIT mixed with hypochlorite or bronopol. Researchers have also discovered the value of adding a biodispersant to a water treatment program to further enhance its effectiveness. Solid biocide options

are available that provide enhanced safety and handling benefits and are more sustainable.

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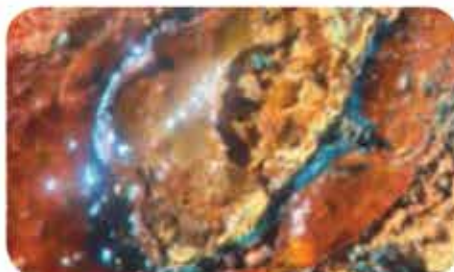


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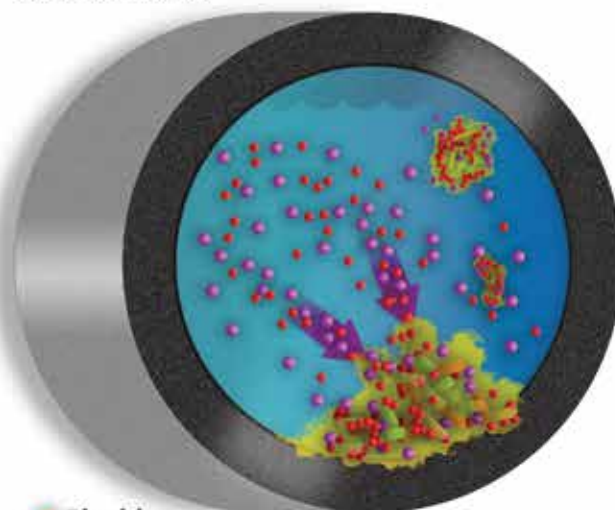
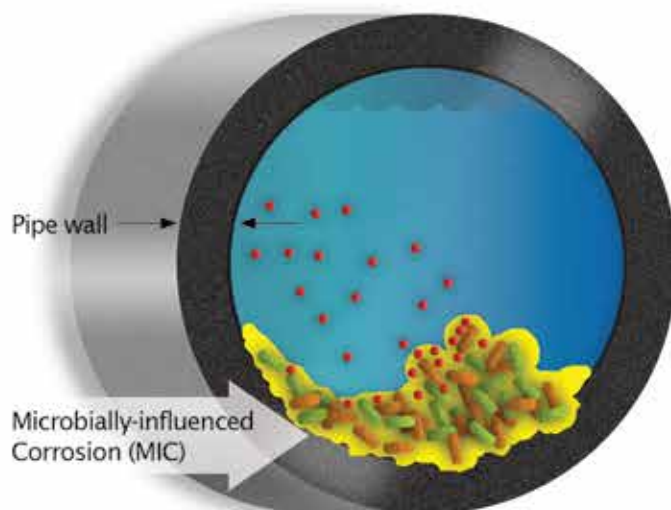
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# Design Considerations For Axial Flow Fans

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## Abstract

Low Pressure Axial flow fans, sometimes referred to as Propeller fans, are used in a variety of industries such as oil and gas, power plants, HVAC, et cetera for cooling purposes. The size of such fans vary from as small as 6 inches, typically used in data center cooling, up to 50 feet, used in Cooling Towers and Air-cooled Condensers. With the concern about energy savings becoming grave and the government imposed standards and subsidies, designing an optimum efficiency fan has become very valuable. Research engineers have been striving hard to strike a balance between airflow produced and power consumed that will make the fan of optimum efficiency. Hence, it is very valuable for everyone dealing with axial fans to understand the various parameters involved in designing an efficient axial fan. This paper is focused on delineating the few fundamental design considerations and methodology that can be adopted for development of axial flow fans which are used in Air-cooled Heat Exchangers, Cooling Towers and Air-cooled Condensers, the size of which range from 5 feet to 50 feet. The author's intention is to direct attention to the aerodynamic sizing and optimization and only briefly cover the structural design of the fan.

## Introduction

The performance of axial flow fans is a critical facet in determining the performance of cooling systems that such fans are a part of. Due to the strict efficiency and noise requirements in the HVAC industry, the research and development for designing an axial fan is in a mature stage for that industry. However, there are only a handful of companies that duly implement an R&D project to develop a new axial fan for the industrial cooling industry. The design process between the two industries will vary in several aspects due to the vast difference in Reynolds number and operating pressures. Due to requirement for higher fan efficiency and the recent demand for lower noise, the design process for such fans has become very crucial. It is a great challenge for the research engineers to develop a high efficiency fan which also produces lower noise since the low noise inherently translates to low rotational speed and a fan that rotates slower will have a lower efficiency. However, in the HVAC industry, advancements have been made to develop a low noise axial fan without sacrificing the performance. Among other concepts, this paper will concentrate in defining and explaining different variables involved in designing an efficient and a lower noise axial fan. The author holds a belief that there is a market demand for accurate fan curves in order to compare different fans for efficiency during the decision making process and in order to achieve accurate and comparable fan curves, standardization of the testing procedure is necessary.



**Bhaumik Modi**

This paper includes suggestions of certain methodologies that may be adopted for fan design and also the laboratory testing procedure that may be standardized for fan curve development. It also emphasizes the uses and importance of numerical analysis in designing an axial fan. Below is a brief description of certain relevant scientific papers that has described the procedures, theories, and experimental and numerical results that has proven useful to bolster the purpose of this paper.

Monroe [1978] has done a laudatory work in his paper, wherein he has covered the fundamentals of an axial fan and a few measures to make them efficient. He has also detailed the procedure for obtaining accurate fan curves for axial fans.

Bredell and Kroger [2006] had carried out an exhaustive research work to improve the efficiency of an Air-Cooled Steam Condenser, and the corresponding paper has detailed the findings of this project. The authors of this paper had carried out a complete numerical investigation of the various aspects of the condenser that will potentially improve the efficiency and determine and address the various problems associated with such condensers. The numerical study allowed the authors to study the numerous scenarios of the subject matter without spending exorbitant resources that would be entailed in physical testing. Louw et al. [2015] have done a riveting numerical study wherein they have used the blade element theory to generate actuator disk model in order to simulate the flow field induced by axial fans. By doing this, they were able to predict the lift and drag characteristics of the airfoil sections along the blade span. Such computational study can prove extremely useful for the modern design engineers who bear the responsibility of designing the most efficient fan blade.

## Aerodynamics

The first step in designing an axial fan blade is generally the aerodynamics of the blade, i.e., the lift and drag characteristics of the fan blade. The intent in designing an aerodynamic blade is to produce the highest amount of pressure difference, i.e., the lift force while inducing the lowest amount of drag force, i.e., force of resistance. The pressure difference will determine the airflow across the fan and the drag forces will influence the power consumption of the fan to produce the said pressure difference. The lift forces act in the axial direction, i.e., parallel to the direction of airflow and the drag forces act in a direction tangential to the local radii, i.e., circumferential direction. Hence, it becomes apparent that the pressure difference (lift) that is responsible for producing airflow will influence the axial load on the fan blades, while the drag forces will impart torque (tangential load) on the entity that rotates the fan, which in turn translates to power consumption. Due to this reason, cambered airfoils that have proven to produce the most amount of lift and the least amount of drag are used as the cross-sectional component of the fan blade.



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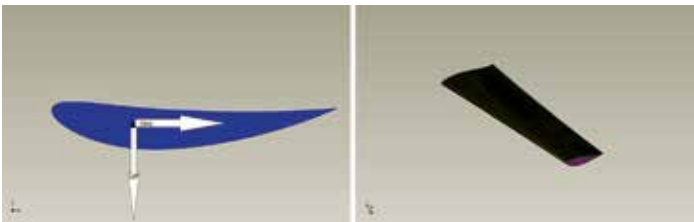
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## Lift & Drag

For the purposes of axial fans, lift is defined as the force acting in the axial direction due to the pressure difference developed by the fan blade airfoil. This differential pressure is what drives the airflow in an axial fan system. Equation (1) is the formula for lift which describes the various parameters that influence the lift of a body (fan blade in this case), where  $\rho v^2$  is the overall dynamic pressure distributed over the blade.  $C_L$  is the coefficient of lift, which is a non-dimensional number that depends on the shape and form of the airfoil chosen for the blade and is determined from experimental testing and/or numerical analysis.  $A$  is the surface area of the blade. It becomes clear from equation (1) that for a given dynamic pressure and surface area, the highest possible lift is obtained by choosing the airfoil with a highest lift coefficient. Figure (1) below illustrates the lift and drag forces and shows a part of the blade span using an airfoil.

(1)

$$L = \frac{1}{2} \rho v^2 C_L A$$



**Figure 1: Cambered Airfoil Section and Isotropic View of a Fan Blade Section Illustrating Cambered Airfoil**

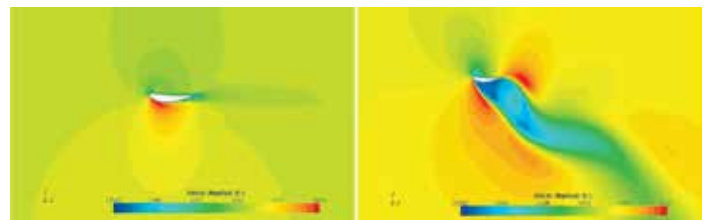
For all intent and purposes of this paper, drag forces is sub-classified as profile drag and induced drag. The induced drag is the drag generated due the trailing vortices in the airfoil wake. When the angle of attack of the airfoil is increased (in order to increase the pressure drop), the size and quantity of such vortices will also increase and thereby imparting higher induced drag. Hence it is said that the induced drag is the drag due to lift. During the design phase of an axial fan blade, there is little that the designer can do that will lower the induced drag, except for selecting an airfoil with higher lift to drag ratio. The profile drag in the fundamental sense is the drag due to resistance to motion, i.e., due to skin friction and shape or form of the airfoil. Reducing the profile drag is where the design engineer spends most of his/her time during the aerodynamic optimization stage. Equation (2) is the formula for drag which addresses the variables that governs the drag that a fan blade will encounter and is very similar to the formula for lift force wherein the lift coefficient,  $C_L$  is replaced by the coefficient of drag,  $C_D$ . The drag coefficient is also determined by experimental testing and/or numerical analysis. Interpreting equation (2) it becomes evident that a higher  $C_D$  will result in a elevated drag force and which in turn will necessitate the fan to consume more power. As a conclusion of this section, the airfoil selection process as described in the next section is a critical step in the aerodynamic optimization stage wherein the designer chooses airfoil(s) cross-sections that will form the span of the fan blade.

$$D = \frac{1}{2} \rho v^2 C_D A \quad (2)$$

## Airfoil Selection

One of the preliminary steps within the aerodynamic design of a fan blade is the airfoil selection. There are millions of different airfoils in the airfoil database, each developed by the research engineers of various industries. The National Advisory Committee for Aeronautics (NACA) possesses the largest library of airfoils which were designed for the aerospace industry, and are popularly known as NACA airfoils. Other than NACA, there are numerous other libraries for the design engineer to choose an airfoil from or he/she may even design a custom airfoil that serves a unique purpose. It is practically impossible to consider or test all the different airfoil options available during the design process. Hence it requires a qualified designer who understands the aerodynamics of airfoils and possesses the noesis of different classes of airfoils in order to reduce the options to a finite and feasible number. The aerodynamicist would pick the airfoil class depending on the application, for instance, a database of supercritical airfoils will be studied if the airfoils are intended to be used in a supersonic flow regime in order to reduce the shock-induced drag. The designer would then implement an objective study of the selected group of airfoils conducive to selecting an optimum airfoil. The airfoil section is responsible for the generation of the optimum pressure distribution on the top and bottom surfaces of the fan blade such that the required pressure difference is created with the lowest aerodynamic cost, i.e. drag and pitching moment.

Without the use of numerical analysis, the designer is limited to referring the published lift, drag and moment data for airfoils. Such data are limited to certain Reynolds numbers and pitch angles. The other option is to carry out wind tunnel testing on the different airfoils, but this can become extremely time consuming and would require a great deal of resources. However, with the recent advancements in the development of numerical tools and the availability of powerful computers, the computational fluid dynamics (CFD) softwares are able to solve more and more complex problems using a considerably small amount of time. Such analysis tools can be very useful to designers which will help reduce the turn-around time and will require fewer resources. Using CFD, the airfoil selection can be done by testing various airfoils in the different flow regimes that are expected over an axial fan blade. Figure 2 below demonstrates the two dimensional velocity contours of an airfoil that the user would study during the selection process.



**Figure 2: Velocity Contours of Cambered Airfoil Illustrating Normal (left) and Stalled (right) Conditions**

It is also possible to consider more than one airfoil for the same fan blade to compensate for the varying tangential velocities across the blade span, i.e., different airfoils at the root and tip of the blade. The more common way to address this varying velocity is to purpose an aerodynamic twist and/or taper to the blade from root to tip, i.e., the root having the widest airfoil chord and the highest angle of attack while the tip of the blade having the short-

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est airfoil and the least angle of attack. The intent is to produce similar pressure drop across the span of the blade which is not possible without twist/taper or selecting different airfoil sections along the span. However, it is critical to ensure that twist is not excessive that the blade root will begin to stall at operational range of pitch angles.

### Computational Fluid Dynamics (CFD)

Computational fluid dynamics (CFD) is a numerical analysis tool that uses iterative algorithms to solve the governing equations of fluid dynamics. The idea behind CFD is that the entire fluid regime that needs to be analyzed is discretized into infinitesimally small cells or nodes wherein the governing equations are solved. The three fundamental equations that CFD stems from are the continuity (3), the momentum (4) and the energy (5) equations. These equations are in its integral (control volume form) and these are broken down to partial differentiation form which can be applied to each of the discretized cell.

$$\frac{d}{dt} \left[ \iiint_{V'} \rho dV' \right] + \iint_A \rho(v \cdot n) dA = 0$$

$$\frac{d}{dt} \left[ \iiint_{V'} \rho v dV' \right] + \iint_A \rho v(v \cdot n) dA + F = 0$$

$$\frac{d}{dt} \left[ \iiint_{V'} \rho e dV' \right] + \iint_A \rho e(v \cdot n) dA - \frac{dE}{dt} + \frac{dW}{dt} = 0$$

The physical meaning of the continuity equation is conservation of mass which breaks down to the fact that a product of density, velocity and the cross-sectional area of the fluid domain will always remain constant. The momentum equation states that the sum of all forces applied on the fluid control volume is equal to the sum of rate of change of momentum inside the control volume and the net flux of momentum through the control surface. The meaning of the energy equation is that the total energy of a fluid particle is conserved except for some frictional losses which are accounted for in the Navier-Stokes equations. The partial differential form of these equations are known as the Navier-Stokes and Euler equations which forms the most fundamental framework for CFD. Euler equations are for inviscid (ideal) flow, which by definition is a flow where the dissipative, transport phenomena of viscosity, mass diffusion and thermal conductivity are neglected. The set of Navier-Stokes equations considers the diffusive and dissipative nature of viscous fluids. All fluids are viscous, however, for some very low viscosity fluids, the Euler equations may be used for approximations. These fundamental equations are coupled with complex turbulence models to form accurate fluid flow solutions. There are a variety of turbulence models and each model has its advantages and disadvantages depending on the application and hence the user is required to possess the knowledge of such models along with the noesis of different solvers such as steady state Euler, the unsteady Navier-Stokes, et cetera mentioned above.

CFD has been utilized in a variety of industries for research and development, troubleshooting and even for reverse engineering. It has proven to be a very great tool which can be coupled with theoretical analysis and experimental testing to save time and resources for various projects. For certain R&D projects, the most

advantageous facet of using such numerical analysis tools is the reduced time for the optimization of the new design. This tool gives the designer the capability to examine and study a variety of different design ideas without incurring additional cost. The modern simulation industry has also developed highly sophisticated optimization softwares wherein the user merely advises the variables available for the software to change and the software will carry out the entire optimization process and provide the optimized model based on the user's criteria. The velocity contours illustrated in the figure 3 below is an important criteria that the designer analyzes during the design optimization stage.

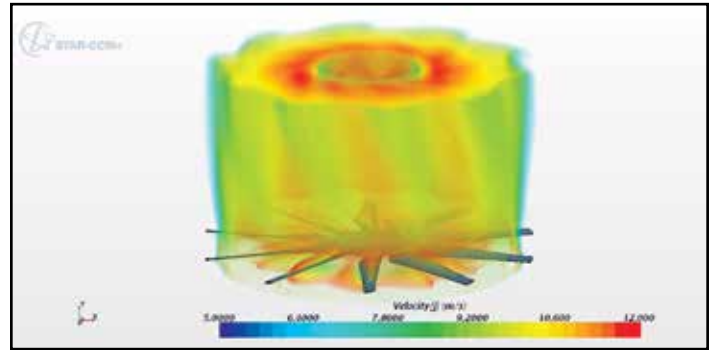


Figure 3: 3D Velocity Contours of a Completely Modeled Axial Fan

After the airfoil selection is completed, the fan blade is modeled and the fan is assembled in the desired application like a cooling tower unit using 3D modeling tools, the model can be brought in to the CFD software wherein the fan operation can be simulated at various rotational speeds and blade pitches. The most basic results from such a CFD simulation will be the velocity and pressure distribution across any given plane and with the help of these parameters, the airflow and the pressure drop can be predicted. Certain CFD tools are also able to predict the power consumption and the noise levels of the fan. The power is calculated from the torsional moment imparted by the fan which is in turn derived from the pressure and shear forces on the fan surface. The noise levels are determined by recording the amplitude and frequency of acoustical pressure waves at various locations which can then be converted to decibels.

The user(s) can run a plethora of simulations using the different fan designs (width, twist, taper, etc), rotational speeds, blade pitches and even different airfoils in order to collect the performance data using which they can arrive on the design that will best fit their application. Hence this step concludes the aerodynamic optimization part of the design process.

### Wind Tunnel Testing/Fan Curve Development

After the aerodynamic optimization, the designer will have settled on one or more designs that showed the highest likelihood of being an efficient and/or low-noise fan based on the design criteria. The next step would be to verify and thereby develop credence to the computational analysis by executing physical testing in a controlled environment. However, in most cases the fan sizes relevant to the subject industry will be too big to be tested in a controlled laboratory environment, due to which a scaled-down model(s) of the selected design(s) which are geometrically similar to the true size model(s) is fabricated for wind tunnel testing. This laboratory testing will verify the CFD results and also develop fan curves if desired, given the verification is successful. The laboratory test-



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ing must be done in a AMCA certified wind tunnel which will ensure repeatability of results and comparability between different products. During or after the aerodynamic performance testing, the noise measurements may also be carried out. Both the performance and noise test data from the scale model can then be translated to the values for a true size fan by using the appropriate conversion formulae.

AMCA stands for Air Movement and Control Association and is an independent entity that is involved in testing and certifying a variety of air moving equipment like axial and centrifugal fans, duct systems, air curtains, et cetera. AMCA has developed standards for testing axial fans for fan curve development and reporting performance values. AMCA 210 is the fundamental standard that contains the various laboratory performance testing methodologies that are appropriate for different applications. AMCA 802 is a specific standard that deals with performance testing of scale model fans which applies to the fans in the industrial cooling application, the size of which is too large to be feasible for testing in a wind tunnel. AMCA 301 describes the methodology for measuring sound power levels of scale size fans and dictates the conversion formulae for determining the sound power levels for the true size fan.

There are two limitations stated in AMCA standards that needs to be considered before settling on the scaled fan diameter. The first requirement comes in the form of minimum model size or maximum scale ratio, which constrains the scale model to shrink below the limit which will hence limit the difference in Reynolds number between the true size fan and the model fan. The other control that AMCA dictates is that the model fan must be such that the cross-sectional area of the fan ring must not be greater than 1/5th the size of inlet/outlet test chamber cross-sectional area. After the aerodynamic performance testing and the noise testing of the scale size model are complete, the resultant data is translated for the true size fan. This will give the designer the complete set of fan curves that he/she can compare other existing fan curves with and make a case of how it is a better performing fan. Equations (6), (7) and (8) below are the formulae that are used to derive the airflow, total pressure and power consumption respectively of the true size fan from the model fan that is experimentally assessed in a laboratory.

$$Q_t = Q_p * \left(\frac{D_t}{D_p}\right)^2 * \frac{N_t}{N_p} * \frac{K_p}{K_t}$$

$$P_t = P_p * \left(\frac{D_t}{D_p}\right)^2 * \left(\frac{N_t}{N_p}\right)^2 * \frac{\rho_t}{\rho_p} * \frac{K_p}{K_t}$$

$$H_t = H_p * \left(\frac{D_t}{D_p}\right)^5 * \left(\frac{N_t}{N_p}\right)^3 * \frac{\rho_t}{\rho_p} * \frac{K_p}{K_t}$$

## Structural Design

There is a variety of manufacturing techniques and also an abundance of materials to choose from for fabricating the fan blades and hub for the large diameter axial fans used in industrial cooling. One of the most important criteria to evaluate while opting the manufacturing process is the capability to twist, change chord widths (i.e., taper) and vary thickness along the span of a fan blade because a fan blade that is straight and of uniform thickness does not make an efficient fan. As discussed in the aerodynamics section, an axial fan will perform with higher efficiency if the velocity and pressure is distributed uniformly along the span of the fan blade which can be achieved by twisting, tapering, using different airfoils

or a combination of these traits. Due to the above reasons, one of the optimum manufacturing methods that is widely famous in various industries is the resin transfer molding (RTM) which would result in a fiber-reinforced plastic (FRP) as the fan blade material. Adopting the RTM method will not limit the designer in making structurally complex conceptual models and thereby allowing him/her to model the most complex of designs to attain an optimized aerodynamic shape. The barriers to entry may be high with the RTM method due to the higher initial capital investment and hence this method is not widespread in the large axial fan industry. Unfortunately, using a method that is not capable to twist and taper the fan blade will incur the cost of developing a less than optimized axial fan. Implementing this aerodynamic design will also help the in the structural design aspect since the aerodynamic loads will be distributed uniformly on the blade as opposed to high load concentration at the blade tip in a straight fan blade.

The structural design is essentially the final step in the development of an axial fan. At this point, the designer has completed the conceptual design and obtained an optimized fan model using CFD and has carried out the laboratory testing of a scaled-down prototype to verify CFD results and to acquire fan curves for the optimized model(s). Hence the final act to conclude the development project is to manufacture the true size fan but before that, the structural analysis must be done to ensure that the fan is strong enough to endure the loads during operation and hence to avoid premature physical failure of the fan while in operation. The structural analysis may be done before fabricating the actual fan assembly by utilizing another numerical analysis tool called Finite Element Analysis (FEA), using which one can predict the loads and stress that the fan will experience when rotating. There are various softwares available that have the capability to be coupled with the CFD solver and hence the FEA tool will import the aerodynamic loads during operation from the CFD tool which will then be used to determine the total loads and stresses on the fan. The result of a FEA exercise is that the user will be able to determine whether the material and thickness that is chosen for the fan assembly will be able to withstand the loads that it is expected to endure during operation.

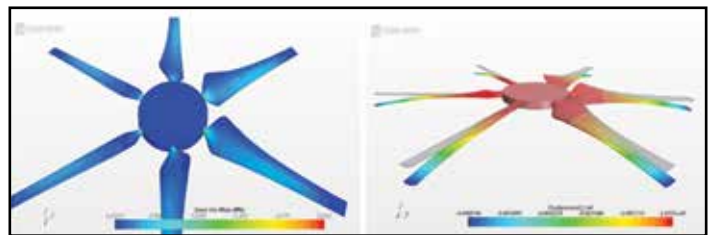


Figure 4: Stress Distribution (left) and Fan Blade Displacement (right) using FEA

Figure 4 above depicts the scalar stress and blade displacement in the axial direction (bending) that the fan blades encounters during operation. These two structural criteria form the most fundamental set of results from FEA based on which the user can make a decision of whether the chosen material is strong and/or stiff enough to withstand operational loads.

## Summary

As concluding remarks, the author would like to mention that there seems to be a market demand for higher efficiency and lower noise industrial cooling fans and to bring such fans to the market, there needs to be more computational and experimental R&D. Duly implementing the development projects in a manner described in this paper can help lower the power consumption



and the noise produced by axial fans which amounts to a great deal in making the environment green. Another important aspect that the current market demands is accurate fan curves. Due to the lack of testing or improper procedure, the fan curves tend to be inaccurate and as a result more resources are squandered in the endeavor of reaching the design duty point and in some cases, replacement of the fan is required. Inaccurate fan curves also leads to a biased market and a misinformed customer. The HVAC industry has already evolved through this phase and thereby has standardized fan curve development procedure wherein a new fan design has to be experimentally assessed as per the method construed in the relevant ANSI/AMCA standard and hence certify the fan curves. It is the author's intention to request other axial fan manufacturers and interested parties to work together and agree upon a standardized testing procedure that will benefit the industry by producing higher accuracy fan curves.

### List of symbols

- $A$  Cross-sectional area of subject fluid volume
- $C_D$  Coefficient of drag
- $C_L$  Coefficient of lift
- $D$  Drag force
- $D_p$  Diameter of the scaled model fan
- $D_t$  Diameter of the true size fan
- $E$  Energy influx, i.e., energy coming into the fluid volume
- $F$  Forces acting on the fluid volume
- $H_p$  Power consumed by scaled model fan
- $H_t$  Power consumed by true size fan
- $K_p$  Compressibility coefficient of the scaled model fan
- $K_t$  Compressibility coefficient of the true size fan
- $L$  Lift force
- $N_p$  Rotational speed of the scaled model fan
- $N_t$  Rotational speed of the true size fan
- $P_p$  Total pressure measured during scaled model testing
- $P_t$  Total pressure for true size fan
- $Q_p$  Airflow produced by scaled model fan
- $Q_t$  Airflow produced by true size fan
- $V$  Fluid Control Volume
- $W$  Energy outflux, i.e., energy expended the fluid volume
- $\rho$  Density
- $\rho_p$  Density of air during scaled model testing
- $\rho_t$  Density of air during true size testing
- $e$  Energy per unit mass of fluid, i.e., specific energy
- $n$  unit vector
- $v$  Fluid velocity

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# Non-Destructive Evaluation of Structural Elements of Cooling Towers: Past and Present

By  
Narendra Gosain, Ph.D., P.E., Ray Drexler, P.E.,  
Mark E. Williams, Ph.D., P.E.

## Abstract

Wood, concrete and steel have been used as structural materials in cooling towers for decades. When evaluations are needed to understand the structural integrity of the materials used after years of service of the towers or during routine maintenance cycles, specialized procedures have been developed to characterize the condition of different materials. These range from visual to in situ tests using various techniques for different materials. This paper describes some of the non-destructive testing techniques used in the past and current testing procedures. Some case histories are discussed.

## Introduction To Non-Destructive Evaluation

As the name implies, Non-Destructive Evaluation (NDE) is a testing technique used in the industry for obtaining specific information on the properties or the condition of various materials and components or assemblies of structural elements without damaging or otherwise scarring the object being tested. Since NDE does not alter the state of the tested element, such elements can be rapidly deployed into service if the testing indicates that the integrity of the element has not been compromised. Such testing techniques have a tremendous potential for cost savings when used judiciously not only in the material cost but also in the downtime of an operating facility. Another commonly used term for such evaluation of materials is also referred to as Non-Destructive Testing (NDT). Thus NDE and NDT are synonymous terms and are frequently used interchangeably.

NDE tests are conducted on the commonly used materials of construction of cooling towers such as wood, concrete and steel. These tests have gained wide acceptance in the industry and are fairly economical. NDE techniques for fiber reinforced polymer (FRP) elements used in cooling tower have not been fully developed and have not yet been widely used in the industry. As such, NDE of FRP structural elements is not included in this paper.

Some testing techniques do require minor invasive procedures. When employed judiciously, the tested elements still maintain their structural integrity without requiring extensive repair work. Such minor invasive techniques employ coring, drilling and excising coupons from materials to be tested. Various tests using concrete cores, drilling concrete sections to access the embedded reinforcement, excising coupons from steel elements to test for essential mechanical properties, or conducting pull-off tests on concrete repair using bonded materials are sometimes conducted to supplement and confirm results from NDE. Such partial destructive tests are done to get a better understanding of the integrity or assessment of the remaining life of the structure. Such examples in concrete elements include conducting petrographic analysis of the concrete cores to understand the makeup of the concrete matrix and to note any effect some external factors such as fire, chemical exposure and other environmental factors may have had on the durability on the concrete. Chloride intrusion tests in concrete core samples are also



Narendra Gosain

done routinely to understand the potential of corrosion in the embedded reinforcing bars.

Testing techniques that require extensive destruction or damage to the element being tested are not desirable especially when NDE options are easily and economically available. Figure 1 shows the contrast between an evaluation using NDE versus an evaluation using destructive methods. Large openings were made in the slab to detect voids which otherwise would have been done using NDE techniques. Intentionally damaged elements for testing will necessarily require some repairs that may involve multiple tradesmen and increase the downtime of the tower being evaluated. Repairing such structures adds to the cost and risks involved in restoring the structure back to service.



Figure 1: Non-Destructive Evaluation versus Destructive Evaluation for Void Detection

## Advantages Of Non-Destructive Evaluation

Engineers are frequently requested to conduct an evaluation of various structural elements of cooling towers and their support structures. The requested evaluation could be to gage how much useful life is remaining in the structure of aging cooling towers ranging from modest roof top units to multi cell circular cooling towers to gigantic hyperbolic cooling towers. There may be situations where the cooling towers and their support structures have not been appropriately maintained and there are obvious indications of deterioration and loss of integrity of the various structural elements. In some instances, it could be an evaluation after extreme loading conditions experienced during a seismic, blast, hurricane and tornadic event. Even though fires are relatively few in cooling towers, such events do occur and the owner's desire may be to ascertain what all elements can be salvaged, repaired or stay in service in the interest of bringing the cooling tower rapidly back into service. Also due to changes in the needs of cooling capacity of a facility, upgrades may be needed that may require an assessment of the various structural elements of the cooling tower. Even after repairs are undertaken, NDE techniques become very useful in evaluating the integrity and efficacy of the repairs performed.



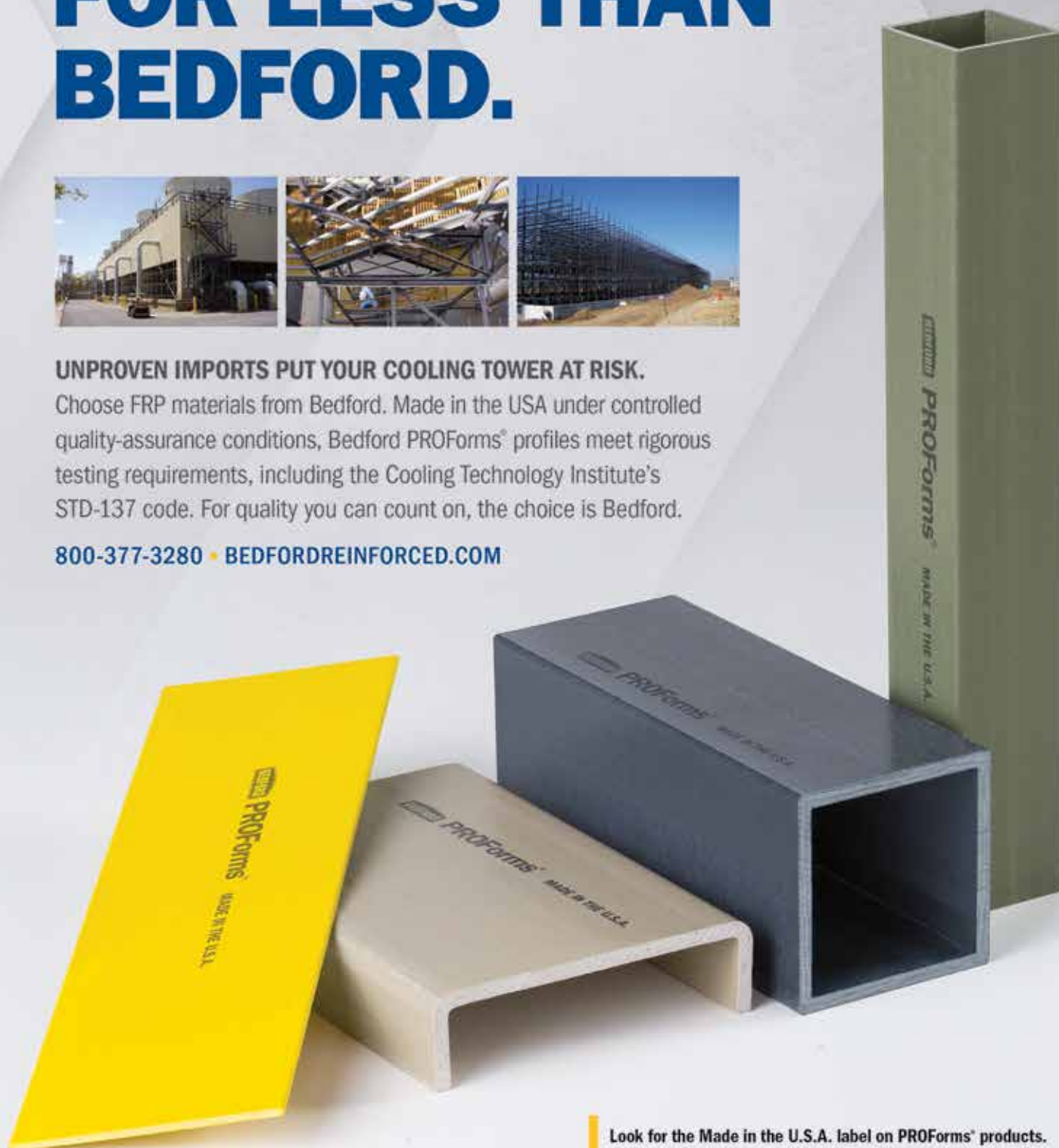
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It is to be noted that sometimes in critical members, the engineer may desire to conduct tensile, compressive, modulus of elasticity and flexural strength tests of actual materials extracted from the cooling tower structure to confirm the material properties. However, when such excise, extraction or partially destructive action in the structural elements are done in the interest of testing, it needs to be conducted after careful understanding that the structural integrity of the remaining structure is not compromised. This may require a detailed analysis that may lead to providing temporary shoring to make up for the extracted element. Although such a process provides the most direct information on the physical characteristics of the material needed by the engineer, it is also the most time consuming and costly way when compared to NDE. As opposed to conducting the aforementioned tests which are generally done in off-site laboratories, NDE tests are done on-site by highly skilled and trained personnel that understand not only the reason for conducting such tests but also the criticality of the information needed and limitations of the tests. Even though simple to use, the data gathered from the NDE instruments does require detailed analysis and interpretation to develop quantitative and qualitative information useful to engineers for evaluation of the structure under review. A significant advantage of NDE over other destructive testing procedures is that relatively a large volume of data can be obtained from different segments of the structure in a relatively short period of time at the site itself where access may be difficult for prolonged and frequent visits. An experienced NDE personnel can then analyze and interpret the field data in a relatively short period of time thus speeding up the turnaround period in making decisions.

Another distinct advantage is that non-destructive methods are particularly helpful for investigative work of cooling tower structures. No localized destructive procedures are utilized and the cooling towers can remain operational during testing when there are no safety concerns or quickly brought back into operation after the testing is completed. Understandably, most non-destructive test methods offer advantages over the more commonplace visual review process when the test methods are utilized within their known limitations. Proper use of these test methods requires both technical knowledge of the methods and continued experience with deploying these methods at the site.

## **Non-Destructive Evaluation: Brief History Of Some Current Methods**

There are several classifications of NDE methods that have evolved over the years. Historical background of some of these are discussed briefly below.

### **Visual Inspection**

The visual method of noting rot in wood, fractures in steel and cracks in masonry and concrete have been practiced for hundreds of years and is still the first method of flaw detection in a material which many times prompts other tests. Early scientifically conducted visual inspections appear to have been initiated due to a catastrophic explosion of a boiler at the Fales and Gray Car Works facility in Hartford, Connecticut in 1854 that killed 21 people (Reference 1). This prompted the State of Connecticut to pass a law that required annual visual inspection of boilers within a decade after this tragic event.

### **Sonic NDE Testing**

It is to be noted that craftsman of various trades have used an NDE method for centuries that was always available then and is still available and commonly used now also. This is the acoustic and sonic NDE method of listening to the sound using our ears for flaw detection. The potters and ceramic craftsman used it to check whether they had any flaws such as cracks and discontinuities in their wares that were not visible to the naked eye; the blacksmiths did the same

when they heated and hammered various metals into shape. A ringing tone indicated a flaw free product and a dull sound indicated a product with flaws.

### **X-Ray Technique**

The first NDE method that was used in the industrial application was the X-Ray technique. In 1895, German physicist Wilhelm Conrad Rontgen discovered X-Rays. In his first publication on this topic, Rontgen described various medical uses including flaw detection. The medical field adopted this discovery, but unfortunately, Rontgen was unaware of the harmful effects of X-rays on humans. Thus many people died due to exposure to X-Rays before radiation protection was introduced. Industrial application was introduced much later in 1930 by Richard Seifert of Germany through cooperation with welding institutes (Reference 2).

### **Magnetic Particle Testing**

In 1868, S.M. Saxby of England observed the presence of cracks in magnetized gun barrels by passing a compass over them. This was followed by William Hoke of USA in 1917 who observed the potential use of magnetism as an NDE method. He noted that while the magnetized precision gage blocks were being ground, the metal filings tended to congregate at the locations of the fine cracks that developed in the grinding process. Industrial application was introduced in 1929 by Foster B. Doane, Carl Betz and Tabor de Forest of USA (Reference 3). They started a company called Magnaflux in 1934 which is still in business.

### **Liquid Penetrant Testing**

The Romans were perhaps the early users of such testing technique. They used oil and flour to detect cracks in marble floors (Reference 4). As if taking a cue from the Romans, some technical staff started using the "Oil and Whiting" process for crack detection in railway components in the second half of 19th century. Regrettably, the names of these innovative testing staff members were not documented. Between 1934 and 1940, Foster B. Doane, Carl Betz and Tabor de Forest of USA developed the liquid penetrating test. The use of such NDE technique became popular during World War II when the aircraft industry started using more non-magnetic metals that could not be tested with magnetic particle testing techniques.

### **Ultrasonic Testing**

Methods of exciting ultrasound were discovered in 1847 by James Prescott Joule. The first application of ultrasonic was proposed after the steamship Titanic was sunk on 15 April 1912 after colliding with an iceberg. Lewis F. Richardson of England claimed that he could detect the presence of icebergs by using ultrasonic testing techniques. Then in 1929, Sergei Y. Sokolov of Russia proposed the use of ultrasonic testing for finding defects in castings. During World War II, the existing NDE methods of X-Rays, magnetic particle, liquid penetrating and eddy current test methods could not be used for detecting laminations in plates and fine non-metallic inclusions in hot rolled sections. Ultrasonic testing, which had improved significantly by then, became the most extensively used NDE method during that time (Reference 2).

### **Schmidt Hammer**

The Schmidt Hammer or the Swiss Hammer is comparatively a fairly new instrument. It was introduced in 1950 by Ernest Schmidt of Switzerland. In the early stages of its introduction, it was mistakenly considered to give a reading of the in-situ concrete strength. However, it just provides a relative hardness of the concrete surface where the test is conducted. This test method is classified as an indirect test since it does not give the absolute strength of concrete being tested.



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# Common Types Of Non-Destructive Evaluation Methods For Cooling Towers

While there are several types of NDE techniques available for testing various structural elements of cooling towers, the following techniques are generally popular and commonly used:

## Basic NDE types

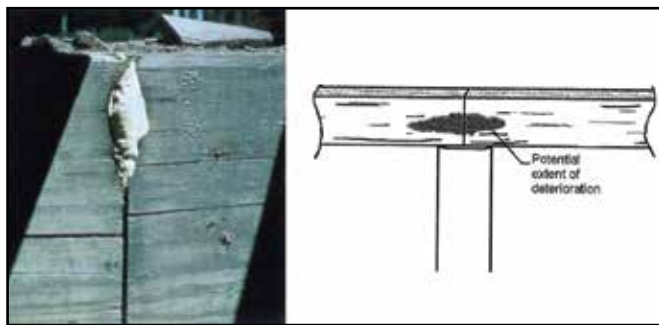
- Visual
- Mechanical
- Sonic/Ultrasonic
- Electrical
- Electromagnetic
- Magnetic
- Nuclear

All methods are not suitable for different materials used in cooling towers. Wood, concrete, steel and fiber reinforced polymers all have different characteristics. Thus different NDE techniques have evolved for different materials.

A brief description of each material is given below and testing methods for different material is presented in a Tables 1, 2 and 3. Many non-destructive evaluation (NDE) methods conform to the protocols specified in the American Society for Testing and Materials (ASTM). Where applicable, ASTM references for the NDE test methods referenced in this paper are listed in a separate section in this paper.

## Wood

Unlike concrete, steel and fiber reinforced polymers (FRP) which are manufactured materials, wood is a naturally occurring biological material. As such, wood has several inherent defects such as knots, slope of grain, resin pockets and splits. Another complexity of wood is the fact that this is an orthotropic nonhomogeneous material whose properties depend on the orientation of the fibers or grain. Also, unless treated for protection and durability, wood is susceptible to attack by various organisms and fungus. An example of fungal attack is given in Figure 2 and the deterioration that can occur with such fungal growth.



(A) Fruiting or Fungal Growth between Two Beams (B) Potential Deterioration in Beams

Figure 2: Fungal Attack in Wood Beams and Potential Deterioration (Reference 5)

Untreated or improperly treated wood that has high moisture content due to prolonged exposure to water can also decay. All such problems can lead to a reduction in the density and mechanical properties and compromise the structural strength of the wood elements.

As it is with all materials, not all distress in wood is due to organisms and fungal attack or other weaknesses of the material. Distress can frequently occur due to overloading and poor design as well.

Over the years some relatively modern NDE techniques have evolved such that engineers can get a qualitative idea of the material properties rather than just depending on visual cues. Table

1 provides a brief summary of different NDE methods available for wood elements. Additional information is given in References 5 and 6.

Test Method	Test Summary	Advantages	Limitations
Visual	Visual review includes naked eye, high-power spotting scope, and aerial drone photography (Figure 3). Visual inspection can reveal fruiting bodies, localized surface depressions and staining.	Easy to do by the trained personnel. Use drones in inaccessible and obstruction free areas.	Limited to the perception of the human eye. With drones, the limitation is based on the power of camera used for images.
Probing (Figure 4)	Probing done with an awl or pick. Sound wood probed will split into long splinters. Decayed wood is brittle and will break into short splinters (also called brash break).	Tests done to supplement visual inspection.	Only the surface is tested. Thicker members require other tests.
Sounding	Poor hammer rebound or a hollow sound indicates possible decay. Non-damaged wood gives a crisp sound. Loose hardware will vibrate.	Test is rapid and can be done while performing visual inspection.	Depth of decay cannot be evaluated. Needs to be supplemented by other tests.
Coring (partially destructive)	Used for determining extent and type of decay pockets, other voids, density, moisture content, timber specie and amount of preservative treatment. In fire damaged elements, thickness of char also determined. Tests done in laboratory.	Positive indication of wood condition. Tests conducted in laboratory once coring is done.	Coring may be time consuming. Laboratory tests take time.
Drilling (Figure 5)	Reduced resistance to drilling indicates pockets of decay. Drill chips sent to a wood pathologist can confirm decay. Drilling done by special electric drill with capabilities of giving information on resistance encountered at various depths.	Initial results are rapid. Cheaper than coring.	Tool cost moderately expensive.
Moisture Meter	Two types of moisture meters: <ul style="list-style-type: none"> <li>• Resistance: Probes driven into wood and moisture readings recorded at various depths</li> <li>• Dielectric: Meter held against wood surface and moisture content at predetermined depth is measured</li> </ul>	Moisture content is a good indication of decay.	Some chemically treated wood are not suitable for such moisture meters. Meter not accurate above the fiber saturation point (Approximately 26 -28% of moisture content).
Stress Wave Method (Figure 6)	This method is based on the speed of sound with the rate of attenuation depending on the strength and stiffness of the wood. A compression wave is generated in the material by tapping it with a hammer. The velocity of this compression wave is calculated by knowing the distance between two transducers and the time taken to travel between the two transducers. By knowing the density of the material, the dynamic modulus of elasticity is calculated.	Equipment is portable and simple to use. Method gives a quantitative measurement of properties. Decayed areas have lower speed of sound when compared to sound wood. By performing the tests in a grid pattern, decay can be mapped.	Readings are affected by wood moisture content, temperature and chemical treatment. Results are considered to be moderately accurate for strength and spatial quantification.
Ultrasonic Technique: Through Transmission Method (Figure 7)	The acoustic velocity and the acoustic attenuation coefficient is used as strength indicators. Through transmission method uses two piezoelectric transducers. The electric pulse generator sends a signal through the transmitter transducer. If there is a defect in the path of the ultrasound, it is partly reflected which is captured by the transmitter whereas the reduced signal is captured by the receiver. The ratio of the two signals indicate the defect.	Equipment is portable. Elastic properties measured with a fair degree of accuracy. Provides quick on-site estimate of mechanical properties.	Same as in Stress Wave Method. This method requires access to two sides of the specimen.
Ultrasonic Technique: Pulse-Echo Method	As in the through transmission method, the acoustic velocity and attenuation coefficient is used as strength indicators. Only one transducer is used in this method which serves as both the transmitter and receiver. Therefore, only the reflected pulse is measured. The time taken is shorter for the reflected pulse from a decayed section of the wood than from the further edge of the wood.	Same as in Through Transmission Method. Additional advantage is that this method works where only one side of the specimen is accessible.	Same as in Stress Wave Method.
Pilodyn Method (Figure 8)	A blunt pin is shot into the wood with a preset energy. The penetration of the pin is measured and from this the density of the wood or the degree of decay is assessed using a calibrated chart.	Different wood species require different spring energy according to their density. The moisture content of the wood affects the penetration and correction factors need to be applied.	This method measures only the surface properties.
Infrared Camera (Figure 9)	This method is based on the theory of emissivity. In absorbent materials, most of the energy is absorbed which is captured by the camera. It is a non-contact method of detecting differences in temperature using infrared rays.	Since it is a non-contact method, the wood element being tested need not be accessible for mounting any sensors or transducers. The method has been shown to work well in detecting termite infested areas of wood.	It only works on absorbent materials. Other than termite infestation, it is uncertain whether detection of decay due to other reasons can be done using this method.

Table 1: NDE and Partially Destructive Test Methods for Wood

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Figure 3: Aerial Drone Photography (Courtesy of ReliaPOLE Inspection Services Company)



Figure 4: Probing by a Pick (From Reference 6)



Figure 5: Resistance Drill for Detecting Decay in a Wooden Member (Reference 10)

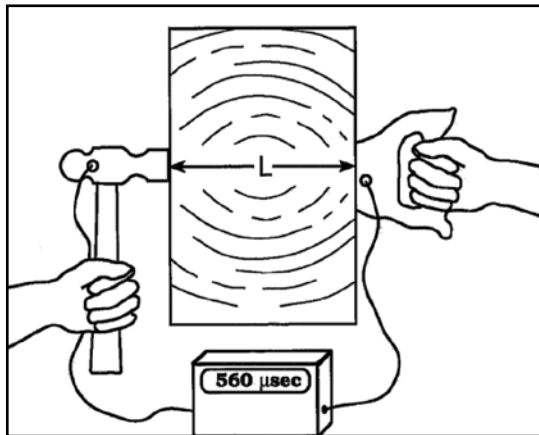


Figure 6: Stress Wave Method to Detect Decay (Reference 5)

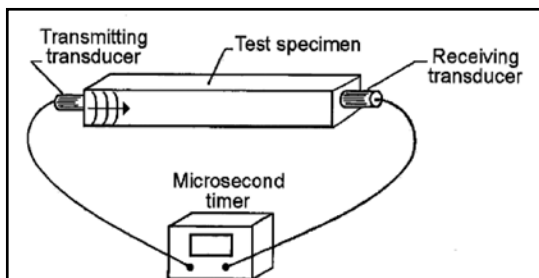
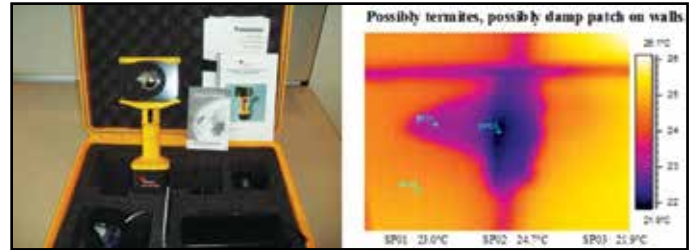


Figure 7: Ultrasonic Technique: Through Transmission Method (Reference 5)



Figure 8: Pilodyn Test Method for Wood Density and Strength



Infrared Camera Typical Thermal Imaging Result (Reference 11)

Figure 9: NDE Using Infrared Camera for Detecting Termite Infestation

## Concrete

Reinforced concrete is a common construction material for cooling towers. Reinforced concrete works well as a composite material in that concrete's relatively low tensile strength and brittleness are counteracted by the inclusion of reinforcement having higher tensile strength and ductility. Reinforced concrete structures can be either precast or cast-in-place.

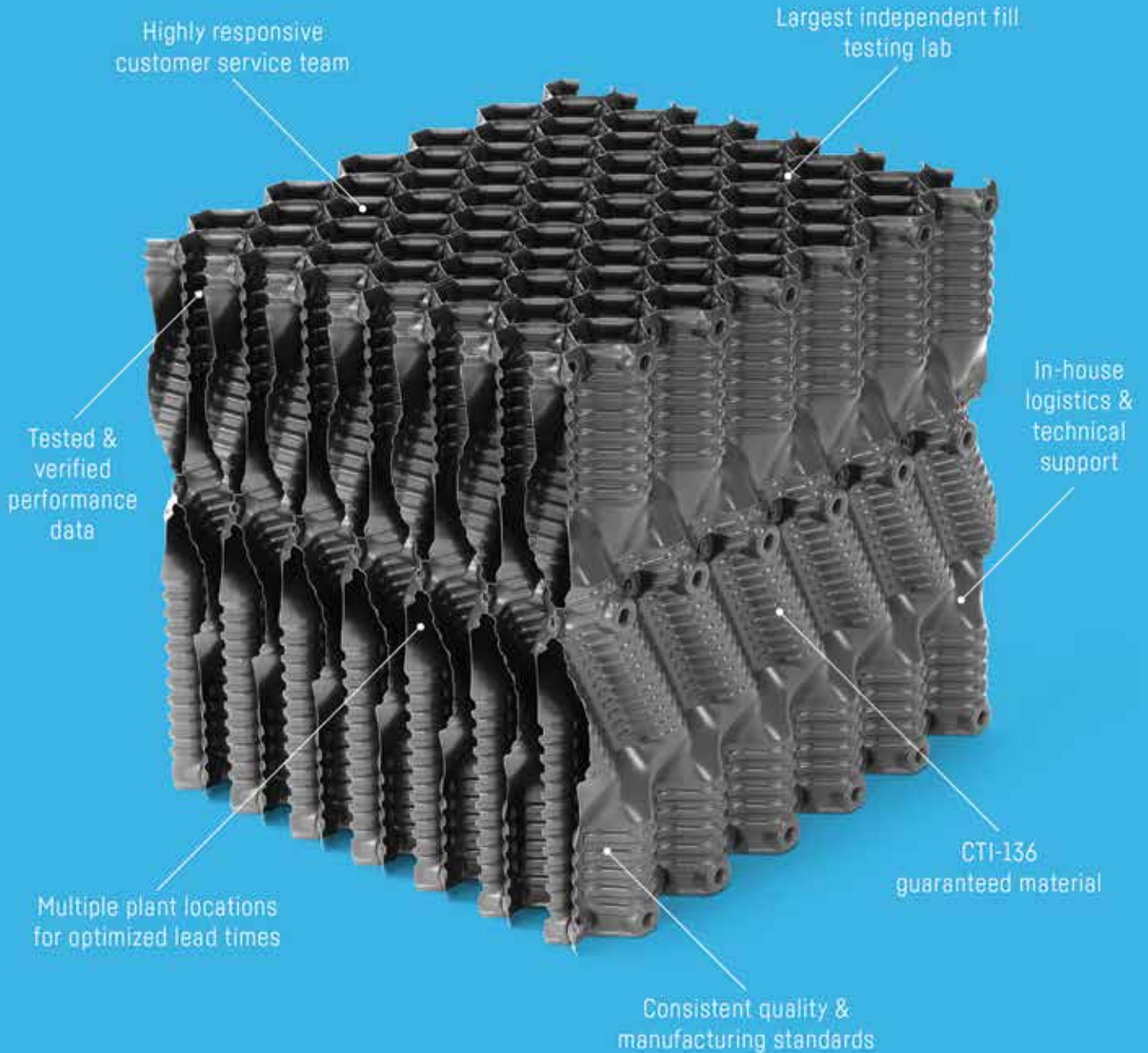
Reinforced concrete cooling tower structures generally perform well when properly designed, detailed and constructed. Deviations from the intended design during construction can create conditions for premature concrete deterioration. Improper placement of concrete can lead to the formation of honeycombing or voids in the concrete. Improper placement of reinforcing steel or failure to provide adequate protective concrete cover can lead to early-stage corrosion of the reinforcement. Improper finishing or curing of concrete can lead to scaling, cracking, and other concrete surface distress. Premature removal of forms can lead to failure, cracking or excessive sagging of horizontal members and failure or crushing of vertical members. Deterioration can also result from internal reactions within the concrete due to the use of reactive aggregates in the concrete, such as alkali-silica reaction (ASR) and delayed ettringite formation (DEF), which produce destructive cracking problems in the frequent presence or exposure to moisture.

Even when they are well designed and constructed, reinforced concrete cooling towers are still subject to distress and deterioration from various environmental factors. The use of various chemicals or salt products in the cooling water can adversely affect the structure and potentially accelerate deterioration. Chloride ions at high enough concentrations in the cooling water are particularly harmful to reinforced concrete structures that will lead to corrosion-induced deterioration of the reinforcing steel. In the frost zone, the use of de-icing chemicals can also lead to corrosion of reinforcing steel. Repeated cycles of freeze-thaw can also rapidly deteriorate concrete if the concrete mix has not been designed for such harsh conditions. Concrete structures are also subject to sulfate attack where dissolved sulfates penetrate the concrete. Finally, the exposure of concrete to atmospheric carbon dioxide (carbonation) can reduce the pH of the concrete, making the reinforcing steel more susceptible to corrosion activity.

There are a variety of test methods available for evaluating distress or suspected distress in reinforced concrete cooling towers and their



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concrete basins. In a 2016 paper, Thomas Kline described some NDE methods used in condition assessment of cooling towers along with relevant ASTM standards (Reference 7).

Table 2 provides a summary of the most commonly used nondestructive test methods for concrete as well as the advantages and limitations of each test method described.



Figure 10: Rebound (Schmidt) Hammer Test

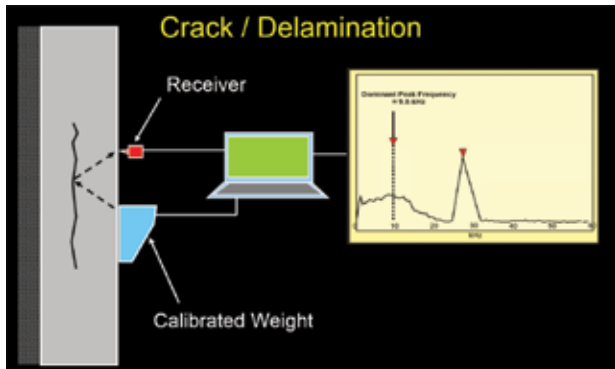


Figure 11: Impact Echo Method to Detect Crack/Delamination

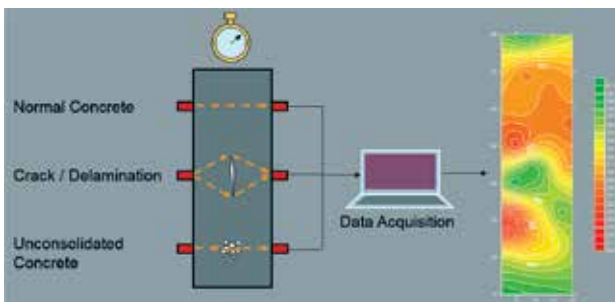


Figure 12: Schematic of Ultrasonic Pulse Velocity Test Method

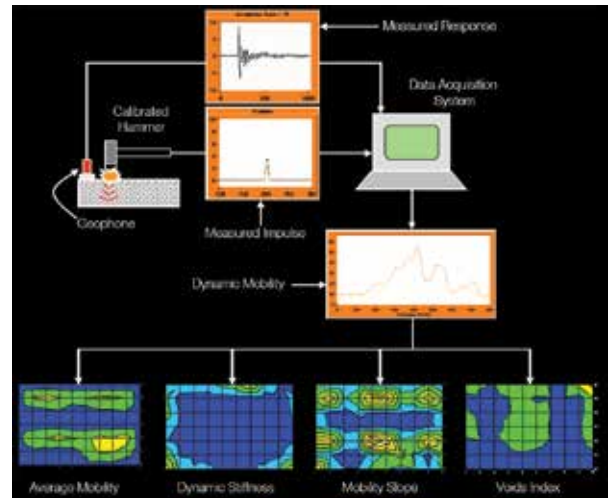


Figure 13: Schematic of Impulse Response Test Method

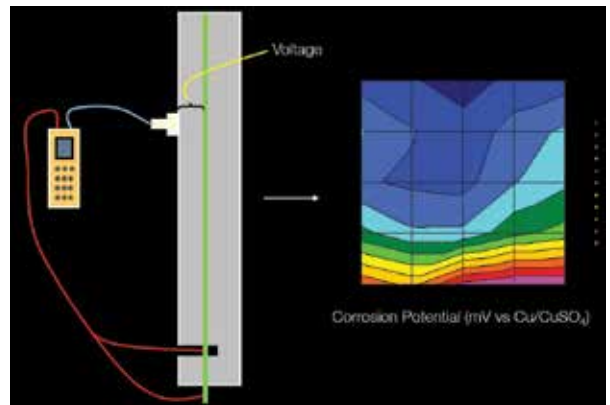


Figure 14: Schematic of Half-Cell Potential Testing for Corrosion

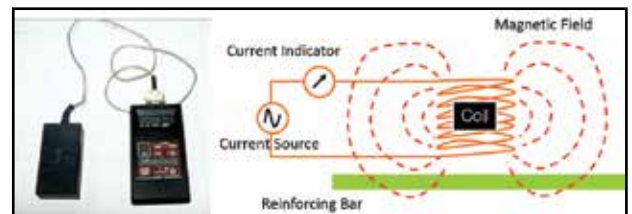


Figure 15: Cover Meter or Magnetic Rebar Locator or Pachometer

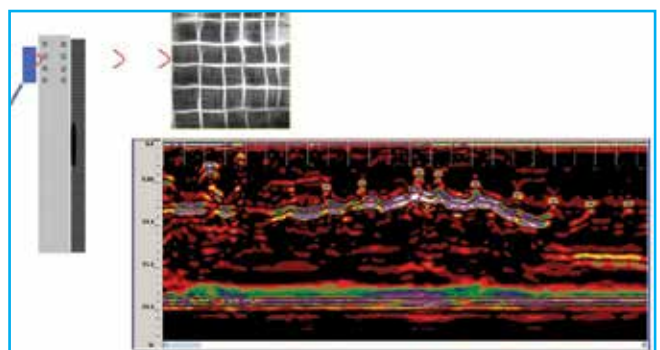


Figure 16: Ground Penetrating Radar (GPR) for Detecting Reinforcing Bars in Concrete

## Steel

While steel consists of iron and various alloying elements and has microstructures with differing mechanical properties, it is considered to be an isotropic material at the macro level since its mechanical properties are the same in all directions. Carbon steels (typical structural steel) are basically iron with small amounts of carbon and other trace elements (carbon 0.18-0.23%, manganese 0.30-0.60%, silicon 0.30% maximum, phosphorus 0.04% maximum, and sulfur 0.05% maximum). Alloy steels contain one or more alloying elements (such as chromium, manganese, molybdenum, nickel, vanadium) to improve the strength, hardness, heat treatability, toughness, ductility, and durability of carbon steels. These two types of steel are generally referred to as ferritic or ferrite-pearlite steels due to the presence of ferrite and pearlite microstructures in the steel related to how the steel cools.

Austenitic chromium-nickel steels (stainless steels) do not undergo the normal phase changes associated with ferritic steels. Common austenitic stainless steels contain high portions of chromium (18-25%) and nickel (8-20%) to provide enhanced resistance to corrosion and other chemical reactions and environmental attacks.

Common problems with ferritic steels include in-service degradation such as corrosion. This corrosion may be associated with water borne chemicals associated with marine environment and cooling tower water, or de-icing salts or dissimilar metals (galvanic corrosion). A less common problem is stress corrosion cracking where some alloying elements in the steel initiate or propagate cracks under certain environmental conditions (such as high tensile stress) along the microstructure boundaries. Stainless steels have enhanced resistance to these types of attack but are not immune to them.

Once the proper grade of structural steel specified by the engineers has been used in construction and protected against corrosion in the environment where the structure is located and maintained regularly, there is usually not much of an issue in the service life of the steel structural members. However, connections are particularly vulnerable to degradation. Bolted connections have crevices (threads, and mating surfaces) that trap moisture and other contaminants. These areas typically degrade more rapidly than the planes associated with the metal shapes and plates that form the bulk of the structure like the cooling tower frame, fill and the tower support frame. Improper welding procedures and practices may result in cracks and porosity where moisture and other contaminants get trapped. Additionally, improper weld sizing for stresses at the connections and lack of consideration of fatigue loading may also result in crack formation. Finally, the heat affected zone (HAZ) of steels may suffer from carbon embrittlement.

As in concrete, there are a variety of test methods available for NDE of steel elements as well. Table 3 provides a summary of the most commonly used nondestructive test methods for steel elements. Advantages and limitations of each test method are also included in the table. These tests are particularly useful when evaluating the quality of welds. The American Welding Society (AWS) recommends supplementing the NDE findings with destructive testing for confirmations. AWS maintains NDE does not eliminate the need for destructive testing (Reference 8). The decision whether to supplement NDE with other confirmatory destructive testing rests on the engineer of record.

Hardness tests leave very minor indentations on the material but are otherwise non-destructive. Other mechanical property testing such as stress-strain plots obtained from tensile testing require coupons and are destructive. These tests are not discussed.

Test Method	Test Summary	Advantages	Limitations
Visual	View review includes naked eye, high-power spotting scope, and aerial drone photography.	Familiarity, use of drones in inaccessible areas.	Limited to the perception of the human eye. With drones, the limitation is based on the power of camera used for images.
High Definition Photography	Uses high resolution cameras to capture concrete surface defects.	Photography for inaccessible areas.	Requires line of sight
Schmidt Impact Hammer (Figure 10)	Correlates the rebound of a hammer to concrete strength.	Quick and relatively inexpensive test for relative quality of concrete.	Variable results. Does not provide accurate concrete strength information for analytical work
Windsor Probe Test	A hardness tester that correlates penetration of a probe with concrete strength.	Quick test with immediate results. Provides relative quality of concrete.	Variable results. Concrete edges, thickness, and depth influence results.
Impact-echo (Figure 11)	Measures properties of reflected P-waves generated by a short-duration, elastic impact of a calibrated weight on a concrete surface. This impact generates low-frequency stress waves that propagate into the structure and are reflected by flaws and/or external surfaces.	Accessibility from one side only. Useful in measuring depth of cracking and detecting subsurface flaws such as honeycombing, ASR distress and delamination in the concrete.	Measures localized conditions; near surface discontinuities not detected, not effective near edges.
Ultrasonic Pulse Velocity (UPV) (Figure 12)	Used for determining the relative condition and quality of the concrete. UPV consists of measuring the time it takes for an ultrasonic pulse to travel through concrete. The velocity of the waves depends on the density and elastic properties of the concrete as well as the presence of any discontinuities or anomalies.	Detection of below surface flaws such as unconsolidated concrete and delaminations.	Generally requires access to both sides of area being tested. Results are qualitative in nature.
Impulse Response (Figure 13)	Uses a low-strain impact from a hammer to excite a structure and then measure the response using a velocity transducer (geophone). The dynamic mobility is analyzed to characterize the condition of the concrete and the probability of internal delaminations and/or voids.	Rapid detection of below surface flaws and delaminations. Detection of flaws in wall anchoring systems. Void detection below slabs on grade. Identifies areas for further detailed testing.	Results are qualitative and relative to the condition of the surrounding concrete.
Half-Cell Potential (Figure 14)	Performed to determine the corrosion activity on the reinforcing steel. The corrosion potential represents the tendency of a metal to corrode in a given environment.	Measuring latent corrosion activity.	Testing requires contact with reinforcing steel within the concrete. Depth of concrete cover to be less than 4". Does not work in saturated concrete and concrete with waterproofing membrane.
Impact-echo (Figure 11)	Measures properties of reflected P-waves generated by a short-duration, elastic impact of a calibrated weight on a concrete surface. This impact generates low-frequency stress waves that propagate into the structure and are reflected by flaws and/or external surfaces.	Accessibility from one side only. Useful in measuring depth of cracking and detecting subsurface flaws such as honeycombing, ASR distress and delamination in the concrete.	Measures localized conditions; near surface discontinuities not detected, not effective near edges.
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Table 2: NDE and Partially Destructive Test Methods for Concrete



Figure 17 (a): BoreScope Instrumentation



Figure 17(b): Borescope in use

Figure 17(c): Image of Anchor from Borescope

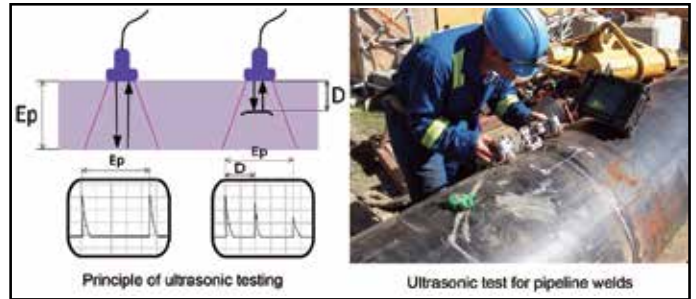


Figure 21: Ultrasonic Testing (Wikipedia: Reference 15)

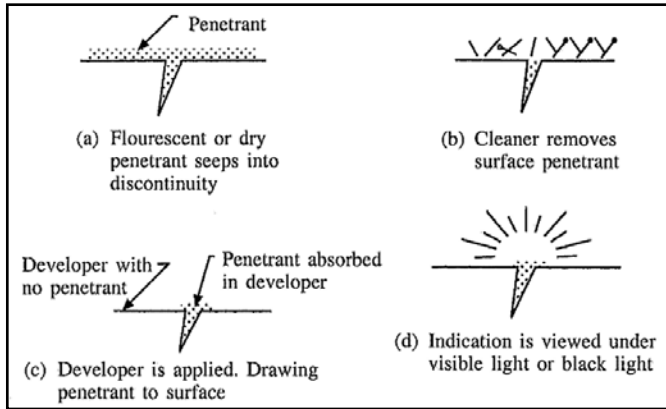


Figure 18: Liquid Penetrant Testing (From Reference 9)

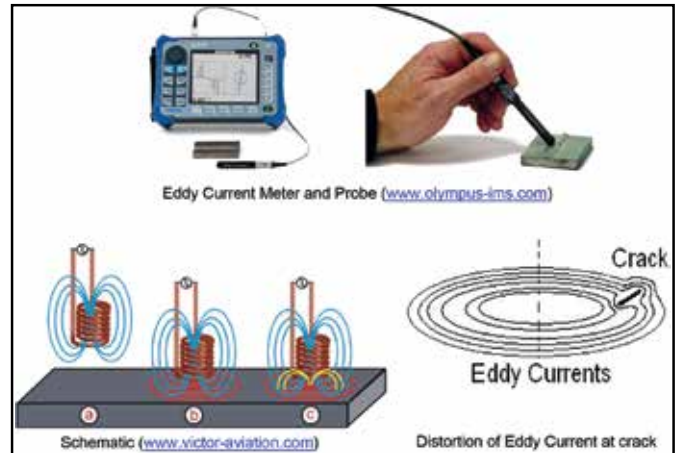


Figure 22: Eddy Current Weld Inspection: (a) The alternating current flowing through the coil at a chosen frequency generates a magnetic field around the coil, (b) When the coil is placed close to an electrically conductive material, eddy current is induced in the material, and (c) If a flaw in the conductive material disturbs the eddy current circulation, the magnetic coupling with the probe is changed and a defect signal can be read by measuring the coil impedance variation.

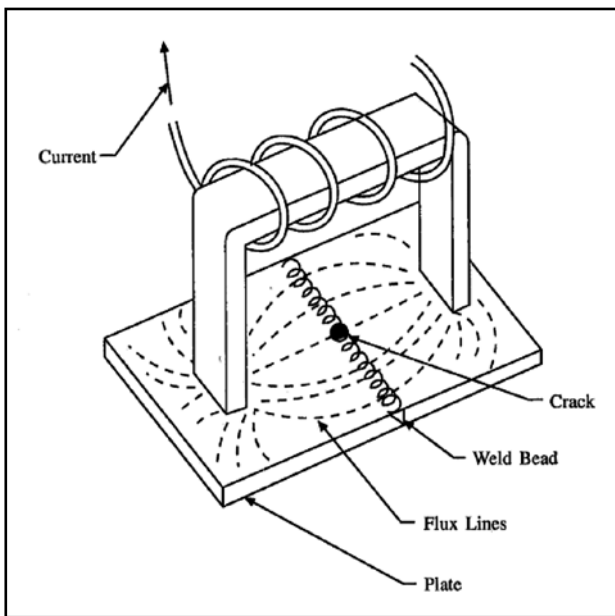


Figure 19: Magnetic Particle Testing with Yoke Magnetization (From Reference 9)

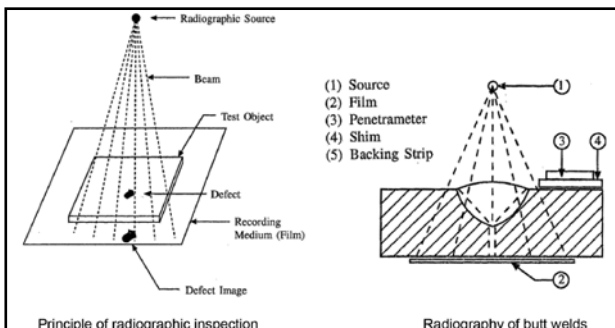


Figure 20: Radiography testing (From Reference 9)



Figure 23: Three Cell Wood Cooling Tower

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The structural system of the cooling tower is best described as a wooden space frame, with an array of 4x4 wood columns braced by a grid of horizontal framing at multiple levels (pairs of 2x6s and 2x4s) and 4x4 diagonal bracing in each direction. The plastic baffles are typically supported by 2x4s at 18-inches on-center. Plywood has been installed to the vertical framing members in selected locations, presumably to direct airflow at the lower level.

Work consisted primarily of a walk-through visual review of the cooling tower lower wooden framing structure to identify structural items in need of repair. No exploratory openings were performed and no destructive testing of elements removed from the framing was done as part of this assessment. The budget did not allow for any sophisticated non-destructive testing other than wood probing using picks (see Figure 3 and Figure 24) to detect concealed and/or deteriorated wood. By using such visual and wood-pick methods, a fairly good understanding of the condition of the cooling tower framing was developed. Work was confined only to the lower level which was visible and accessible but not the upper level which was concealed by the plastic baffles.



Figure 27: Typical failed vertical wood member due to wood splitting.



Figure 24: Wood pick probe used in evaluating depth of deterioration in wood



Figure 28: Depth of probing into a failed wood member with decay deterioration

Typical distress conditions from visual observations are given in Figure 25 through Figure 30.



Figure 25: Typical failed connection due to wood splitting of framing members



Figure 29: Typical failed vertical wood member with decay deterioration



Figure 26: Typical failed connection due to decay of framing members



Figure 30: Typical failed wood member with decay deterioration and crushing distress



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Figure 31: Typical column member with minor decay



Figure 32: Typical horizontal member in serviceable condition

These non-destructive evaluation methods using visual observations and simple wood picks allowed the documentation of the distressed condition of the cooling tower. A sample of the noted distressed conditions as well as those that were found to be serviceable is given in Table 4 below:

Item No.	Description of Structural Distress	Reference Figures
1	6 connections failed due to by wood splitting and/or decay	25 and 26
2	Approximately 15% of the vertical members failed by wood splitting or advanced (deeper than 1/4-inch) decay deterioration	27, 28 and 29
3	Approximately 40% of the horizontal members failed by wood splitting or advanced decay deterioration	30
4	Approximately 35% of the column members had minor wood distress in the form of splitting and surface decay deterioration	31
5	Approximately 10% horizontal members appear to be in serviceable condition	32

Table 4: Structural Evaluation of Wood Framing Tower using NDE

Once the structural evaluation is done, the client can be advised of the priorities that need to be assigned to repair the observed distressed conditions. Understandably, items that involve safety and structural integrity of the cooling tower need to be placed in the high priority list. For the wood cooling tower described above, some of the high priority items are listed in Table 5 below.

Item No.	High Priority Repairs	Reference Figures
1	Repair all connection	25 and 26
2	Vertical column members exhibiting wood splitting and advanced decay	27 and 29
3	Horizontal members exhibiting wood splitting and advanced decay	25 and 30
4	Diagonal bracing members exhibiting splitting and advanced decay	None

Table 5: Sample of High Priority Repair Items

Some members that were observed to be severely distressed and on the verge of collapse were noted to be shored immediately. Repair recommendations to restore the structural integrity of the frame consisted of either replacement or “sistering” new members abutting the distressed members.

### Case History 2A: Concrete Cooling Tower Basin

A five cell cooling tower shown in Figures 33 and 34 built in 2001 was reviewed in 2010 at the request of the owner who noticed some corrosion activity, spalling of concrete and deterioration of the waterproofing in the basin. Review consisted of visual walk through observation after the water was drained from the basin along with non-destructive evaluation using ground penetrating radar (GPR) and limited partial destructive testing. Cores were excised to conduct petrography examination, chloride intrusion tests and pH evaluation of concrete.



Figure 33: General view of five cell cooling tower

Visual walk-through review indicated some distress conditions of the cooling tower basin. Examples of some structural and non-structural conditions are noted in Table 6.

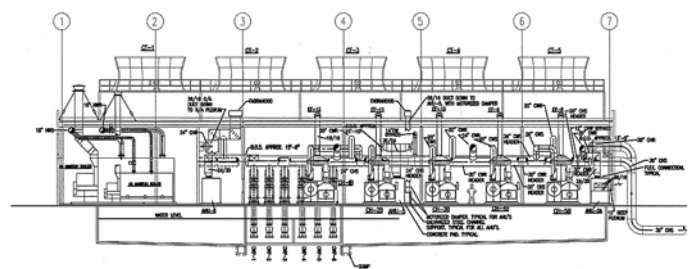


Figure 34: Sectional View showing Cooling Tower Basin



Item No.	Description of Structural Distress	Reference Figures
1	The concrete walls of the cooling tower basin were noted to have chemical attack at two locations. These two locations corresponded with the discharge location of the sulfuric acid line and the splash zone/waterline of the cooling tower basin. The chemical attack has resulted in concrete cavities approximately two inches deep at one location and approximately three inches deep at the other distress location.	35 and 36
2	Reinforcing steel at the backside of Core C1 appeared to be epoxy coated mild steel. The existing steel generally appeared to be free of corrosion product where the coating was scraped by the core bit.	37
3	GPR scans generally indicated the concrete cover was approximately 3" on the north wall in the east cooling tower basin, except at the location of the acid line where the cover increased to 5.5".	38
4	Tight concrete cracking was observed in the concrete ceiling of the cooling tower basin with crack widths less than 20 mils (0.020").	None
5	Corrosion of the filtration grill and support steel channels.	39
6	Corrosion of non-submerged piping at the acid discharge location in the basin.	40

Table 6: Structural Evaluation of Concrete Basin Using NDE

The GPR scan described in Item 3 of Table 6 not only confirmed the as-built condition, but also provided information on where the cores may be excised without cutting through the reinforcement.

Although the focus of this paper is on NDE of structural elements, visual observations were also made on some embedded items in concrete as well as waterproofing of the concrete basin reviewed. Such items were needed to be documented for corrective actions by the owner to enhance the durability of the concrete basin. Table 7 describes briefly such typical conditions.



Figure 37: Epoxy Coated Reinforcement Bar with 5.5" Cover

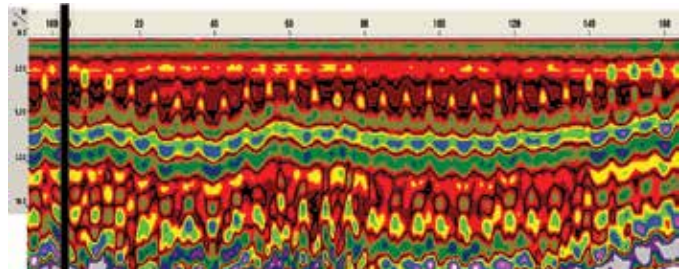


Figure 38: Typical GPR Scan of Basin Wall



Figure 35: Chemical Attack on Cooling Tower Basin



Figure 36: Depth of Chemical Attack on Cooling Tower Basin



Figure 39: Corrosion of filtration grill and support channels



Figure 40: Corrosion of non-submerged pipe at the acid discharge point

Item No.	Description of Structural Distress	Reference Figures
1	Corrosion of the filtration grill and support steel channels	39
2	Corrosion of non-submerged piping at the acid discharge location in the basin	40
3	Major blistering of coating on wall of cooling tower basin	41
4	Minor blister in the coating on wall	42

Table 7: Some Examples of Non-Structural Distress in Cooling Tower Basin



Figure 41: Extensive blistering of coating on basin wall

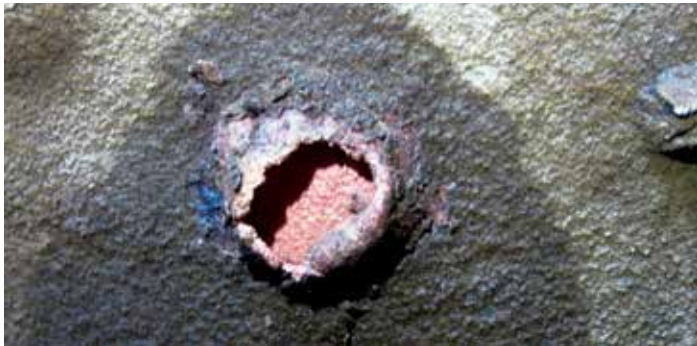


Figure 42: Close-up of blister in the coating with the failed coating still within blister

### Petrography, pH and Chloride Content Testing:

As discussed earlier, sometimes NDE tests need to be supplemented by partially destructive tests. In this water basin concrete assessment, it was evident that certain areas of the cooling tower basin were exposed to acid attack. A decision was made to excise three cores from the basin walls and conduct the following three kinds of tests to evaluate the condition of the concrete matrix:

1. Concrete petrography test conducted in accordance with ASTM C856
2. pH test for alkalinity of concrete
3. Water-soluble chloride content analysis following procedures specified in ASTM C1218

The three cores were taken from locations described in Table 8 below and sent to an independent testing laboratory for testing.




Core No.	Location of Core	Reference Figure for Location	Image of Core Excised
C1	Chemical attack region	43	
C2	Location of severely distressed waterproofing coating but no evidence of concrete distress	43	
C3	Location of good condition of waterproofing coating as noted visually	43	

Table 8: Location of Concrete Cores for Petrography, Chloride Intrusion and pH Tests



Figure 43: Core Locations in Basin for Petrography, pH and Chloride Intrusion Tests

Petrographic Analysis: Petrographic analysis indicated that the concrete is generally in fair condition except for the area of direct chemical attack evidenced from Core No. C1. Some micro-cracks were observed as seen in Core No. 3 even though this core was taken at a location of good condition of waterproofing coating. Samples of thin-section photomicrographs of the three cores are shown in Figures 44, 45 and 46 for cores C1, C2 and C3 respectively.

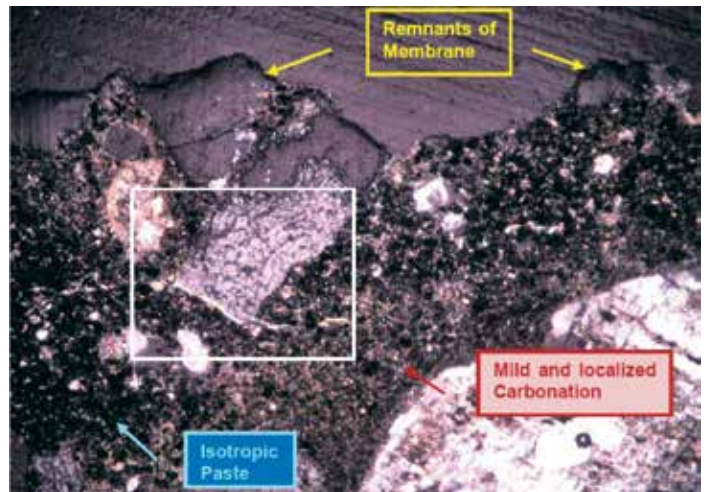


Figure 44: Thin-Section Photomicrograph showing the Cementitious Paste Microstructure in Near Surface region: Core C1

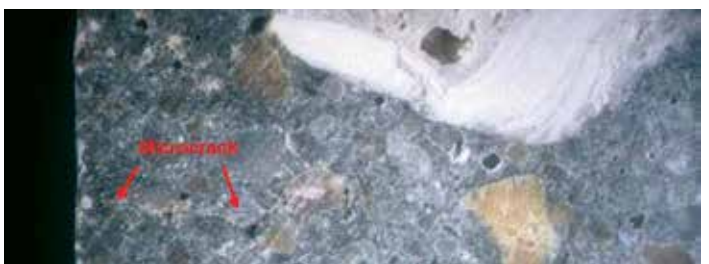


Figure 45: Photomicrograph showing a micro-crack extending inward from the outer surface: Core C2

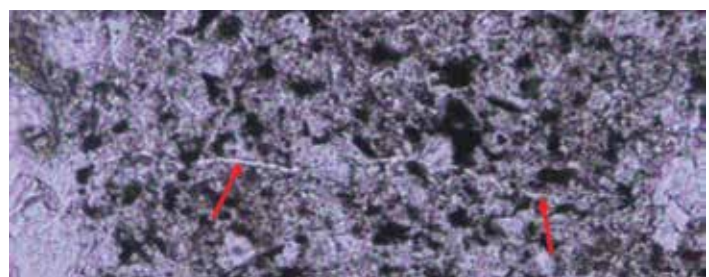
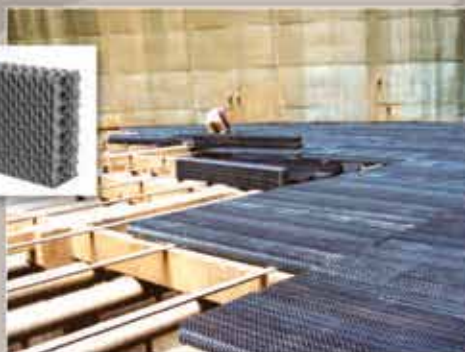
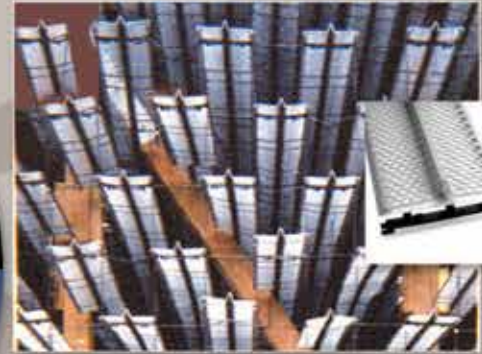


Figure 46: Thin-Section Photomicrograph showing the Cementitious-Paste Microstructure- Arrows indicate subsurface micro-cracks: Core C3

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Testing for pH: Testing to determine pH content was performed during the petrography analysis. New well cured concrete not exposed to the environment has a pH value of about 12.5. When exposed to environmental carbon dioxide, the moist alkaline material slowly begins to interact with carbon dioxide which then forms a weak carbonic acid material that lowers the pH value of concrete. Such a phenomenon is called carbonation. The results of the pH testing indicate that carbonation and chemical attack has not affected the pH of concrete in a significant manner. See table 9 for pH test results.

Water Soluble Chloride Content: This testing was performed on concrete core samples submitted for concrete petrography. Measured chloride concentration levels are then compared to maximum levels recommended by ACI 318-14 (Reference 12) which states that the upper water-soluble chloride threshold for “reinforced concrete wet in service” is 0.08% by weight of cement. High levels of water-soluble chloride in the concrete matrix may indicate a higher corrosion potential for the reinforcing steel. Water-soluble chloride content analysis for the extracted concrete cores indicates the concrete has water-soluble chloride contents of only 0.01% by weight of cement, which is less than the 0.08% maximum level recommended by ACI-318 for wet service. See Table 9 for results of water soluble chloride test.

Core No.	Location of Core	Level Tested (Inches from Exposed Surface)	pH	Chloride Ion Content by Weight of Cement (%)
C1	Chemical attack region	2.0 – 2.5	11.89	0.01
		4.0 – 4.5	11.61	0.01
C2	Severely distressed waterproofing region	0.5 – 1.0	11.81	0.01
C3	Good condition of waterproofing region	0.5 – 1.0	11.91	0.01

Table 9: pH and Chloride Content Analysis Results

Based upon the NDE and partially destructive test procedures, it was concluded that no urgent repairs were needed. It was suggested that repairs to waterproofing coating and distressed concrete be done when the thermal demand for the cooling tower is reduced within a year.

**Case History 2B: Concrete Hyperbolic Cooling Tower Structure**

In the 2011 Annual CTI Conference, authors’ colleagues Javier Balma and Dilip Choudhury described the evaluation of an existing corrosion protection system installed in two identical concrete hyperbolic cooling towers (Reference 13). The concrete shell hyperbolic cooling towers built in the 1980s are 453 feet tall, 317 feet diameter at the base, and 183 feet diameter at the throat. An image of one of the cooling towers is given in Figure 47.

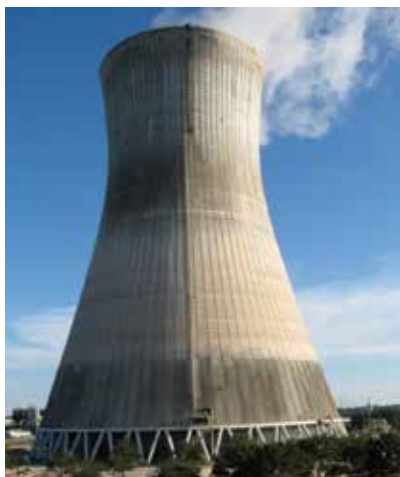


Figure 47: View of Hyperbolic Cooling Towers

The focus of the referenced paper was on evaluation of the existing galvanic corrosion protection system installed in Lifts 1-12 as shown in Figures 48 and 49. The zinc mesh was fastened to the face of the concrete shell by post-installed pins and electrically connected to the concrete reinforcing steel. A shotcrete overlay was then installed over the zinc mesh.

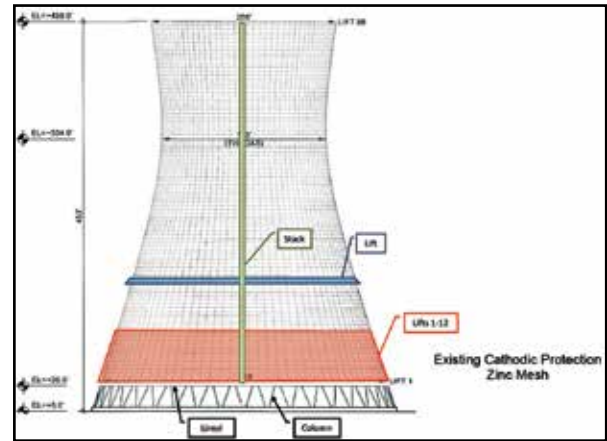


Figure 48: View of Hyperbolic Cooling Tower Showing Lower Lifts 1-12 with Existing Zinc Mesh



Figure 49: Exposed Zinc Mesh

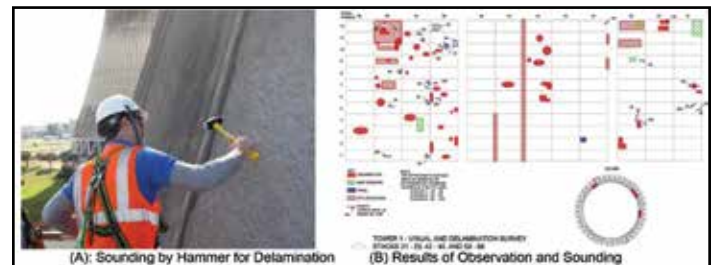


Figure 50: Visual and Delamination Survey

Extensive NDE was done to review the integrity of the mesh and the shotcrete overlay system. With permission of Balma and Choudhury, some excerpts from the original paper (Reference 13) are given here. Briefly, the tests included:

1. Visual observations and delamination surveys of the accessible portions.
2. Half-cell potential and corrosion rate measurements over select areas.
3. Impulse response testing of the shotcrete overlay.
4. Bond testing of the shotcrete overlay.
5. Thickness measurements of the zinc mesh specimens excised from the sacrificial cathodic protection system.

Brief description of the above NDE procedures are described below:

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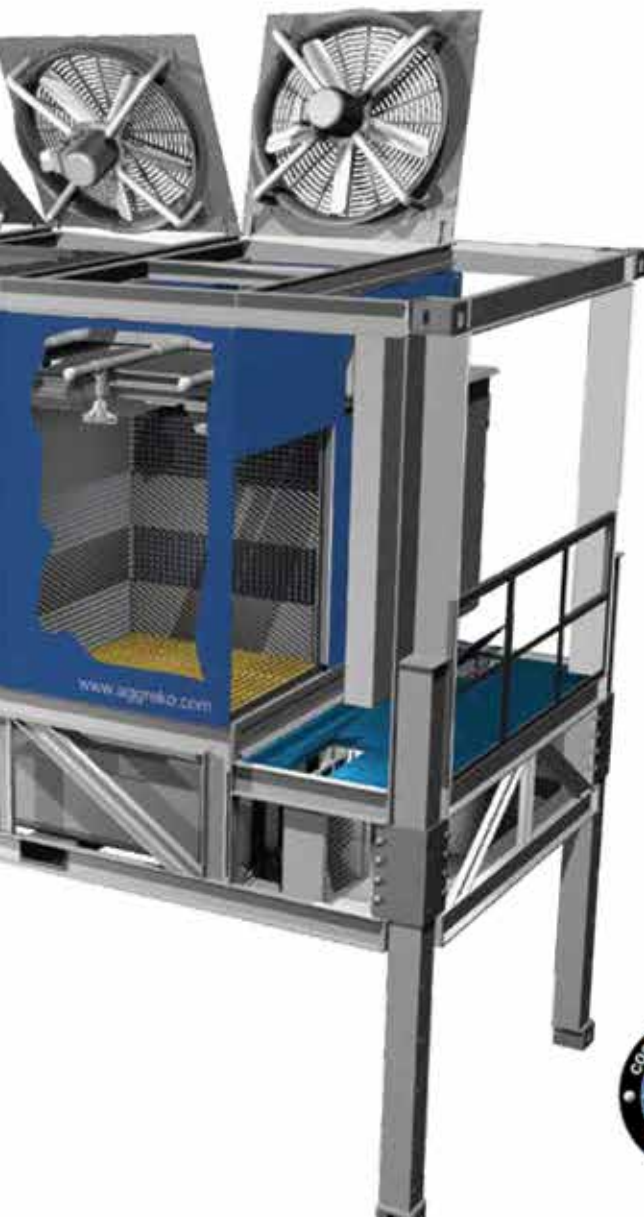
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1. “Delaminations were identified by sounding the shotcrete overlay using either a delamination wheel or a hammer. Spalls, cracks, and areas exhibiting efflorescence were also documented” (Figure 50).
2. Half-Cell Potential and Corrosion Rate Measurements: These “tests were performed as one of two methods for determining the corrosion activity on the reinforcing steel. The corrosion potential represents the tendency of a metal to corrode in a given environment. Half-cell corrosion potential monitoring was performed according to ASTM C 876 (Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete). The corrosion potential of the reinforcing steel is measured relative to the potential of a reference electrode (e.g. copper-copper sulfate, silver-silver chloride). The measured corrosion potential will depend on the reference electrode used. For potentials measured relative to the same reference electrode, the more negative the corrosion potential, the higher the tendency of the metal to corrode. Table 10 shows the interpretation of the half-cell potential according to ASTM C 876”.
  - a. “Corrosion rate testing was also performed to evaluate the corrosion activity of the reinforcing steel in the concrete veils. The corrosion rate is a measure of the thickness of steel that is lost due to corrosion and is usually given in mils per year (mpy) or micrometers per year ( $\mu\text{m}/\text{year}$ ) ( $1 \text{ mpy} \approx 25 \mu\text{m}/\text{year}$ ). Measurements were obtained with the Galvapulse equipment from Germann Instruments”.
  - b. Figure 51 shows corrosion testing of reinforcing steel using Galvapulse and a sample of test results. In general, the corrosion rates of the reinforcing steel tested were low and considered acceptable.
- b. “Impulse response testing was performed at select locations on both towers. Impulse-response testing was performed on a 3 foot by 3 foot grid over an area of approximately 9 feet by 50 feet in the selected stacks”.
  - c. Based on tests performed, the shotcrete overlay system on the zinc mesh was considered to be in generally good condition.

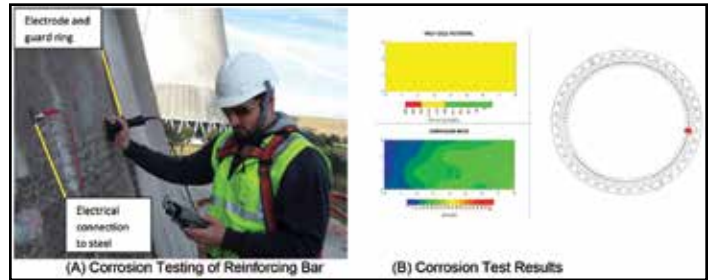


Figure 51: Half-Cell Corrosion Potential Tests

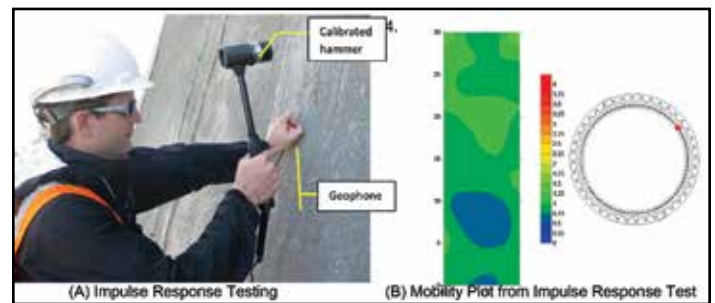


Figure 52: Impulse Response Tests for Shotcrete Overlay Integrity

Half-Cell Potential vs. $\text{Cu}/\text{CuSO}_4^{(1)}$	Probability of Corrosion
More positive than -200 mV	Less than 10%
Between -200 and -350 mV	Between 10% and 90%
More negative than -350 mV	More than 90%

<sup>(1)</sup>  $\text{Cu}/\text{CuSO}_4$ : Copper-copper sulfate electrode

Table 10- Interpretation of Half-Cell Readings According to ASTM C 876 (From Reference 13)

3. Impulse Response Tests: This NDE was done to evaluate the integrity of the shotcrete overlay on the zinc mesh. “A low-strain impact is applied to the structure and the response of the structure is measured. The concrete element is struck with a small hammer which has a built-in load cell that measures the impulse imparted. The response (vibration) of the concrete element is monitored by a velocity transducer (geophone) placed adjacent to the impact location (Figure 52(A)). The hammer and the geophone are connected to a data acquisition and processing system which calculates the dynamic mobility as a function of the frequency of the excitation. The dynamic mobility is analyzed to characterize the condition of the concrete and support conditions, as well as the probability of internal delaminations and/or voids in the concrete which may not be visible at the surface”.
  - a. “The testing is performed on a grid pattern and contour plots (Figure 52(B)) are developed for the different factors. Based on the analysis of these contour plots, probable locations of delaminations and/or voids are determined”.



Figure 53: General View of Cooling Tower Supported on Steel Framing



ed replacement. It was also noted that many welds were corroded and the integrity of such connections was questionable. Magnetic particle testing and eddy current testing were considered to check the integrity of such welded connections but abandoned due to cost and time involved in performing such tests. This was compounded by designing the shoring system taking into consideration of some members to remain. A visual survey was done that indicated that most of the members needed replacement due to severe corrosion. Figures 54, 55 and 56 are example of severely corroded steel elements that did not need any testing or further evaluation. Details on the design and methodology of providing new support framing for this cooling tower are given in Reference 14.



Figure 54: Corrosion of Stub Column and Main Steel Girder Supporting Cooling Tower



Figure 55: Typical Cooling Tower Spring and Housing Distress



Figure 56: Extensive Loss of Steel Section in Stub Column Supporting Cooling Tower

## Conclusions

Roots of NDE go as far back as the ancient Roman times. However, the genesis of current day NDE work is about 150 years old. Tremendous strides have also been made in making the NDE equipment far more user friendly and robust than in the past couple of decades due to the digital world that we live in now. The benefits

accrued in the various disciplines of engineering from cooling towers to buildings to bridges, from automobiles to the aerospace industries has been immense. The few case histories illustrated above show that small cooling towers to gigantic hyperbolic cooling towers can benefit tremendously from employing NDE techniques for structural assessments. In summary, it can be stated that the NDE techniques when used judiciously and implemented properly has the following benefits for the cooling tower industry:

- **Safety:** NDE can provide an additional level of safety by having the capability to detect flaws or defects in structural elements that may not be detectable by just visual methods. Where needed, repairs can be done to restore the integrity of the compromised elements.
- **Affordability:** With the high cost of labor in any field investigation work, NDE can provide the capability of gathering and analyzing a large volume of data in a short period of time.
- **Accuracy:** When the proper NDE equipment is used and its limitations understood, the data gathered can be relied upon for the needed course of action.

## Acknowledgements

The authors gratefully acknowledge the assistance provided by their colleagues at Walter P Moore, Louis Kahn, P.E., Rick Miles, P.E., and Javier Balma, Ph.D., P.E. They very readily and willingly shared their experiences in NDE work they had done on cooling towers. We are indebted to our colleague, Jacob Bice, Ph.D., P.E., who masterfully created some images of NDE that we have used in this paper. Sincere thanks also goes to M.J. Ameli, Ph.D. of Walter P Moore who helped the authors in formatting and adding illustrations in the paper. The authors also acknowledge Todd Allen of Radarview/UCT for permitting the use of some illustrations on petrography used in the paper. The credit for the image of drone used in one of the figures goes to Wesley J. Oliphant, P.E., Principal of Advanced Aerial Inspection Resources and ReliaPOLE Inspection Service Company.

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# Using Direct Drive Technology for Improved Reliability and Efficiency in Wet Cooling Towers

Thomas Weinandy, Baldor/Abb  
Josh Barron, Southern Company

## Abstract

This paper discusses the development of low speed, permanent magnet motors and how they can be used in direct-drive applications to eliminate the gearbox, NEMA motor, driveshaft, and disc couplings from field erect cooling tower designs. Improved reliability of cooling tower fan drives is now possible due to advancements in motor technology as evidenced over the last 9 years of operation. A Case study is presented where a cooling cell has been retrofitted. Design considerations, performance data, maintenance practices and material costs will be reviewed. Air flow considerations and efficiency comparisons will also be discussed.

## Introduction

This technology has been presented in previous papers. The permanent magnet Direct Drive motor for the Direct Drive operation of Cooling Tower fans eliminates the induction motor, driveshaft, disc coupling, gearbox arrangement, and replaces these items with a slow speed permanent magnet motor and variable frequency drive (VFD). The use of this technology could potentially offer increased energy savings, simplified installation, and reduced maintenance costs over the traditional geared solution. This paper reviews the design basics of the technology and then explores a case study in detail.

## Installed Base

Permanent Magnet Direct Drive Motor Technology has been employed in the operation and control of Direct Drive Cooling Tower fans for over 9 years. Since that time, over 675 cooling cells across a variety of industries have either been retrofitted or installed new with this technology.



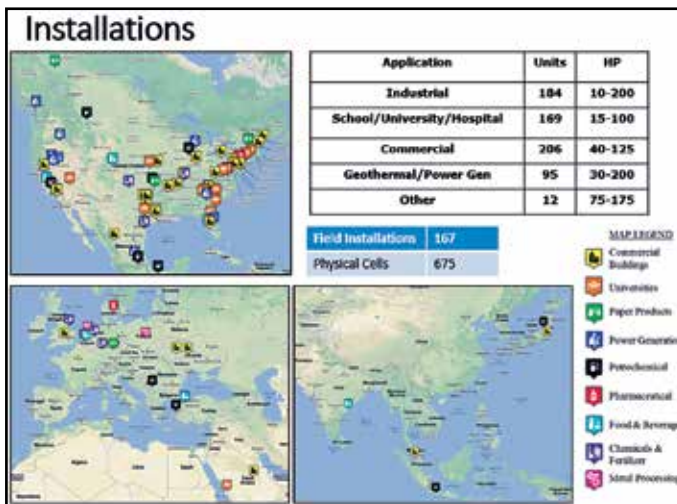
Thomas Weinandy

## User Input

Compared to other areas within the plant, the Cooling Tower installation is an area where a lot of time and effort is required to properly maintain the equipment. As the experienced worker moves off to retirement, his work is spread among his co-workers or his replacement is often someone with less experience. That inexperience creates a learning curve. In industry today, doing more with less is a common term we all have become too familiar with.

Worker safety is a high priority across all organizations today. Inspection activities that could have been tolerated just a few short years ago no longer exists. The ability to send an individual out to check on something within the cooling tower does not occur. When work needs to be performed, in many cases there are at least two workers involved. If there are no guard rails or hand rails, it would be defined as a “confined space area” and treated accordingly. Safety harnesses have to be used. An inspection that used to take a few hours and could possibly be done while the tower is running is now relegated to a LOTO (lock out tag out) situation and the Cooling Tower being out of service for a period of time.

Every User has a procedure on how they properly maintain their gearboxes. Some will follow the instructions as provided to them by the gearbox manufacturer, AGMA, or CTI standards. In an effort to extend the time between oil changes, Users often migrate to an oil inspection analysis program. The time is determined by the periodic lab sample sent in for analysis will dictate the frequency of the change. Yet others have migrated to synthetic oil in an effort to provide even longer life. Every User has a different standard. Everyone uses what they believe works for their particular situation. What clearly separates all the installations is the quality



Fan		Gearbox	
5. Service Factor	2.9	1. Manufacturer	Hudson Products
a. Helical	2.6	2. Diameter, ft.	.40
b. Spiral bevel	2.5	3. Fan speed, rpm	97.5
6. Gear Efficiency	95	4. Number of blades	8
		5. Tip speed, fpm	12000
		6. moment of WK2	241817
		7. Blade pitch angle	9.5 plus or minus .12 deg
		8. Blade material	Fiberglass/epoxy
1. Type	Floating	9. Fan horsepower	191 at gearbox output est 207 amps
2. Manufacturer	Rexnord	10. Total static press below fan in H2O	0.4919
3. Model Number	SN5F - 350	11. Velocity press at fan in H2O	0.1181
		12. Air delivery per fan in ACFM	17,745,000
		13. Air delivery, specific vol in ft3	15.752
1. Type	TEFC		
2. Manufacturer	Westinghouse		
3. Horsepower	250		
4. Volts	460	1. Type	Spiral bevel
5. Full speed, rpm	1785	2. Manufacturer	Western Gear
6. Service factor	1.15	3. Ratio	18.325:1
7. Motor load, hp	202 est 219 amps	4. Horsepower	250
8. Motor load, kw	150.7		

Motor FLA at 250 HP is 271 amps

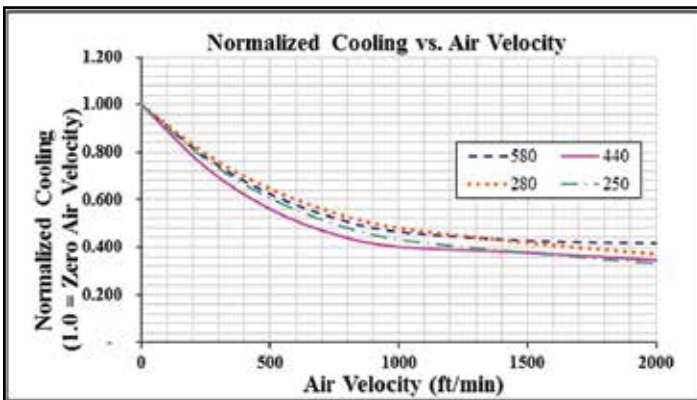
Measured amps were 260 – 265 amps at the MCC

of water used for cooling. From city water to well water to grey water, every type of water has chemical properties that will drive the overall maintenance schedule (refer to page 12 for PM maintenance requirements).

### Proper Motor Sizing

Since the gearbox and drive shaft have been eliminated, no mechanical losses have to be accounted for in the motor sizing. With Direct Drive technology, the motor sizing brake horsepower is based off of the fan curve. So how is a retrofit handled? Do we size off of the existing motor? Care needs to be exercised to analyze all information. On projects where there were EPC's (Engineer, Procure, Construct) involved, in most cases there were plant data books available that contained original design information. In the books are the selection sheets for the equipment. An example is shown below. Making a selection purely based on the brake horsepower (bhp) of the fan may lead to incorrect sizing. There are (2) brake horsepower ratings shown. Knowing the motor full load amps, the amps can be approximated for the bhp ratings. How does this calculated value compare to the measured value as identified at the MCC or switchgear? In this instance, the measured value is close to the motor full load amps. What occurred at some point during the operational years, the fans were repitched to take advantage of the full motor rating. In this example, making a selection solely on the design brake horsepower rating as listed in the original data book would have been in error.

### Airflow Design



In applying Direct Drive technology, obtaining the required amount of cooling air is critical to proper sizing and providing a long, reliable motor life. Based on testing, it has been determined that incremental cooling air velocity up to 1250 fpm provides normalized cooling to the motor frame. Above 1250 fpm, the value of more air does not have the same effect as it does below 1250 fpm. Maximizing the air velocity on a given rating insures that the motor frame selection is the smallest possible.



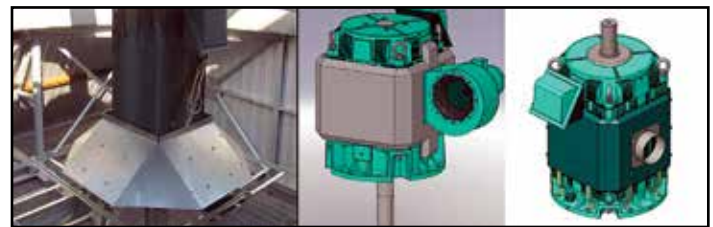
Pictured above are a couple of examples of fan designs. All motors pictured are of the same diameter. Note the hub size difference and

the impact of the seal disc. The fan and hub design can have an effect on the amount of cooling air the motor sees.

### Additional ways to obtain cooling air

Differential Air Cooling has been determined to be effective in providing additional cooling air for a Direct Drive motor. On a fan size of 28 feet in diameter, a fan of this size would normally provide 500-750 fpm of cooling air over the motor. On this particular installation, in an effort to stay in a 440 frame diameter, 1250 fpm of cooling air was required. The 440 frame was identified as the preferred solution since it is smaller frame that reduces the weight and cost. As evidenced by the pictures, 8 inch PVC was routed from the outside just about the drift eliminator level and directed to the motor. As a result, per the chart, 2000 fpm airflow was achieved, without an externally powered blower.

Air Flow thru Pipe			
Fan Speed	Street Side FPM	Building Side FPM	Avg. FPM
51	709	659	684
87	1305	1210	1257
136	2106	2185	2145

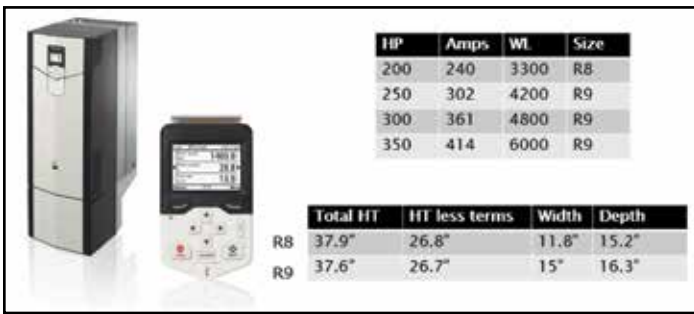


Pictured above are different methods available for additional cooling. The air deflector is used primarily on larger fans since those fans operate at a slower speed. The air deflector increases the amount of air over the motor by a factor of 2 to 3 times and are used on all FL5800 frame units.

Additional cooling air can be provided to the motor through the use of a motor mounted blower or through the use of an external mounted blower and piping air to the motor. Both types of blower cooling will provide approximately 2000 fpm of cooling air to the motor. This type of solution will require a separate source of power for the blower and will increase the sound pressure level of the installation.

In addition, the overall motor efficiency will be effected. As an example, a 150 HP motor at 125 rpm in a frame FL5826 has a full load efficiency of 92.7%. A blower motor at 5 HP has a full load efficiency of 89.5%. Converting both units to kw, the total kw rating is 124.43kw. When compared to the motor only kw rating of 120.65kw, the revised efficiency of the package (motor including the blower) is now 89.9%.

## Variable Frequency Drive (VFD)



The ability to control a permanent magnet motor today with conventional starting methods does not exist today. A drive with special control algorithms to provide sensorless control for smooth, low speed operation is required to properly operate this technology for this application. Because of the need for the special software, the direct drive motor and control are applied as a package.

The technology design is focused on simplifying startup as well as providing efficient operation and control of the permanent magnet motor. Variable frequency drives manufactured today are designed with capabilities to control a wide variety of applications. Since in this application we are controlling a fan, a reduced drive parameter set is included as well. This is a standard variable frequency drive with the addition of special cooling tower firmware.

Additional functionality includes providing trickle current to the motor when it is not in use which performs two functions:

1. It eliminates condensation in the motor. The trickle current produces heat and therefore acts like space heaters.
2. The trickle current provides anti-wind milling torque which minimizes shaft rotation. This functionality automatically occurs after a drive command to stop the unit and the motor is at zero speed. Note that this requires that the drive have power applied when it is stopped. Should the drive power be removed, this functionality is not available and other alternate means would need to be provided.

Common options requested for cooling tower installations include input reactors, output reactors and bypass contactors for bypass operation. The drive manufacturer of choice needs to be consulted as the input inductor may already be built in to the drive. The output inductor is normally used to accommodate long lead length runs between the motor and the drive. The question needs to be asked to the drive manufacturer of choice as to what is the maximum lead length. If the maximum length is exceeded, an output inductor may need to be provided.

Bypass operation is used to provide a means to operate the cooling tower across the line at 60 hertz should the variable frequency drive indicate a fault or failure. With Direct Drive technology, the technology does not exist today to allow the motors to operate in bypass mode. The only solution available today would be to install a second drive to operate the motor should the first drive fault or have a failure.

## Best Practices

In general, maintenance practices can be defined as predictive, proactive or reactive based on the type of activity it is. With the technology advancements made today, it is much easier and less costly to install a wireless condition based monitoring system.

## Condition Based Monitoring

Today, the ability exists to provide easier, better predictive information as it relates to the operation of your cooling tower. The Direct Drive solution is a premium solution and based on the investment made and it needs to be treated as such. Don't think of the 200 HP 120 rpm motor as a conventional 200 HP motor. Think of it more like a 3000 HP 1800 rpm (equivalent torque standpoint) motor. That places it more in the critical realm versus balance of plant designation.

Condition based monitoring is available in many different versions. The traditional wired system exists in plants today but very rarely was it ever carried out to the cooling tower. The cooling tower tends to be located away from the plant and the traditional NEMA motors are designated as balance of plant. Today, it is not uncommon for data to be gathered on a monthly basis by taking hand-held vibration data and trending it.

Today, wireless systems are more affordable allowing what vibration data that was collected on a "route" basis to now be automated and collected on a continuous basis. Now the ability exists to have this data 24/7 compared to monthly "snapshots". A couple of examples of wireless systems on the market are shown below.



A wireless system suitable for distances up to ½ mile.



A wireless system employing wireless HART technology and a dial in system for remote installation locations

HART communications protocol was originally designed back in the 1980's for smart field instrumentation. Today, in conjunction with a HART gateway, the industrial protocol allows the sensors to be monitored using a mesh network configuration.

## Thermostats

Typically a normally closed device that opens when the motor winding reaches a pre-determined temperature. The thermostat signal is connected to the VFD to automatically shut down the unit. For motor protection, the motor thermostat MUST be used for motor warranty to be valid.



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## RTDs

Resistance Temperature Detectors (RTD) allow for continuous monitoring of motor winding and bearing temperatures. Data can be gathered to provide trending for future analysis. Can be used to identify an abnormal condition long before a thermostat would trip. It can also be used to help to optimize the lubrication cycle for bearings by observing exact operational temperatures.

## Vibration Switches

Much like a thermostat, switch opens if a pre-determined vibration level is exceeded. Good for catastrophic type events (loss of blade, etc.).

## Accelerometers

Allow continuous monitoring of motor/fan vibration. Can identify abnormal condition much quicker than a vibration switch. Allows trending to predict maintenance for outage or emergency service.

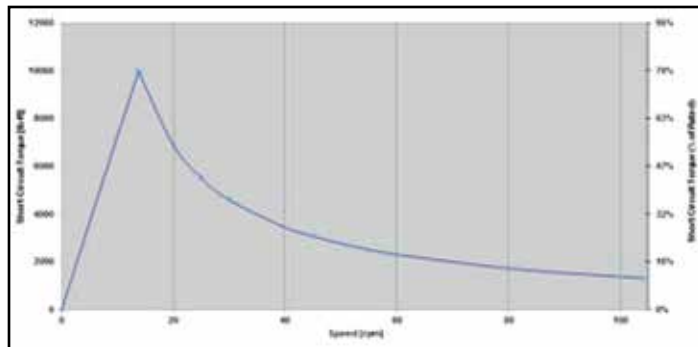
## Grease / Lubrication Sampling & Analysis

Similar to the Oil Analysis performed on Gear Boxes. Used to evaluate the Wear / Oxidation / Contamination / Consistency of the grease. Ferrography can be used as well to determine abnormal wear patterns. Trending of the data is important to establish a pattern of wear.

## Disconnect

To provide additional safety measures when accessing the cooling cell, a shorting disconnect can be added at the entrance. The disconnect will provide isolation between the motor and the drive to insure that accidental operation by the drive cannot happen. Additionally, on PM design motors, the shorting disconnect will also reduce windmilling or shaft rotation by shorting the leads. The amount of torque available for holding the shaft is per the graph below. A typical design is provided. Note that maximum torque is not obtained at zero speed.

Available holding torque. Note that maximum torque value is obtained at 15 rpm and not at zero speed.



Available holding torque. Note that maximum torque value is obtained at 15 rpm and not at zero speed.

## Motor Maintenance & Repair

Suggested maintenance practices as identified in the motor instruction manual are to visually inspect the motor at regular intervals, approximately at every 3 months of operation. Insure that the motor is clean and the ventilation openings are clear.

The DDCT motor is designed for 20 year life and to operate in the harsh environment of a wet cooling tower. As such, the motor design includes the appropriate electrical and mechanical features for operating under these conditions. In general, a motor should not operate with temperatures above its maximum design temperature. A good rule of thumb is that continuous operation 10 degree C above design temperature will result in a 50% reduction of motor insulation life. For every 10 deg C below the rating, the life may double. In the case of the DDCT motor, the materials actually used are Class H rated (180 deg C or 356 deg F) even though the design HP is based on a Class F rise (155 deg C or 311 deg F) or below. Per NEC, appropriate temperature protection must be provided. A motor thermostat is included as standard and will protect the motor in case of an overload condition (165 deg C trip). As stated earlier, protection must be provided or warranty will be voided.

There are a number of factors that need to be evaluated to determine the motor's condition. They include:

- **Environmental conditions:**  
What is the ambient the motor is subjected to? How does it relate to the ambient on the nameplate? Note that the nameplate ambient reflects what the motor is designed to see. Is it higher or lower than what is expected? Any additional chemical or contamination concerns? The likelihood is the ambient in the cooling tower cell under the fan will be higher than outside of the cooling tower cell.
- **Loading conditions**  
What load is placed on the motor? If the motor is designed correctly, it will operate at full load speed within the specified design temperature as noted above. What are the full load amps? How does that value compare to the nameplate value? If the loading is too great, speed must be reduced to bring the motor down to an acceptable temperature. What season is it? Is the blade pitch correct for the current season of operation? What voltage is the motor seeing? A lower voltage at the motor will provide higher amps and therefore a higher temperature will be indicated. Long lead runs from the drive to the motor can contribute to this issue.
- **What are the megger values of the motor?**  
Where are they trending? A 500v megger reading needs to be taken at the motor leads (phase to ground) with the mo-



# COOLING TOWER



## PROTECTION



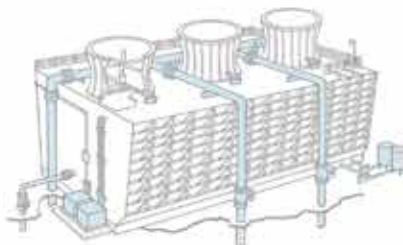
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tor leads disconnected. It is important to take the readings directly at the motor and not at the drive. A reading of 10 megohms or higher is acceptable. The fan needs to be tied down as well to prevent any shaft rotation. Ideally, the readings should be taken when the motor is cold (25 deg C) but can otherwise be adjusted if this is not practical. Megger reading should be trended over time to determine the health of the motor insulation system. The stator winding of a permanent magnet motor is no different than an induction motor.

**Air flow over the motor**

The air (fpm) the motor is exposed to has a direct correlation to its operating temperature. If there are motor heating issues, verification of design air flow needs to be confirmed.

**Grease analysis**

Today, we have limited experience with large motors installed in the cooling cell. Factoring this with new motor technology and installing the motor under the hub creates an operational environment that we continue to learn about. We are learning about air flow at the motor and the effect it has on motor temperature. If the motor temperature exceeds its design temperature, it may be prudent to have the grease analyzed. In general, with the limited experience we have today, we encourage Users to have their grease analyzed should they have concerns about the temperature the motor has seen. Increased re-greasing cycles may be a requirement based on the operating temperatures. Current regreasing frequency for most applications is at one year. An example of the evaluation of some grease conditions is shown below. Smell, consistency and color are what we are looking for.

Examples		
Motor End	Picture of Sample	Comments
Drive End Bearing		<ul style="list-style-type: none"> <li><b>Color:</b> Based on the Beige Color, this appears to be Klübersynth BH 72-422, which is the grease that shipped with the motor. The color has darkened slightly in several isolated spots, so it is not clear if this was due to a mixture with another Grease.</li> <li><b>Consistency:</b> No issues, appears to have softened slightly from its original NLGI 2 condition</li> <li><b>Smell:</b> No issues, does not smell burned</li> <li><b>Overall:</b> No issues</li> </ul>
Opposite Drive End Bearing		<ul style="list-style-type: none"> <li><b>Color:</b> Based on the Beige Color, this appears to be Klübersynth BH 72-422, which is the grease that shipped with the motor. The color is a Dark Brown almost Black.</li> <li><b>Consistency:</b> No issues, appears to have softened slightly from its original NLGI 2 condition</li> <li><b>Smell:</b> No issues, does not smell burned</li> <li><b>Overall:</b> No Major Issues, continue to monitor or go ahead and add additional grease per instruction Manual</li> </ul>

Examples		
Motor End	Picture of Sample	Comments
Drive End Bearing		<ul style="list-style-type: none"> <li><b>Color:</b> Based on the Beige Color, this appears to be Klübersynth BH 72-422, which is the grease that shipped with the motor. The color has darkened slightly in several isolated spots, so it is not clear if this was due to a mixture with another Grease.</li> <li><b>Consistency:</b> No issues, appears to have softened slightly from its original NLGI 2 condition</li> <li><b>Smell:</b> No issues, does not smell burned</li> <li><b>Overall:</b> No issues</li> </ul>
Opposite Drive End Bearing		<ul style="list-style-type: none"> <li><b>Color:</b> Based on the Beige Color, this appears to be Klübersynth BH 72-422, which is the grease that shipped with the motor. The color is a Dark Brown</li> <li><b>Consistency:</b> Has drastically softened from its original NLGI 2 condition. It appears the Oil has separated from the Soap.</li> <li><b>Smell:</b> No issues, does not smell burned</li> <li><b>Overall:</b> Based on the Consistency this Bearing needs to be lubricated</li> </ul>

**Rotor**

If there is a concern the motor temperature was severely exceeded, there may be a fear that the rotor magnetization could be compromised. In order to verify, an open circuit voltage test would need to be performed to verify its integrity.

This test in all likelihood would need to be performed back at the motor manufacturing plant.

**Polarization Index**

Knowing the polarization Index of a motor or generator can be useful in appraising the fitness of the machine for service. The index is calculated from measurements of the winding insulation resistance (megger reading) over 10 minutes. Proceed by applying either 500 volts dc between the winding and ground using a megger. The voltage is applied for 10 minutes and kept constant for the duration of the test. The polarization index is calculated as the ratio of the 10-minute to the 1-minute value of the insulation resistance, measured consecutively.

$$\text{Polarization Index} = \frac{\text{Resistance after 10 minutes}}{\text{Resistance after 1 minute}}$$

The recommended minimum value of polarization index is 2.0 or greater. Machines having windings with a lower index are less likely to be suited for operation. The polarization index is useful in evaluating windings for:

- Buildup of dirt or moisture.
- Gradual deterioration of the insulation (by comparing results of tests made earlier on the same machine).
- Suitability for operation.

The procedure for determining the polarization index is covered in detail by IEEE Standard No. 43.

Load and Motor temp data: What additional information do we know?

In summary, determining the health and condition of the motor is not determined by any one measurement, visual indication or a review of collected data. Rather it is a review and analysis of all the data gathered and trended.

**Case Study: Power Plant**

Bucks, AL



**Specification**

Referenced Plant is a 550 MW combined cycle unit that utilizes (2) 10 cell mechanical draft towers in 2x5 configurations. The cooling tower is comprised of the following components:

- The modified cooling tower uses 32 feet diameter 8 blade fans that are capable of manual pitch adjustment.
- The fans are driven by 200 hp 1800 rpm motors.
- The motors are connected to the reducer through a 171 inch driveshaft.
- The gearboxes utilized are right angle double reduction with a ratio of 15:1. Each unit uses an external oil filter.

Condition Based Maintenance is periodically performed on the units. These include quarterly oil sampling and regular oil & filter changes. Periodic infrared imaging was also performed.

## Problems

Gearbox failures were common. The plant was experiencing 1-2 failures/year for a 10 cell tower.

Replacement costs for a new gearbox is approximately \$20,000. Labor to change-out the unit was an additional \$3,000. This cost does not reflect the cost of Lost Generation due to failure or poor efficiency. Contributing factors for the mode of failure are:

- Cycling - Fatigue Failure
- Temperature
- Structural - Vibration
- Oil Degradation/Contamination



Installation was performed by site craft labor. This installation represented the first use of this drive brand with the Direct Drive permanent magnet design in this frame size. Overvoltage faults were observed and were caused by fan free-wheeling or the rotor not orienting itself.

A new firmware update corrected the issue by implementing a revised startup sequence which did a better job of orienting the motor to the drive.

## Direct Drive Retrofit



The Direct Drive retrofit was completed in May 2014. The cost to install the technology is as follows:

Modify the cooling cell for accepting the direct drive motor - \$25,000 parts and labor  
Cost of 200 HP 120 rpm motor and drive – \$65,000.

The drive was installed in the Power Distribution Center near the cooling tower. Operation to date has been via manual speed control.

The mechanical retrofit design and fabrication of the cooling cell was performed by International Cooling Tower (ICT). Electrical retrofit design was by SCS.

## Mechanical Installation



Mechanical Install began with the installation of pre-fabricated supports. Only drilling and bolting. Top right: flying in mounting frame. Bottom: mounting frame in place.



Top pictures show completed installation of supports  
 Center: vertical supports (x6)  
 Bottom right: connection of supports to motor mounting frame  
 Overall mechanical install went very smoothly: 5 man crew, 5 days (day shift only) and crew had no prior experience with this.



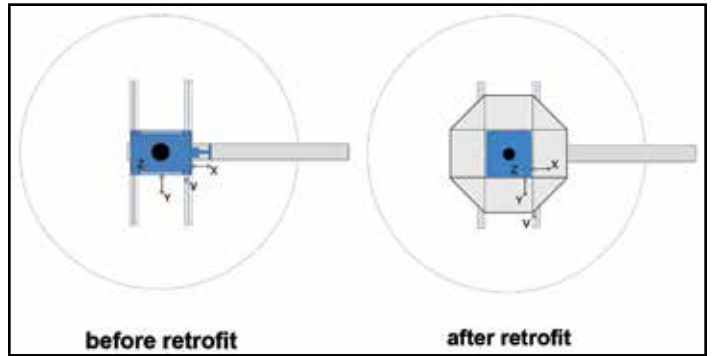
Post installation fan was ~18" higher than originally. Fan sack clearances were re-adjusted.

**Vibration Analysis**

Accelerometers were mounted on the inside of the cell on the gearbox/motor and on the internal structure. Portable, triaxial accelerometers were used to measure stack and deck vibration at various locations. In general vibration levels were low with gearbox/motor, and slightly decreased after installation. There was no excessive vibration of either the gearbox or the structure prior to the drivetrain replacement outage. The largest peaks in the frequency spectrum coincide with the blade passing frequency, while the other peaks are most likely gear meshing frequencies and harmonics.

The response of the internal structural (steel) components to vibration excitation at the blade passing frequency is moderate. There was no apparent resonance excitation at this frequency.

The vertical vibration levels of the deck generally decreased in the post-outage measurements. This coincides with the reduced axial vibration levels of the internal structure.



**Air Flow Testing**

Flow traverses were completed after installation and compared back to design specs.

	Test	Design
Average Normal Velocity (fpm)	1675	1410
Volumetric Air Flow (acfm)	1,446,380	1,200,185
Mass Air Flow (lbm/min)	97,489	84,133

**Instrumentation**

Clean Air Engineering was responsible for design/install of instrumentation (research contractor through EPRI). Included w/ motor: (3) winding RTDs, 1 upper bearing RTD, X, Y, Z accelerometers.

Added upper low frequency ultrasonic sensor and (2) 3 axis accelerometers (1 on lower part of motor, 1 on frame)



Top left: data acquisition unit in NEMA box located on fan deck. Transmits data wirelessly via cell modem to computer (bottom left). Computer logs data and is accessible from off-site.

## Conclusion

Advancements continue to be made in the application of Direct Drive technology on Cooling Towers. As evidenced by the number of installations, customer interest and experience continues to grow. Identified key drivers are improving reliability and having less maintenance while reducing the overall environmental impact. With continued development of the technology, we continue to learn on how to properly apply air flow and maintain the motor to provide longer life. Opportunities continue to exist to develop better ways of improving cooling which ultimately will help extend motor life.



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# A Study on Bio-Fouling Characteristics of Contemporary Trickle and Modular Splash Fills

By  
Angela Zaorski, M.S. &  
William C. Miller, P.E.  
Brentwood Industries, Inc.



William C. Miller

## Abstract:

The development and marketing of contemporary modular trickle and splash fills has yielded a perception that any “wire frame model” type fill offers similar resistance to fouling as classic splash bar fills. However, laboratory testing and real world experiences have shown that these fills exhibit similar responses to bio-fouling problems as film fills with respect to product design and flute geometry. A systematic laboratory method of evaluating weight gain due to bio-fouling and sediment accumulation illustrates the effects that these different design elements have on the actual fouling resistance of this type of fill.

## Introduction

### Splash Fills to Film Fills:

There is a vast library written about the evolution of cooling tower fills and the history of splash fills and film fills. The development of film fills in the 1970’s and 1980’s offered the cooling tower industry a leap forward in cooling efficiencies, and counterflow towers that were originally built with 9m (30ft) air travel depth of splash fills were able to be reduced to only 1.2m (4ft) of a high efficiency cross-fluted film fill. Unfortunately, the great wonder of high efficiency brought with it the specter of fouling, which can totally eliminate any efficiency gains.

The problems and large dollar costs caused by the fouling of high efficiency fills when applied to large electrical generation plant cooling towers provided an impetus for further film fill development. The goal was to find a way to maintain higher thermal efficiencies while trading away some efficiency in order to gain resistance to fouling, with the prize being a fill that is able to maintain a set level of cooling capability over a long period of time.

It is important to realize that this prize can sometimes create difficulties for a tower owner/operator because for a new tower, the decision on what tower to buy is generally driven solely by dollars. A tower built around a more efficient fill will be smaller than or use less fan motor power than a tower built around a less efficient fill; both of which mean less money being spent up front. What needs to be understood is that the long-term operation of the tower and the costs associated with it are heavily influenced by the fill choice. As the power industry learned hard lessons in the 1980’s, it does not matter how “efficient” your fill is when it is brand new.



Angela Zaorski

What is critical is can you get the required cooling capacity out of your cooling tower months and years after the tower is built?

### Film Fill Evolution:

The first film fills were sheets of asbestos cement board, and the invention of the first cross-fluted fills by Munters in the late 1960’s revolutionized the cooling capability in a given volume of fill. As noted by other authors including Monjoie (TP11-26), Zelek (TP06-19), Mortensen & Conley (TP94-05, TP98-14, & TP01-02), manufacturers of film fills applied research and development projects into finding ways to attempt to mitigate the highly fouling nature of cross-fluted fills with the result being the rather large and continually evolving variety of counterflow fills that are now available on the market.



Figure 1: Basic Flute Geometries

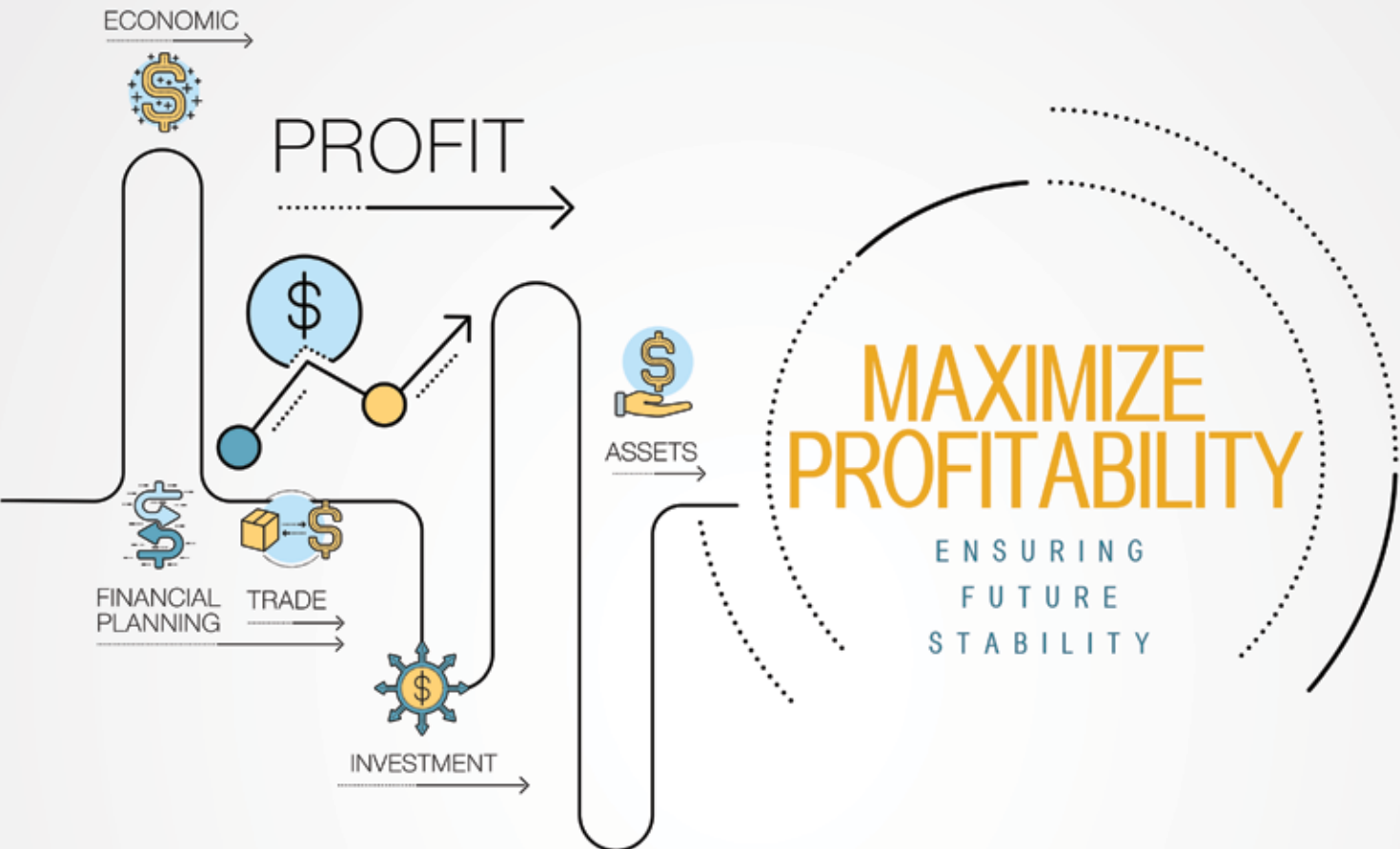
Cross-fluted fills generally provide the highest cooling capacity per volume along with the highest potential for fouling. The cross-flutes help to slow down the water film velocity in the pack. This increases the time for air-water interaction within the pack and is one reason these designs give the highest efficiencies. However as discussed by Whittemore and Massey the reduction in water film velocity has one of the largest impacts on the biofoulant growth.

Offset fluted and vertical offset fluted fills are a more recent development blending some of the characteristics of cross-fluted fills and fully vertically fluted fills. As a blend, they generally still offer relatively high cooling capacity per volume of fill, but the vertical geometries of these fills provide higher water film velocities which provide much greater resistance to biofouling due to the higher hydrodynamic shear stress. Due to the sheet geometries, these designs also offer fewer mixing and distribution (“cross-over”) points within the fill packs, which again helps to keep water film velocities high. Even a highly sloped cross-fluted fill (sometimes also referred to as a “shallow corrugation angle” product), provides these crossover points which reduce water film velocities.

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Vertically fluted fills provide the greatest fouling resistance of all film fills since they maximize water film velocities and have no cross-over points. When this design is used in a pack with large sheet pitch (the spacing between individual sheets), fills of this design can be applied to some of the most demanding applications.

### Development of “Wire-Frame” fills:

Another path of fill development has been the creation of various “wire-frame” fills that have the appearance of a wire-frame 3D drawing of a fill pack. The intent with these packs has been to provide much less surface area when compared to a film fill, in the hope that this type of product will thus provide greater fouling resistance than a film fill. As with film fills this type of pack design lends itself towards the same types of flute geometries as film fills with cross-fluted, offset flutes, and vertical flute geometries all being offered by various manufacturers.

A critical difference between these types of fills lies in the different inherent modes of providing the thermal characteristics. These can be categorized as either “trickle” fills or as “modular splash” fills. As noted by Kröger,

“Trickle packs or grids are much finer than splash packs and are made up of plastic or metal grids onto which the water is sprayed. It runs down the grid rather than splashing. Because of the much finer mesh than the splash type fill, they tend to clog more easily and have a greater pressure drop.”

Since the water is forming a film along the strands of the trickle pack, the cooling occurs such as that in a film fill. Therefore, in order to maximize cooling capacity, reduction in water film velocity is a key to maximizing the cooling capacity of a trickle pack. For this reason, cross-fluted trickle packs with large numbers of fine strands were developed in order to give the highest efficiencies to these types of fill packs.



Figure 2: Sample Trickle Fills

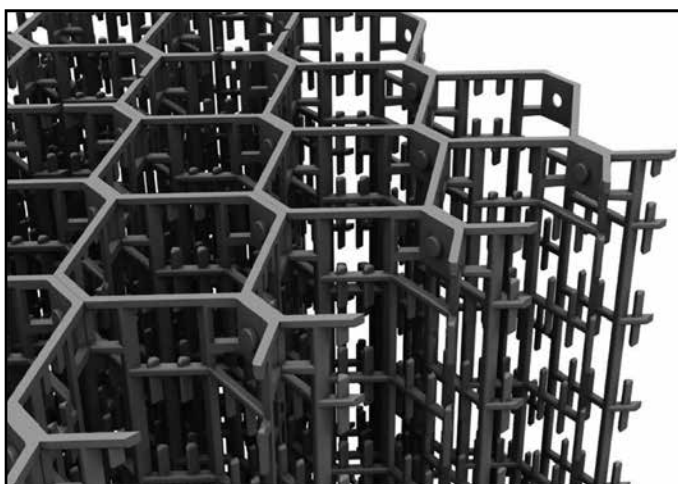


Figure 3: Sample Modular Splash Fill with detail of droplet generating features

In contrast modular splash fills achieve their thermal characteristics via droplet cooling, just like a splash fill. Instead of the water only forming a film along the strands of the “wire frame,” a modular splash fill incorporates design features that create droplets, such as those shown in Figure 3. When this feature is combined with a flute geometry that maintains water film velocity such as a vertical-offset flute, there are noticeable gains in fouling resistance.

It is this contrast between contemporary trickle and modular splash fills that is the subject of the tests in this paper.

## Introduction to Biofilms and Fouling

### How biofilm layers form and grow:

Biofilms are a complex, three-dimensional matrix of organic and inorganic material. A biofilm is more resilient than a single-floating bacteria with its distinguishing characteristic being the extracellular polymeric substance (EPS) created by the bacteria themselves. EPS is a sticky substance that is used to adhere the bacteria to surfaces and to adhere nutrients to the bacteria. The EPS may account for 50-90% of the matrix, and as the age of the biofilm increases, so does the amount of EPS the bacteria secrete. Using this matrix, the bacteria will develop attached communities that can vary in thickness depending on the environmental conditions. Once the biofilm has reached a safe population level they will use the matrix to communicate with other cells to trigger certain genes. Sub-colonies have also been observed within the biofilm and within the bacteria community. The attached layer may be considered one sub-colony, and their only function is to maintain surface attachment and to provide nutrients to the layer above them. The layer above them would be a separate sub-colony which only has the function of reproduction and making the community larger.

### Biofilm life cycles in relation to cooling tower fills:

New PVC and PP fill packs are initially hydrophobic. Therefore, they repel water and cause it to bead up, which is detrimental to achieving the full thermal efficiency potential of the fill. Due to this circumstance fill packs need to be conditioned, a.k.a. “seasoned” or “aged,” such that a very thin insulating layer of organic and inorganic materials form on the plastic surface. Once this layer is formed the free-floating bacteria have a surface they can land on and begin the absorption phase. This phase is still reversible, and the length of it will depend on the shear forces and nutrients at the surface of the plastic. Once there are enough bacteria on the surface they will begin to secrete the EPS matrix and develop an irreversible layer which become the foundation of the biofilm. At this point they will use the matrix to signal other cells to begin the growth and division stage which will eventually grow into a mature micro-colony three-dimensional film. This mature micro-colony will be able to send signal molecules within itself in order to signal for dispersion which will allow bacteria to leave the colony, float into the water, and land to form new colonies. They will also be able to send signal molecules to other forms of bacteria in order to form a multispecies colony complete with water channels, bridges, and other microstructures designed for easy communication and travel of nutrients.

It is the combination of the EPS, the water channels, bridges, and other microstructures, and the presence of solids that lead to fouling. The circulating water within the cooling tower flows through the channels, bridges, and microstructures, and the EPS provides the “glue” that holds any solids contained within the circulating water to the biofilm.



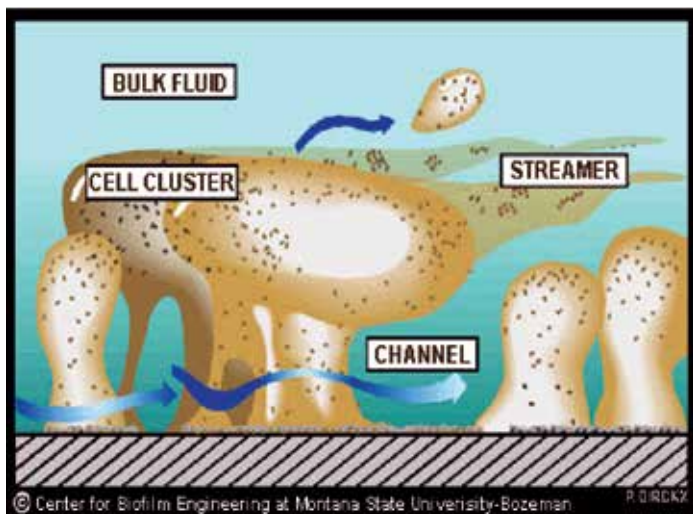


Figure 4: Basic structure of a biofilm

## Fouling Tests

### Field tests:

There have been numerous field test programs to measure fouling tendencies of fills throughout the years. In some instances, fill has been installed directly into operating cooling towers in “test bays,” and in other instances small test towers have been installed onsite that use a side-stream of the circulating water loop. The goal in either scenario is to monitor and gain data on the fouling potential of a particular fill based on the water quality of a specific operating condition – that of the test site itself. Refer to sources Whittemore & Massey; Monjoie, Noble, & Mirsky; Mortensen & Michell; and Mabrouk, Azarou, & Marconnet for further details.

The usual monitoring criterion is weight gain since that provides a measureable data set and is somewhat more readily achievable than other methods such as visual inspections. The basic premise is that the higher the weight gain, the greater the fouling. Research presented by Whittemore & Massey, Monjoie, Noble, & Mirsky, and Southern Company provided data that related the weight gain values of different fills to the thermal performance (degradation) of the fill. The test data proved that higher weight gain of the fill packs resulted in lowered cooling capabilities.

### Laboratory tests:

Research has also been performed in laboratory environments by multiple entities where fills were exposed to artificially enhanced fouling environments in an effort to provide comparative results between different fill designs. It is acknowledged that the specific test environment in a laboratory setting is not equal to a field installation, if only for the fact that every field installation will have its own unique parameters that set it apart from any other site. The benefit of a laboratory test is that the fouling parameters can be controlled and different fill designs can be evaluated and compared based on the same conditions and at the same time. Laboratory tests also provide the opportunity to accelerate the fouling process, if wanted, so that a process that might take months or years in the field can be observed in a much shorter period of time. As such, results from laboratory fouling testing must be considered as relative results and not absolute results. However, they still provide an important evaluation tool for fill choice.

## Brentwood Laboratory Fouling Test Program:

### Fouling Test Rig Description:

Brentwood’s fouling test rig is designed to concurrently evaluate six (6) fills with each fill bay being suspended from its own individual load cell. Each fill bay measures 305mm W x 610mm L x 1829mm H (12in W x 24in L x 72in H). A variable frequency pump pulls the water up from a pump basin to a gravity feed nozzle basin where the nozzles are evenly distributed across the top of the bays. A feed system is injected into the upward flow of water to allow for a gradual addition of nutrients and solids.

### Test Protocol:

1. Install the fill packs into the fill support assemblies that are suspended from the load cells and record the weight of each individual fill pack.
2. Fill weights are to be calculated as the sum of the individual fill packs that are installed onto the fill support assemblies.
3. Start the water flow at 16m<sup>3</sup>/hr (70 gal/min).
4. The biological feed consists of 30:4:4 (nitrogen:phosphate:potassium) fertilizer and sucrose sugar to accelerate weight gain.
5. Bentonite clay is added to act as the silt inorganic substrate.
6. Through the use of a PLC, several conditions are monitored every five (5) minutes. These conditions include: date, time, flow rate, dissolved oxygen, pH, total suspended solids (TSS), weight from each load cell, air temperature, and water temperature.
7. Values that are monitored on a daily basis include: COD (Chemical Oxygen Demand), Total Nitrogen, and also TSS as calculated via a secondary method.
8. When COD levels fall below 350mg/L more sucrose is added. When nitrogen levels fall below 30mg/L more fertilizer is added, and when TSS levels fall below 375mg/L more bentonite clay is added.
9. On a weekly basis the water flow is turned off, all water is allowed to drip off the packs, and a dry weight is recorded. This is listed as the “drip dry” weight, and it is used as the comparison to the original dry weight of the packs since it provides the best comparison with minimized water hold-up weight.
10. Weight gain is also monitored on a daily basis by subtracting the water hold-up weight measured at the beginning of the test before any bacterial growth has started.
11. The pH probe is calibrated on a weekly basis.

## Contemporary Trickle Fill vs Modular Splash Fill Fouling Test:

Since extensive research has been performed on a large variety of film fill products over the years, as detailed in the referenced documents in the bibliography, the authors wanted to perform a similar study on the more recently developed trickle and modular splash fills currently available to the cooling tower industry. Of particular concern was the notion that all of these fills are non-fouling fills, without regard to geometrical differences between competing products. Since geometrical differences yield different fouling potentials in film fills, the theory is that the same trend would apply to wire-frame type fills.

## Test Program:

The test program involved the selection of two (2) competing wire-frame type fills: a cross-fluted trickle fill (CFTF) and a vertical-off-set modular splash fill (VOMSF). Both products were made of PP. Three (3) bays of CFTF alternated with three (3) bays of VOMSF to fill the six (6) total bays in the fouling test rig.

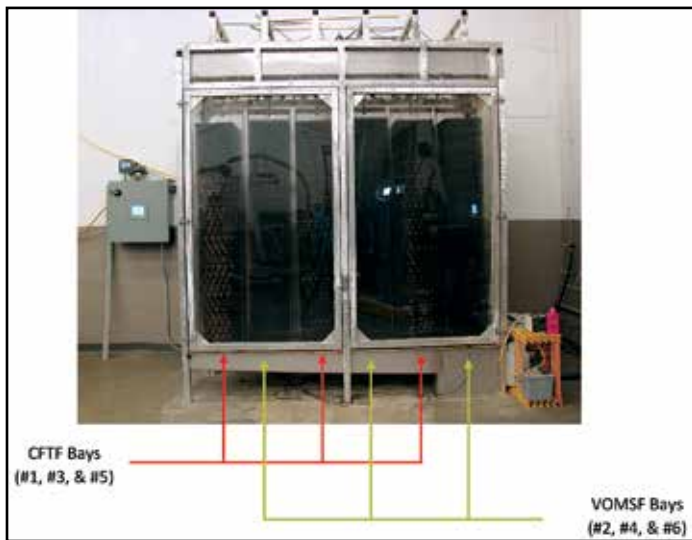


Figure 5: Fouling Test Rig Set-up

The fill packs were placed into fouling rig and data was collected for a period of slightly over 22 weeks. This was an extended duration test which provided a view into the nature of the biofilm life cycles. Initial heavy growth periods are followed by plateaus that reflect the limit of a colony's ability to sustain itself. At that point the colony sends out danger signals which cause the organisms to conserve energy and cause dying members to slough off. Once the colony has retracted enough to survive within the available nutrients, the cycle starts again.

## Test Results

### Initial Observations:

One of the most startling observations of this test was the initial rapid biofilm growth on the CFTF fill packs, and this was very unexpected since the general perception of these products is that they are low-fouling or even "anti-fouling" fills. The following pictures shows the biofilm growth of the six (6) test bays at the three-week drip-dry weighing.



Figure 6a: Bays 1 - 2 - 3 at Week 3 (CFTF / VOMSF / CFTF)

Figure 6b: Bays 3 - 4 - 5 at Week 3 (VOMSF / CFTF / VOMSF)

1. The CFTF bays (#1, #3, & #5) all had significant biofilm growth compared to the VOMSF bays (#2, #4, & #6) which had almost negligible growth.

2. Bay 1 showed an appreciably greater amount of growth compared to Bays 3 & 5. Upon an investigation, it was learned that the local environment at that bay had a slightly elevated temperature which provided a more hospitable climate for the bacteria, and they were able to multiply more rapidly than in the other bays. A means to moderate the temperature to match the other bays was enacted.

As the test period continued it was interesting to note how the life cycle process brought the weight gain on Bay 1 back to amounts comparable to Bays 3 & 5 by approximately Week 10. Due to the larger colonies, there was a much greater sloughing off of dead bacteria in Bay 1 so that by Week 10, the biomass matched the available nutrients similarly to Bays 3 & 5.

## Weight Gain Data:

### Total Weight Gain

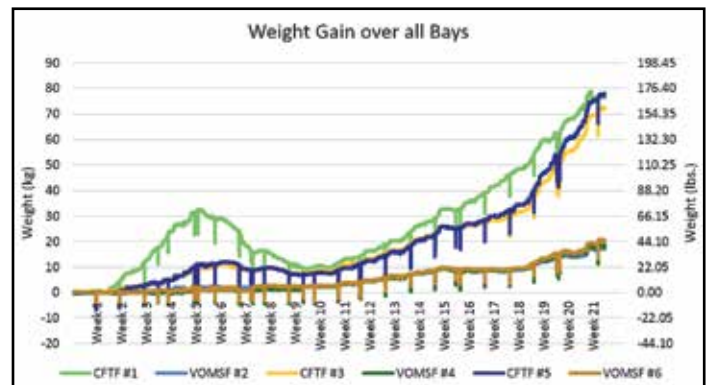


Figure 7: Overall Weight Gain

### Average Weight Gain/Volume

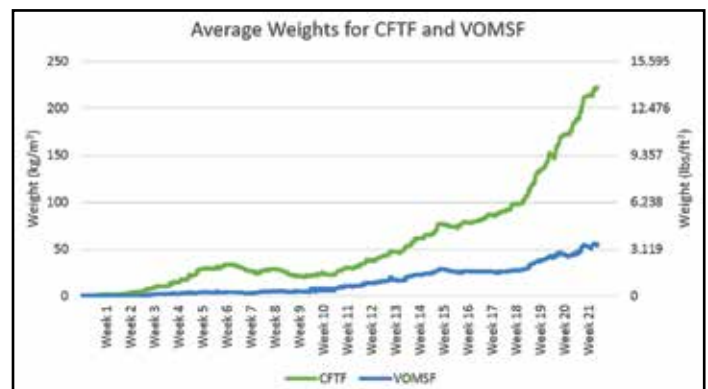


Figure 8: Average Weight Gain / Volume

\*NOTE: CFTF Bays 3 & 5 and VOMSF Bays 2 & 6 Only

### Failure of Fill CFTF Fill in Bay 1

Between Weeks 20-21 the fill in Bay 1 gained so much weight that the fill collapsed around the fill supports, shifted, and fell out of the rack. At that point further data collection for that tower was invalidated. This is the reason that Figure 7 only shows average weight gain per volume for two (2) each of the CFTF and VOMSF bays instead of three (3) each. The middle weight gain VOMSF bay (#4) was excluded from the calculation of the averages in order to keep each fill type to an average of two values.

## Effect of Fouling on Tower Cooling Capability:

At the end of the day, the overarching impact of fouling relates to how that fouling degrades a cooling tower's cooling capability. If the purpose of a low-fouling fill is to minimize the reduction in cooling capability, then a tower designer or the owner/operator that purchases a cooling tower can make an informed decision to possibly spend a little more money up front on a slightly larger tower or a tower that uses more energy for air movement knowing that the extended duration of relatively constant colder water will provide a return on investment in a reasonable period of time. In order to illustrate the effects of fouling on performance, both un-fouled and fouled packs of each fill type above (CFTF and VOMSF) were tested in Brentwood Industries' Counterflow Cooling Tower Test Cell. This test cell provides a means to test a 610mm W x 610mm L x 1829mm D (2ft W x 2ft L x 6ft D) fill section in a fully instrumented fashion and yield the KaV/L vs L/G heat transfer and the pressure drop vs air velocity characteristics of a fill.

## Heat Transfer Characteristic Results

### CFTF Packs

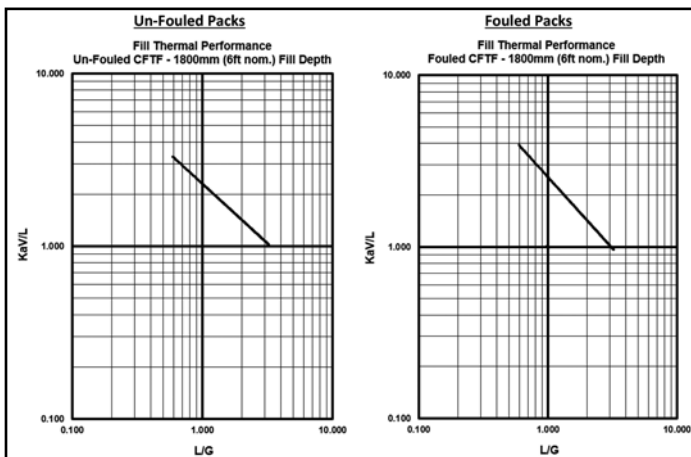


Figure 9: Heat Transfer Characteristics of Un-Fouled & Fouled CFTF

### VOMSF Packs

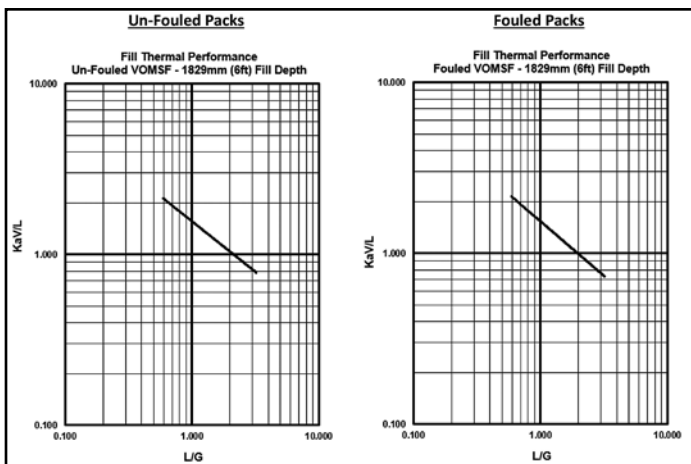


Figure 10: Heat Transfer Characteristics of Un-Fouled & Fouled VOMSF

## Pressure Drop Characteristic Results

### CFTF Packs

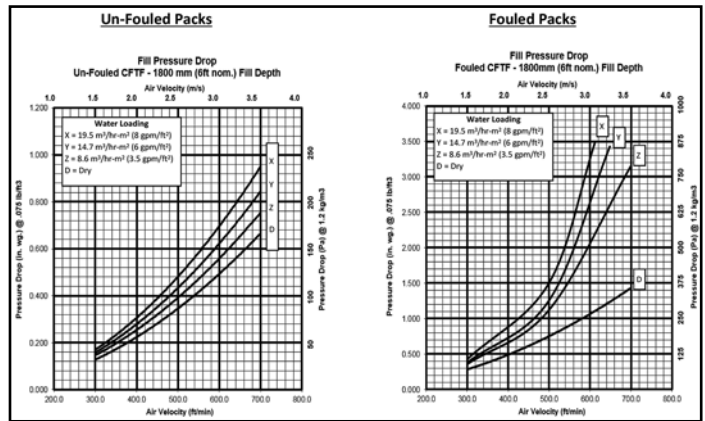


Figure 11: Pressure Drop Characteristics of Un-Fouled & Fouled CFTF

### VOMSF Packs

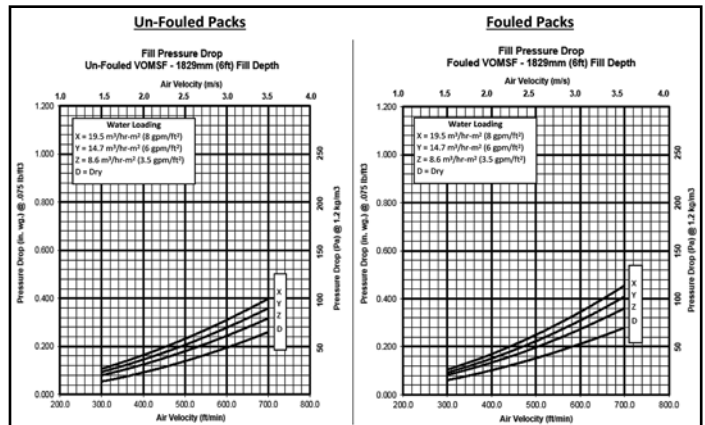


Figure 12: Pressure Drop Characteristics of Un-Fouled & Fouled VOMSF

## Comments on Fill Performance Data

### Heat Transfer Characteristics:

The heat transfer characteristics do not change much at all between the un-fouled and the fouled packs. The CFTF product actually shows a very slight gain in heat transfer at low L/G values, but the slope of the line is slightly steeper such that there is a very slight decrease in heat transfer at high L/G ratios. The VOMSF product also reflects a very slight increase in the slope of the line with all heat transfer values being very slightly lower at all L/G values except for the lowest L/G value tested which were virtually identical.

### Pressure Drop Characteristics:

It is in the realm of pressure drop that the influence of the fouling stands out. The pressure drop of the VOMSF product showed a small increase in pressure drop, and this correlates well with the visual inspection of the packs where only a small amount of foulant is seen adhered to the fill. The pressure drop of the CFTF product, however, exhibits a massive increase in resistance to airflow as detailed below. This too correlates with the visual inspection of the packs where large amounts of foulant are seen clinging and growing to the many fine-strands of the wire-frame type product. (Refer to Figure 13 for a visual comparison of the fouled packs at the time of the thermal tests.) As you can see in the following table, whereas

the Fouled VOMSF increases in pressure drop by about only 11-12%, the Fouled CFTF increases in pressure drop an average of over 375%!

The tower was modeled such that the Un-Fouled VOMSF fill yielded 100% tower capability. The other fills were compared to that based on the fill performance information provided above, and yielded the following results:

Water Loading	Air Velocity	CCTF			VOMSF		
		Un-Fouled	Fouled	Ratio	Un-Fouled	Fouled	Ratio
8.6 m <sup>3</sup> /hr-m <sup>2</sup> (3.5 gpm/ft <sup>2</sup> )	2.5 (500)	97 (0.39)	274 (1.1)	2.82	45 (0.18)	50 (0.2)	1.11
	3.0 (700)	189 (0.76)	772 (3.1)	4.08	80 (0.32)	90 (0.36)	1.13
14.7 m <sup>3</sup> /hr-m <sup>2</sup> (6 gpm/ft <sup>2</sup> )	2.5 (500)	105 (0.42)	324 (1.3)	3.10	50 (0.2)	55 (0.22)	1.10
	3.3 (650)	184 (0.74)	847 (3.4)	4.59	80 (0.32)	90 (0.36)	1.13
	3.0 (700)	212 (0.85)	N/A N/A	N/A	90 (0.36)	102 (0.41)	1.14
19.5 m <sup>3</sup> /hr-m <sup>2</sup> (8 gpm/ft <sup>2</sup> )	2.5 (500)	115 (0.46)	374 (1.5)	3.26	57 (0.23)	60 (0.24)	1.04
	3.1 (615)	187 (0.75)	872 (3.5)	4.67	82 (0.33)	92 (0.37)	1.12
	3.0 (700)	239 (0.96)	N/A N/A	N/A	100 (0.4)	115 (0.46)	1.15
*Key: SI Units (IP Units)	m/s (ft/min)	Pa (in W.G.)	Pa (in W.G.)		Pa (in W.G.)	Pa (in W.G.)	

Table 1: Pressure Drop Comparisons

It is important to note that the pressure drop on the fouled CFTF fill was so great that it exceeded the capability of the fan power on the test cell to increase air velocity any higher than 3.3 m/s (650 ft/min) at the middle water loading and 3.1 m/s (615 ft/min) at the high water loading.

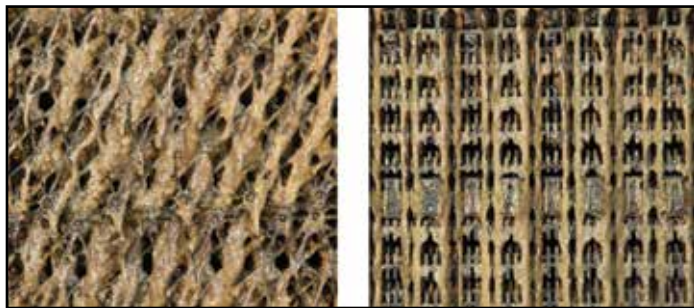


Figure 13: CFTF (left) & VOMSF (right) fill packs showing fouling amounts at the time of the thermal testing in the Brentwood Industries Counterflow Cooling Tower Test Cell. The CFTF fill had a weight gain of 222 kg/m<sup>3</sup> (13.8 lbs/ft<sup>3</sup>) and the VOMSF a weight gain of 54.8 kg/m<sup>3</sup> (3.42 lbs/ft<sup>3</sup>) at the time of testing.

**Resulting Effect of Heat Transfer & Pressure Drop Characteristics on Tower Cooling Capability:**

In order to analyze the net effect of the above changes in heat transfer and pressure drop characteristics on the cooling capability of a tower, Brentwood Industries' S.T.A.R. rating software was used to model a "typical" field-erected industrial application type counterflow cooling tower as follows:

**Example Field-Erected Tower Information:**

1. Cell Size: 14.6m x 14.6m (48ft x 48ft)
2. Fan Diameter: 9.1m (30ft)
3. Air Inlet Height: 4.9m (16ft)
4. Fan Deck Height: 11.9m (39ft)
5. Water Flow: 3139m<sup>3</sup>/hr (13,824gpm)
6. Range: 11°C (20°F)
7. Wet Bulb Temperature: 26.7°C (80°F)

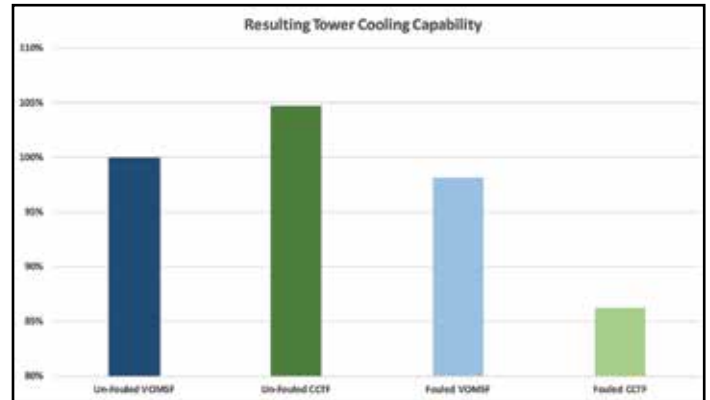


Figure 14: Comparison of Un-Fouled & Fouled CCTF & VOMSF Effects on Total Tower Cooling Capability

**Conclusions:**

As fill designs evolve in the constant quest to meet new challenges and improve on known deficiencies, there are opportunities to meet those challenges and also opportunities to create new problems. As the advent of film fills and the initial application of them into dirty water towers in the 1970's and 1980's showed that a misapplication could turn a "magical" fill into a "nightmare" fill, there is evidence that not all wire-frame fill designs are the "low-fouling" products that they are largely perceived to be.

Unfortunately, even though trickle packs resemble a modular splash fill and the lack of surface area leads to a misconception that trickle packs offer much greater fouling resistance than film fills, real world and laboratory experiences show that they offer the same pitfalls of the "magical" film fills of yesteryear if they are not applied properly.

The "prize" to be won is a long-term resistance to fouling so that the cooling capability achieved on the day the cooling tower is initially turned on is maintained for many years into the future. That choice provides the greatest overall cost benefit and highest level of reliability for a tower owner/operator.




Figure 15: A Vertical Offset Modular Splash Fill pack still in service in a field installation.



Figure 16: Two different fouled CFTF packs from field installations.

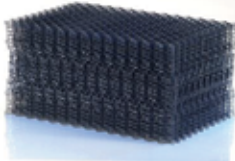
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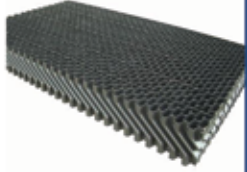
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# Failure of Building Water Systems: How to Plan for Success and Manage Liability

Adam Green  
Baker, Donelson, Bearman,  
Caldwell & Berkowitz, PC  
Robert J. Cunningham, P.E.  
Arthur Freedman Associates, Inc.

## Abstract

The premature failure of building water systems and mechanical equipment can result in large liabilities. In many instances, parties are wrongfully accused and forced to incur significant legal expense to prove their innocence. The resulting lawsuits reflect that the reasons for these failures are both common and, in many instances, avoidable. Some of the usual suspects include: (1) failure to clearly define scope of work and responsibilities; (2) failure to prepare and follow comprehensive job specifications; (3) failure to properly coordinate passivation and start-up; (4) not understanding responsibilities after turnover; and (5) lacking the documentation needed to defend yourself when wrongfully accused. This publication identifies common case scenarios with the objectives of planning for success and managing exposure.

## Introduction

In recent years, there have been a large number of corrosion-based failures of system water piping associated with HVAC, Process Cooling, and Fire Water systems. Systems designed to provide long term service life are failing due to leaks and obstruction incident to severe pitting attack, corrosion and massive tuberculation in both galvanized and un-galvanized carbon steel and copper piping. It is not uncommon to encounter systems where complete penetration has occurred within a few years after initial commissioning. These events can occur even though an appropriate water treatment program is in place and no issues appear in the bulk waters being tested and treated on a monthly basis. These premature failures are now finding their way into the courtroom, where the assignment of responsibility and the calculation of damages rests in the hands of attorneys and laypeople, who are completely unfamiliar with industry standards and practices and the respective responsibilities in the design, construction and maintenance of such systems. Many attorneys and potential jurors are not well-versed in the scientific and technical aspects that are crucial to understanding and accurately determining the nature and cause of these failures.

Anyone involved in the design, construction, installation, commissioning, start-up and maintenance of these systems may find themselves in the crosshairs. Attempts to determine responsibility and to seek compensation for these failures, result in consider-



Robert J. Cunningham



Adam Green

able legal expense, as well as business disruption that may last for years. Moreover, the scope of a defendant's potential liability may far exceed the amount they were paid for their services, as it may include not only the damages incident to the repair and replacement of the water system and its attendant equipment, but also to any surrounding structures and improvements, the expenses incident to constructive eviction of the building tenants who are displaced while such repairs or re-

placements are performed, and, in some cases, the prevailing party's attorneys' fees and costs.

There is a high degree of inherent risk in defending complex, technical cases with significant damages to an inexperienced and unfamiliar audience. This publication presents common scenarios leading to system failure and the lawsuits resulting therefrom. Some of the usual suspects include: (1) failure to clearly define scope of work and responsibilities; (2) failure to prepare and follow comprehensive job specifications; (3) failure to properly coordinate passivation and start-up; (4) not understanding responsibilities after turnover; and (5) lacking documentation needed to defend yourself when wrongfully accused.

This publication identifies common case scenarios based upon actual building system failures and the corresponding lawsuits that followed with the objective of planning for success and managing exposure.

## Failure To Provide And Follow Comprehensive Job Specifications

The root cause of system failures can result from the lack of clear, unequivocal, site-specific specifications delineating respective responsibilities for the various tasks involved in design, construction, commissioning, start-up, maintenance and water treatment for condenser water systems. Unfortunately, job specifications are frequently recycled, generic forms that are not tailored to the current project. Contractors commonly bid these specifications as written with a sense that all parties have an unwritten understanding that the specifications are a mere form document and therefore, there can be no reasonable expectation that they will be performed to the letter. They may likewise fear that if they do not simply bid the specifications as presented, that another contractor who is willing to do so will be awarded the work. As indicated by the case studies below, the failure to comply with specific items of otherwise generic

specifications can lead to costly litigation despite the fact that the lack of compliance had nothing to do with the system failure.

**Form Over Substance.** Parties who do not perform to the exact language of specifications are frequently targets of complex litigation. Unfortunately, innocent parties are often forced to incur significant legal expense to prove that their technical non-compliance was unrelated to the cause of the occurrence. Parties seeking recovery may deliberately confuse or conflate the difference between a "flaw" and a "defect." Flaws are imperfections in the performance of responsibilities that have no causal effect on the damages incurred. Defects are those errors, omissions or failures that actually cause or contribute to the harm at issue. Such form over substance litigation often places faultless parties in the unenviable and expensive position of proving their innocence. In a complex, technical lawsuit, these expenses can be significant.

### Case Study:

The condenser water system for a 30-story high-rise luxury condominium suffered from corrosion and leaks less than five years from the date the system was commissioned. As a result, the Owner's Association filed a lawsuit for damages exceeding \$8 million. The evidence revealed that the HVAC mechanical subcontractor who constructed the system repeatedly introduced untreated water into the system for more than a year before contracting with the water treatment contractor. It was undisputed by all parties that this scenario created irreversible corrosion leading to complete system failure.

Nonetheless, the building owner sued 14 different entities, citing each and every instance wherein a party failed to comply with the exact verbiage of the generic specifications used for the project. For instance, it was alleged that the general contractor, the HVAC mechanical subcontractor and the water treater each failed to comply with the express requirement to "conduct a complete characterization analysis of the raw water supply." Each of the entities had worked in the geographic area for the ten years preceding the project and were highly familiar with the characteristics of the area water. Because the parties failed to conduct an independent characterization analysis specifically for this project, Plaintiff alleged that the elevated chloride and sulfate content of the raw water supply was not properly accounted for and caused microbially-influenced corrosion. This situation could have been avoided by performing a new water characterization study. Alternatively, a simple email confirming with the owner/developer that the most recent raw water characterization study was sufficient could have avoided the issue.

The water treatment contractor likewise did not fully comply with the form specifications by failing to: (1) provide written reports of each visit to the jobsite; (2) have a service branch office within 50 miles of the jobsite; (3) ensure the administration of the program was under the supervision of a full-time employee with a B.S. in Chemistry; (4) submit an affidavit from a corporate officer affirming prior performance of the type and scope of treatment program at issue; and (5) install corrosion coupons and conduct 30-day tests each month. In total, the water treatment contractor failed to comply with the exact language of the specifications in 11 different respects. As a result, the water treater, who was paid \$5,500 for a



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year of treatment, was forced to endure three years of litigation and more than \$400,000 in legal expense to successfully prove that its lack of conformity to generic specifications was not the actual cause of the system breakdown. Ultimately, the water treatment contractor was dismissed because its failures to comply with the form specifications were determined to be flaws and not defects. In other words, none of the listed shortcomings were found to be an actual cause of the damages at issue.

## **Failing To Clearly Define Scope Of Work And Responsibilities**

The design, construction, commissioning and maintenance of condenser water systems is a multi-party and multi-disciplinary practice. The lack of a clear understanding by and between the building owner and the various contractors about each discipline's scope of work and division of responsibilities frequently leads to litigation. To avoid being wrongfully implicated in a lawsuit arising from system failure, these entities are behooved to clearly define what is included in their scope of work to the exclusion of other responsibilities.

Vague Duties with Superlative Performance Standards. Generic descriptions of project responsibilities are not limited to loose job specifications. The contracts entered by and between the crafts on a project frequently have job duties that are not well-defined. To compound the issue, these contracts may simultaneously contain warranties that the vague job description will be performed to the highest possible standards. As provided below, this is a dangerous combination that can lead to the wrongful implication of innocent parties.

### **Case Study:**

Within two years from start-up, the open loop portion of a condenser water system in a large high-rise building experienced catastrophic failure incident to corrosion and leaks. The open loop system design employed was novel, untested and critically flawed. During deposition testimony, the design engineer admitted that the design was problematic and that an alternative design should have been implemented. After the leaks were discovered, the areas of the building serviced by the failed open loop were converted to a closed loop design. No further issues occurred after this change.

Despite the facts, the building owner filed a \$4,000,000 dollar lawsuit not only against the design engineer, but also the general contractor, the mechanical subcontractor who built the system, the pipe supplier, the construction phase water treater, and the ongoing monthly water treater. The lawsuit exploited the lack of clearly delineated roles while relying on contract superlatives used to describe the standard to which the work was to be performed. For instance, both the general contractor and the HVAC mechanical subcontractor warranted in their contracts that their responsibilities to coordinate the construction of the system shall be completed: (1) "in accordance with the Contract Documents, including those items reasonably inferable from the Contract Documents necessary to produce the indicated results" while also warranting that (2) the work would be "first class and in accordance with the highest standards of the construction industry." The building owner used these broad terms to argue that the "indicated result" was a functioning open loop system free from defects. The owner further alleged that to achieve this result in accordance with the highest standards of the construction industry, the contractors were required to not only coordinate with the design engineer but to challenge the design

choice. The owner charged these parties with failure to diagnose the poor design and warn the owner despite the fact that neither entity had design expertise.

The owner used similarly undefined terms to frame allegations against the water treatment contractors based upon general language in their contracts, providing that they would "check the systems" with "highest standards of attention to detail." Based upon these terms, the owner concocted a theory that in fulfillment of the duty to "check the systems," the water treaters were somehow required to perform periodic internal pipeline inspections throughout the property to somehow discover the corrosive problems that arose due to the poor design. There was no reference in any of the contract documents to internal pipeline inspections, how they were to be conducted (by borescope or otherwise), the frequency at which they were to occur, the associated expenses associated or who would pay for them. Both treaters properly testified that this was far beyond the scope of their limited monthly visits (wherein they would visit the designated mechanical rooms to take bulk water samples, perform maintenance on the chemical feed station, record the water chemistry readings and replenish chemicals) for which they were paid \$200.

## **Failing To Properly Coordinate Passivation And Start-Up**

The failure to properly coordinate chemical treatment with the initial introduction of water can prove fatal to a system. Pressure to meet construction deadlines and a lack of understanding of the true impact of introducing untreated water to the inner wall of virgin pipe surfaces can lead to severe corrosion and costly litigation.

The Critical Passivation Period. After construction of the piping system is complete, the mechanical contractor who built the system will typically conduct one or more hydrostatic pressure tests during which the piping system is filled with water and pressurized to test for leaks before insulation is applied and surrounding sheetrock is installed. This is the point where the corrosion process should be addressed. A water treatment contractor should be contacted so that the water chemistry itself can be adjusted by the addition of a high level of chemical corrosion inhibitors during the entire testing process. Specifically, the exposed metal surface should be chemically "passivated," to ensure that the piping system metals have some reserve "corrosion resistance" to carry the protection forward. In the absence of proper corrosion and microbial control during this period, the addition of water jumpstarts the microbial proliferation and the ensuing corrosion acceleration.

### **Case Study:**

The condenser water system for a 28-story commercial office building suffered from corrosion and leaks less than two and one-half years from the date of start-up. As a result, the building owner filed a lawsuit for damages exceeding \$6 million. The undisputed evidence revealed that the HVAC mechanical subcontractor constructed the system by lowering the system pipes by overhead crane for assembly five floors at a time. Once five floors were constructed, the pipes were fitted with end caps and then hydrostatically pressure tested. If the pipes did not leak, the water was left to sit stagnant in the pipes while the next five floors were constructed and the testing process repeated. This process occurred for six months before the water treatment contractor was retained. Plaintiff's metallurgical expert testified that this process was fatal to the system and that the corrosive process became irreversible within six weeks of untreated



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water being introduced and left to sit stagnant in the unprotected pipes.

More troubling was the fact that the proposed water treatment contract required the water treater to provide chemical treatment upon "the initial introduction of water." Unbeknownst to the water treater, this event had already occurred, making the contract impossible to perform on the day it was signed. When asked about the failed sequence, the mechanical contractor who built the system testified that it was under immense pressure from the owner and general contractor to expedite the construction schedule. Specifically, the general contractor advised that sheetrock installation was imminent and as a result, the hydrostatic pressure testing of the pipes was expedited. It was also apparent that the mechanical contractor regarded the water treatment portion of the process as a low-level, line item maintenance expense and a relative "speck of dust on an elephant." Despite its many years of experience, the mechanical contractor never developed an accurate understanding about the need for chemical passivation. Specifically, the foreman testified that he believed only the water used for the initial fill immediately preceding start-up needed passivation chemicals. He mistakenly believed that water introduced for hydrostatic pressure testing would not have a corrosive effect on the pipe interior. The mechanical contractor was proven to be liable for the damages.

**Detecting the Undetectable.** The failure to discover the presence of hidden under deposit corrosion often leads to water treaters being implicated for failing to detect the undetectable. Commonly, the evidence of this corrosive process is concealed from the bulk waters to which the treater has access for testing and treatment. It is commercially impracticable for a water treater to disassemble or otherwise probe the entirety of an existing system to the degree necessary to adequately ascertain its condition prior to treatment. Nonetheless, despite their limited functions, pay and access to the property, water treatment contractors can be wrongfully regarded as guarantors of system maintenance and performance.

### **Case study:**

The condenser water pipes in a luxury hotel experience failure due to corrosion and leaks. The evidence reveals that the system was not properly passivated and under deposit corrosion began to form before the first water treatment chemicals were introduced into the system. Specifically, the evidence reflected that precipitated corrosion products (such as iron oxide) and microbiological depositions (such as iron and sulfate reducing bacteria which imbed themselves into iron deposits) formed on the inner wall of the pipe surface. These deposits formed a concrete-like concealing layer that rendered subsequent attempts to introduce corrosion inhibitor ineffective. Once this layer was formed, inhibitors could no longer make physical contact with the inner wall of the pipe they were meant to protect, and corrosion products were hermetically sealed off from the bulk water supply, rendering them inaccessible to subsequent testing or treatment of the bulk waters.

The monthly water treatment contractor was not hired until 16 months after the corrosive process began. Consistent with its contract, treatment entailed monthly site visits by the water treatment representative to collect water samples and review tests of the treated waters that are actually flowing through the system. These tests included monthly readings for conductivity, alkalinity, pH and other factors, but only for the accessible waters flowing through the pipes.

Accordingly, the issues within the system were not discovered until leaks occurred when the corrosion breached the other side of the pipe.

Plaintiff alleged that the water treater should have detected this under deposit corrosion and somehow "reversed or retarded the corrosive process." The Field Service Reports reflected that the levels for all relevant metrics were well within the designated control levels and that the corrosive process was not evident in the accessible waters. Despite these facts, Plaintiff alleged that the treater had extra-contractual responsibilities to perform internal inspections of the system piping (as with a borescope), external inspections of the system piping for signs of leaks and environmental inspections throughout the building to affirmatively find signs of leaks (such as rust stains on insulation or the floor). This case ultimately resolved short of trial.

## **Understanding Responsibilities After Turnover**

The lack of a clear understanding of mechanical, operational and maintenance responsibilities after turnover is a frequent source of litigation. Despite having full time maintenance personnel on the premises, building owners frequently allege that the General Contractor and HVAC Mechanical Contractor retain responsibilities after turnover. Owners also frequently allege that the monthly water treatment contractor has day-to-day mechanical and operational responsibilities ranging from mechanical cleanings of condenser water system equipment to building-wide inspections for signs of degradation or leaks.

**Who Maintains the System?** A clear understanding of maintenance responsibilities of the condenser water system after turnover is critical. The transition of responsibilities from the contractors who built and commissioned the system to the building maintenance team is a common source of legal contention.

### **Case study:**

The hydronic water system in a commercial high-rise development experiences catastrophic failure causing more than \$3 million damages. One cause of the occurrence is discovered to be inadequate water flow throughout the system including areas where the system was end capped because no tenants had yet occupied the space to be serviced by that portion of the system. The mechanical contractor testified that after the building was turned over to the owner that the owner was responsible for ensuring that there was adequate flow in the system. When asked, the maintenance supervisor testified that none of the maintenance personnel had experience or training with regard to managing flow in the system. Maintenance personnel knew nothing of measuring flow, how to adjust bleed valves, how to spot potential areas of low circulation or dead legs. With respect to the subject jobsite, maintenance personnel was also not made aware of any issue with the piping that serviced the unoccupied tenant space sitting idle with no load.

The owner filed a lawsuit alleging that the General Contractor and HVAC Mechanical Contractor were responsible for educating the owner about quality control as it related to the management of water flow even for the spaces that were not yet built-out or occupied. The subject contracts were silent as to these responsibilities. The owner likewise alleged that the monthly water treater was responsible for the management of water flow on a day-to-day basis despite the fact that it was allowed access to the premises for only 12 days of the year.

## Defending Yourself Through Documentation

Missing or incomplete documentation relating to the construction and maintenance of the condenser water system may wrongfully result in exposure for events wholly beyond the knowledge or control of a given defendant, and substantially increase the cost of any subsequent litigation.

No Daily Logs. The events giving rise to the occurrence frequently occur many years before the lawsuit is filed. As time passes, important dates and significant events can be forgotten or confused if not memorialized. The lack of affirmative evidence that important events did occur can leave parties open to substantial risk and expense.

### Case Study:

The condenser water system for a 22-story building failed within four years of start-up causing \$2.2 million in damages. Despite the fact that the HVAC mechanical contractor who constructed and commissioned the system was paid more than \$32 million for this project, it failed to keep any daily logs showing its activity. When asked, the foreman stated, "we are builders – not secretaries."

By the time the mechanical contractor testified, more than seven years had elapsed since it completed its work on the project. Having constructed numerous other systems since that time, the foreman had little memory of the details of the project. He could not attest to the date water was introduced, the date hydrostatic pressure testing was complete, the date of passivation or the date that the water treatment contractor was advised that water was being introduced.

He testified that it was standard practice to call the water treater before water was first introduced but had no documents or independent recollection that this occurred. The water treatment contractor testified that it was not contacted to provide initial water treatment services until weeks after water had been introduced. The conflicting testimony created an issue of fact that had to be decided by a jury after years of litigation and corresponding expense.

Failure to Document Customer Refusals. Contractors frequently make recommendations or offer services that are declined by the customer for a myriad of reasons. Many companies are not in the business of documenting failed sales attempts and only make a record of the recommended services that are accepted. As illustrated below, the failure to document the full recommendation so that it may be compared with the services provided can prove to be a costly omission for entities ranging from the design engineer to the monthly water treatment provider.

### Case Study:

Two 15-story twin commercial buildings are constructed with open loop condenser water systems and rooftop cooling towers. The developer solicited only bids for an open loop design citing the desire for "free cooling." In light of its concern about possible microbiological fouling and corrosion control incident to the open nature of the system for this particular geographical area, the design engineer met with the developer's lead representative to suggest a more expensive closed loop alternative. This suggestion was declined and the open loop system design was implemented. Within six years, the open loop system experienced catastrophic failure due to excessive



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fouling, tuberculation and aggressive corrosion. The closed loop system for the building had no issues.

The owner/developer filed a \$3 million lawsuit against the design engineer citing the choice to use an open loop system design without any alternative. During the lawsuit, the design engineer conceded that the open loop design employed was the design option that was most susceptible to fouling and corrosion related failure. The developer's lead representative who attended the meeting regarding the alternative closed loop design option left his position with the developer five years before the lawsuit was filed and could not be located. The design engineer had no writings reflecting his concerns over the open loop design option and no writings proposing any alternative designs.

**Failure to Document Prior Conditions.** While building owners and post-turnover contractors will not likely be able to discover concealed issues like under-deposit corrosion, these parties are well-served to communicate about system issues that have been discovered. Contractors are especially behooved to document apparent system issues upon arrival to avoid later allegations that they somehow caused those conditions and the damages resulting therefrom.

### Case Study:

In a 20-story commercial building, multiple heat exchangers experience failures incident to corrosion and degradation of the aluminum surfaces. The initial water treatment contractor failed to keep the pH levels within the range appropriate for the system. In June 2009, the owner solicits and awards the bid for the 2010 water treatment year with a start date of January 1, 2010. Two months before the new treater will begin its program, the heat exchangers experi-

ence complete failure. These units are replaced the week prior to the new treater's tenure, without the system being cleaned and flushed.

The owner did not disclose to the new water treater that the system at issue had encountered substantial problems and that the heat exchangers had been replaced. The new units fail within 30 days. The owner then filed a lawsuit against the subsequent treater for the new failed exchangers citing poor water treatment incident to high levels of pH and low levels of nitrites.

### Conclusion

There is an ongoing need to balance business relationships and the risk of litigation with business partners. While the scenarios described in this publication underscore the need to avoid risk and manage exposure, it is both unreasonable and impractical to require exhaustive legal disclaimers and disavowals at every instance. Most business relationships are based upon trust. Business realities demand a certain allowance for what steps can reasonably be taken to manage project risk without tarnishing relationships through "over lawyering the deal" and losing the business to less demanding competitors.

The purpose of this publication is to educate the reader about possible risks and expenses incident thereto. While each scenario is different and no measure can guarantee that litigation will not occur, there are some basic measures that can possibly reduce the risk of innocent parties being wrongfully accused or expedite litigation defense.

Bidders are well-served to read the portion of the specification that they are bidding thoroughly and note the portions that are generic and do not apply to their work on the project. For those items that

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do not apply or for which you are seeking a waiver or exception, a quick note in plain language to that effect in the bid submission may help you avoid involvement in litigation. These excepted items are typically inconsequential to the project and noting that your bid is subject to your notes may save you from being wrongfully accused.

Contractual language with vague job descriptions should be approached with caution. Job responsibilities that are ambiguous are subject to multiple interpretations and may result in allegations that your job responsibilities far exceed their actual scope. To the extent possible, state your responsibilities simply and include a provision stating that the contract is the complete agreement between the parties and any expansion of your duties must come through a change order.

Despite best efforts to specify your scope of work in specifications and contracts, litigation may be unavoidable. When possible, document significant events so that you are able to swiftly prove your innocence. Keep daily logs of important dates and events. Follow up phone calls with simple emails so there is a record of what occurred and you are not being tasked to remember specific dates from years ago during cross-examination.

While lengthy, self-serving disclaimers are off-putting, simple emails or letters can achieve the same purpose. For instance, write your full recommendations to the client. If they later choose to only partially accept the services recommended, an easy comparison can be made from the recommendation to the work accepted and invoiced.

The potential risks facing businesses involved in building water systems are frequently nuanced and complex. When in doubt, confer with counsel to educate you as to your risks so that you may determine which risks are acceptable and which need to be managed.

## Illustrations

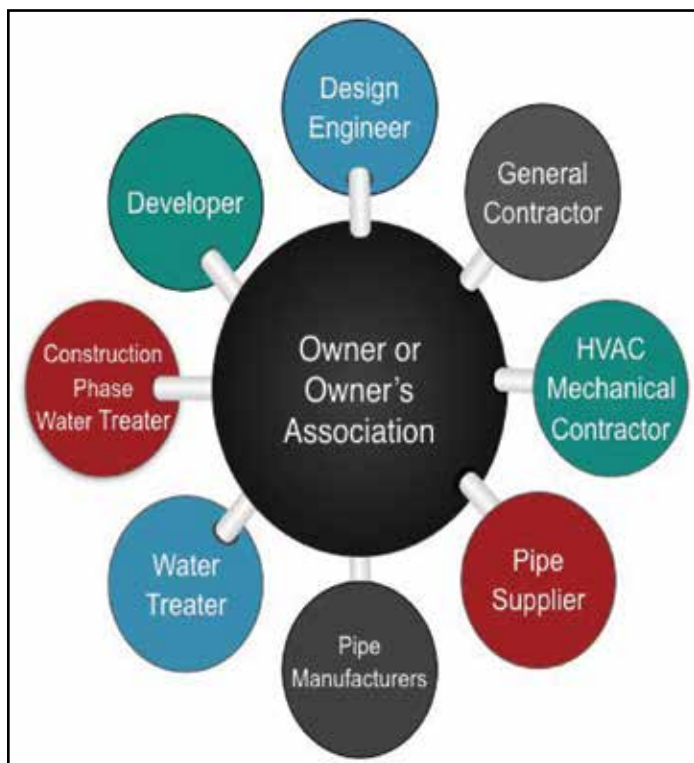


Figure 1. Common Building Water System Litigants



Figure 2. Classic example of pitting under deposits

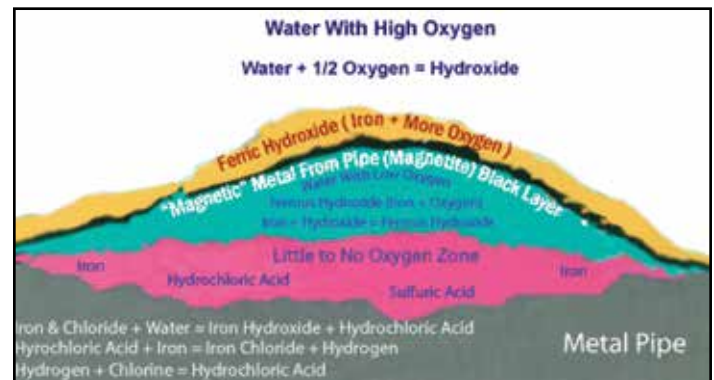


Figure 3. Diagram of under deposit corrosion mechanism



Figure 4. Corrosion product accumulation with subsequent pitting and MIC secondary to low or no flow (top of pipe section appears on the bottom of this photo – note heavier accumulation on the bottom)





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- The knowledge gained can help set priorities for solving specific problems. Industry standards and guidelines optimize the operation, maintenance of the equipment; maximizing value for the Owner/Operator.
- Two CTI meetings a year, an Annual Conference and Summer Committee Workshop. The Annual Conference includes the presentation of Technical Papers, Owner/Operator Seminar, Education Seminar, Committee Meetings and a Technical Exchange Exhibition.
- CTI Annual Conference provides a platform to publish and present technical papers.
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Contact: Ronald Rayner

### **Cooling Tower Test Associates, Inc.**

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

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



# Cooling Technology Institute Sound Testing



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

## Licensed CTI SoundTesting Agencies

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

### McHale Performance

4700 Coster Rd  
Knoxville, TN 37912  
865.588.2654  
Fax 865.934.4779  
www.mchaleperformance.com  
ctitesting@mchaleperformance.com  
Contact: Jacob Faulkner

## Cooling Technology Institute Certification Program STD-201 for Thermal Performance



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

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

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

## Licensed CTI Thermal Certification Agencies

Agency Name / Address	Contact Person / Website / Email	Telephone / Fax
<b>Clean Air Engineering</b> 7936 Conner Rd Powell, TN 37849	Kenneth (Ken) Hennon www.cleanair.com khennon@cleanair.com	800.208.6162 or 865.938.7555 (F) 865.938.7569
<b>Cooling Tower Test Associates, Inc.</b> 15325 Melrose Dr. Stanley, KS 66221	Thomas E. (Tom) Weast www.cttai.com cttack@aol.com	913.681.0027 (F) 913.681.0039
<b>Cooling Tower Technologies Pty Ltd</b> PO Box N157 Bexley North NSW 2207 Australia	Ronald Rayner coolingtwrtech@bigpond.com	+61.2.9789.5900 +61.2.9789.5922
<b>DMT GmbH &amp; Co. KG</b> Am Technologiepark 1 45307 Essen, Germany	Dr. Ing. Meinolf Gringel meinolf.gringel@dm-group.com	+49.201.172.1164
<b>McHale Performance</b> 4700 Coster Rd Knoxville, TN 37912	Jacob Faulkner www.mchaleperformance.com ctitesting@mchaleperformance.com	865.588.2654 (F) 865.934.4779

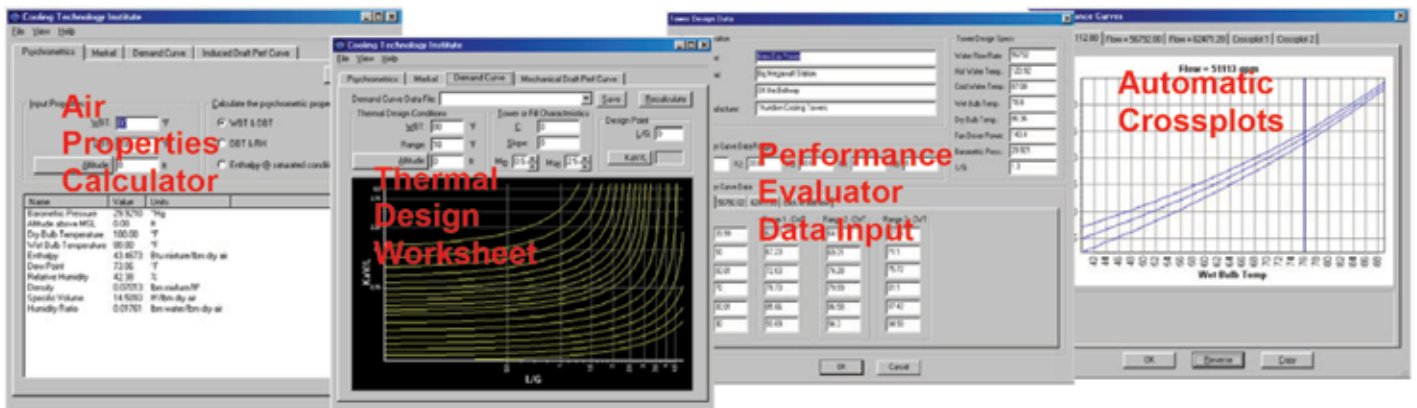


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8/8/08



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- Rich Harrison, Jr. ATC-105 Task Group Chairman

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# Cooling Towers Certified by CTI Under STD-201

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

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

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



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

The CTI STD-201 Thermal Performance Certification Program has grown rapidly since its' inception in 1983 (see graphs that follow). A total of 58 cooling tower manufacturers are currently active in the program. In addition, 11 of the manufacturers also market products as private brands through other companies.

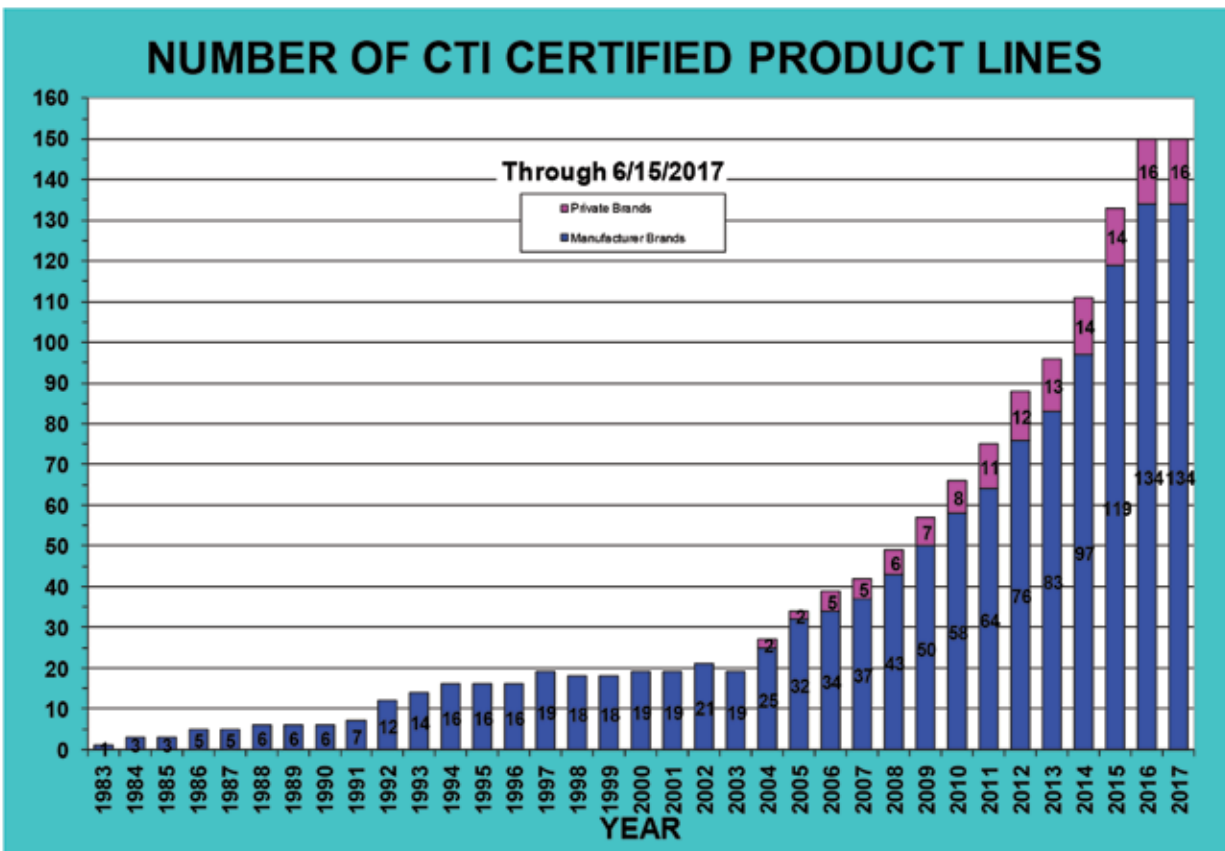
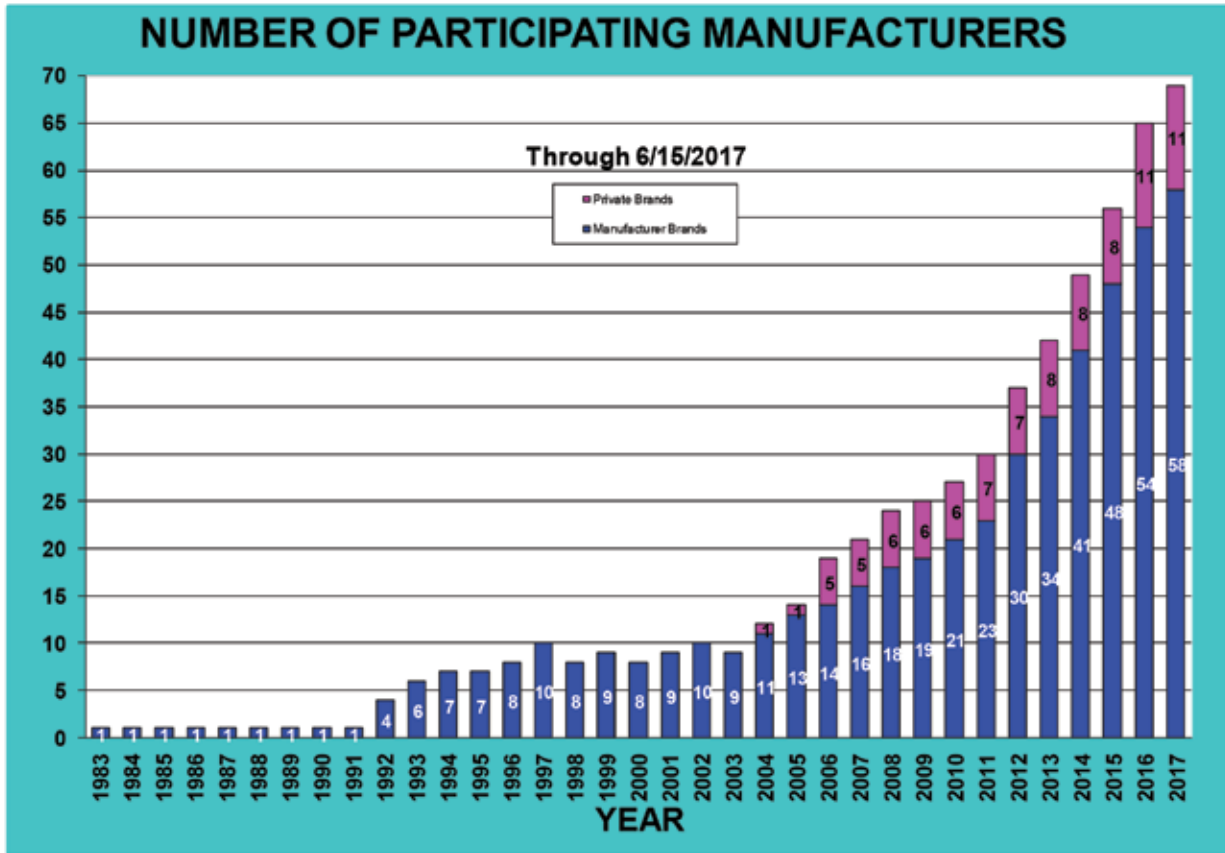
While in competition with each other, these manufacturers benefit from knowing that they each achieve their published performance capability and distinguish themselves by providing the Owner/Operator's required thermal performance. The participating manufacturers currently have 134 certified product lines plus 16 product lines marketed as private brands which result in approximately 30,000 CTI Certified cooling tower models to select from.

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

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

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

# Thermal Performance Certification Program Participation



# Current Program Participants

(as of June 15, 2017)

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

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

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

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

<p><b>A</b></p> <p><b>Advance GRP Cooling Towers, Pvt.,Ltd.</b> Advance 2020 Series A Validation No. C31A-07R03</p> <p><b>Aggreko Cooling Tower Services</b> AG Line Validation No. C34A-08R02</p> <p><b>Amcot Cooling Tower Corp.</b> Series R-LC Validation No. C11E-11R02</p> <p><b>AONE E&amp;C Corporation, Ltd.</b> ACT-C Line Validation No. C28B-09R01 ACT-R/ACT-RU Line Validation No. C28A-05R04</p> <p><b>Approach Engineering Co., Ltd</b> NS Line Validation No. C76A-16R00</p> <p><b>Axima (China) Energy Technology Co., Ltd.</b> EWX Line Validation No. C72A-15R01 EWK Line Validation No. C72C-17R00 ACC Line Validation No. C72B-15R01</p> <p><b>B</b></p> <p><b>Baltimore Aircoil Company, Inc.</b> FXT Line Validation No. C11A-92R02 FXV Line Validation No. C11J-98R10 PF Series Validation No. C11P-12R02 PT2 &amp; PTE Series Validation No. C11L-07R05 Series V Closed VF1 &amp; VFL Validation No. C11K-00R02 Series V Open VT0,VT1,VTL &amp;VTL-E Validation No. C11B-92R06 Series 1500 Validation No. C11H-94R09 Series 3000 A,C,D,E, Compass &amp; Smart Validation No. C11F-92R18</p> <p><b>Bell Cooling Tower Pvt, Ltd.</b> BCTI Line Validation No. C43A-12R02</p>	<p><b>C</b></p> <p><b>Cool Water Technologies</b> RTAi Line Validation No. C52A-13R02 RTi Line Validation No. C52B-13R01</p> <p><b>Composite Cooling Solutions, Inc.</b> PLC Line Validation No. C79A-17R00</p> <p><b>D</b></p> <p><b>Delta Cooling Tower, Inc.</b> TM Series Validation No. 02-24-01</p> <p><b>Decsa</b> RCC Series Validation No. C42C-14R00</p> <p><b>Dongguan Ryoden Cooling Equipment Co., Ltd</b> RT-U Series Validation No. C71A-15R01 RTM-L Series Validation No. C71B-15R00</p> <p><b>E</b></p> <p><b>Elendoo Technology (Beijing) Co., Ltd.</b> EL Line Validation No. C50C-15R01 ELN Line Validation No. C50D-17R00 ELOP Line Validation No. C50B-14R02</p> <p><b>Evapco, Inc.</b> AT Series Validation No. C13A-99R18 ATWB Series Validation No. C13F-09R08 AXS Line Validation No. C13K-15R03 ESWA &amp; ESWB Series Validation No. C13E-06R09 L Series Closed Validation No. C13G-09R04 L Series Open Validation No. C13C-05R03</p>
---	---

# G

## Genius Cooling Tower Sdn Bhd

MT Series *Validation No. C67A-16R00*

MX Series *Validation No. C67B-16R00*

## GOHL (E.W.Gohl, GmbH)

DTC-ecoTec Line *Validation No. C92A-14R01*

## Guangzhou Laxun Technology Exploit Company, Ltd.

HMK Line *Validation No. C45A-12R04*

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

PL Line *Validation No. C45E-16R00*

LC Line *Validation No. C45F-16R00*

PG Line *Validation No. C45G-17R00*

## Guangdong Feiyang Industry Group Co., Ltd

LK Line *Validation No. C77A-17R00*

## Guntner U.S. LLC

ECOSS Line *Validation No. C84A-17R00*

# H

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

MK Series *Validation No. C66A-15R01*

## Hunan Yuanheng Technology Development Company, Ltd.

YHA Line *Validation No. C40A-11R03*

YHD Line *Validation No. C40B-15R00*

YCF-H Line *Validation No. C40C-16R00*

## HVAC/R International, Inc.

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

Therflow Series TFW *Validation No. C28A-05R04*

# I

## Industrial Mexicana

Series 1000 *Validation No. C60A-15R00*

Series 2000 *Validation No. C60B-16R00*

Series 6000 *Validation No. C60C-15R00*

# J

## Jacir

KS Line *Validation No. 12-46-01*

KSF Line *Validation No. C46B-15R00*

VAP Line *Validation No. C46C-16R00*

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

FKH Line *Validation No. C83A-17R00*

## Jiangsu Dayang Cooling Tower Co., Ltd.

HLT Line *Validation No. C94A-14R01*

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

TMH Series *Validation No. C75A-16R00*

REH Series *Validation No. C75B-16R00*

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

CTNX Line *Validation No. C91D-16R00*

CTHX Line *Validation No. C91E-16R00*

# K

## Kelvion B.V.

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

Polacel XF Series *Validation No. 13-25-02*

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

CKL Line *Validation No. C18B-05R03*

Endura Cool Line *Validation No. C18A-93R08*

## King Sun Industry Company, Ltd.

HKB Line *Validation No. C35A-09R03*

HKD Line *Validation No. C35B-09R03*

KC Line *Validation No. C35-11R01*

KFT Line *Validation No. C35D-16R00*

## Korytko Systems, Ltd.

KDI Line *Validation No. C70A-16R01*

## Kuken Cooling Tower Co., Ltd.

GXE Series *Validation No. C81A-16R00*

GXC Series *Validation No. C81B-16R00*

# L

## Liang Chi Industry Company, Ltd.

Series C-LC *Validation No. C20B-09R02*

Series D-LC *Validation No. C20F-14R01*

Series R-LC *Validation No. C11E-11R02*

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

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

LCTR Line *Validation No. C20H-17R00*

TLC Line *Validation No. C20G-16R00*

# M

## Marley (SPX Cooling Technologies)

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

AV Series *Validation No. C14D-98R03*

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

MD Series *Validation No. C14L-08R03*

MHF Series *Validation No. C14G-04R07*

NC Series *Validation No. C14A-92R20*

Quadraflow Line *Validation No. 92-14-02*

NX Series *Validation No. C14M-15R01*

DTW Series *Validation No. C14N-16R01*

LW Series *Validation No. C14P-16R01*

### Mesan Cooling Tower, Ltd.

MCC Series *Validation No. C26G-12R03*  
MFD Series *Validation No. C26J-16R00*  
MXC Series *Validation No. C26H-12R01*  
MXR-KM, MXL, MXH Series *Validation No. C26C-08R07*

### MITA S.r.l.

PM Series *Validation No. C56B-16R00*

## N

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

HMP-NB Line *Validation No. C55A-14R00*

### Nihon Spindle Manufacturing Company, Ltd.

KG Line *Validation No. C33B-12R04*

## O

### OTT Company, Ltd.

OTTC Line *Validation No. C44A-12R02*  
OTTX Line *Validation No. 12-44-02*  
OTTC-C Line *Validation No. C44C-14R00*  
OTTX-C Line *Validation No. C44D-14R00*

## P

### Paharpur Cooling Tower, Ltd.

CF3 Line *Validation No. C51A-13R01*  
OXF-30K Line *Validation No. C51B-14R00*

### Proficool Fans Sp z.o.o.

BORA Line *Validation No. C90A-15R00*

### Protec Cooling Towers, Inc.

FRS Series *Validation No. 05-27-03*  
FWS Series *Validation No. 04-27-01*

## Q

### Qingdao VOFAT Air Conditioning Equipment Co., Ltd.

MF Series *Validation No. C82A-16R00*

## R

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

HFC Line *Validation No. C22F-10R3*  
RT & RTM Series *Validation No. C22G-13R03*

### Rosemex, Inc.

RC (RSC/D) Series *Validation No. C54A-13R02*  
RO (ROS/D) Series *Validation No. C94A-14R01*

### RSD Cooling Towers

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

### Ryowo (Holding) Company, Ltd.

FCS Series *Validation No. 10-27-04*  
FRS Series *Validation No. 05-27-03*  
FVS Series *Validation No. 12-27-06*  
FWS Series *Validation No. 04-27-01*

## S

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

AC Line *Validation No. C80A-17R00*

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

BTC Line *Validation No. C49A-12R01*

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

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

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

FBH Line *Validation No. C54A-13R02*  
FKH/FKHL Series *Validation No. C94A-14R01*

### Shangyu Dongjie Cooling Tower Co., Ltd.

DMNC Line *Validation No. C63A-15R00*  
DHC Line *Validation No. C63B-15R00*

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

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

### Sung Ji Air-Conditioning Technology Co., Ltd.

SJMO Series *Validation No. C74A-16R00*  
SJCO Series *Validation No. C74B-16R00*

## T

### Ta Shin F.R.P. Company, Ltd.

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

### The Cooling Tower Company, L.C

Series TCIA *Validation No. C29B-15R00*

### Thermal-Cell sdn bhd

TYH Line *Validation No. C40A-11R03*



**Tower Tech, Inc.**

TTXL Line Validation No. C17F-08R04  
TTXR Line Validation No. C17F-15R00

**Truwater Cooling Towers, Inc.**

EC-S Series Validation No. C41A-12R03  
EX-S Series Validation No. C41B-12R04  
VXS Series Validation No. C41C-13R01

**W**

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

FBF Line Validation C78A-16R00

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

FKH Line Validation C64A-14R00  
FNB Line Validation C64B-15R01

**Y**

**Yantai Ebara Air Conditioning Equipment Company, Ltd.**

CDW Line Validation No. C53A-13R02  
CXW Line Validation No. C53B-14R01

**York (By Johnson Controls)**

AT Series Validation No. C13A-99R18  
LSTE Line Validation No. C13G-09R03

**Z**

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

SF Line Validation No. C76A-16R00

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

JFT Series Validation No. C28C-16R00  
JNC Series Validation No. C28B-09R01  
JNT Series Validation No. C28A-05R04

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

SFB Line Validation No. C73A-15R01

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

FBH Line Validation No. C54A-13R02

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

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

**Always look for the CTI Certified Label with Validation Number on Your Equipment**



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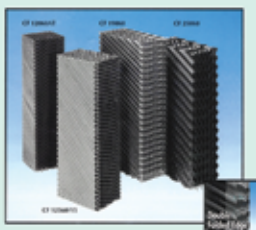
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# 50% MORE COOLING CAPACITY THAN ANY OTHER COOLING TOWER IN THE WORLD\*



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Use up to 35% less fan power\* and achieve higher energy savings.

### REDUCED COSTS

Reduce piping and electrical costs and realize greater installation savings because NC Everest's ambitious design minimizes piping and electrical connections.

### LOW DRIFT RATE

Patent-pending MarKey™ Drift Eliminators achieve the lowest measurable drift rate, down to 0.0005% of circulating water flow, so less water escapes the tower.\*

### CERTIFIED SOUND

NC Everest's sound level is independently verified, per CTI ATC-128, by a third-party certified acoustical engineer and CTI-licensed test agent.

### UNRIVALED ACCESS

7-foot high doors and interior service decks yield unrivaled access and make inspections and maintenance easier and safer.

**Take Cooling To A Higher Level – [spxcooling.com/NCEverest](http://spxcooling.com/NCEverest)**

\* Compared to other single-cell, factory-assembled cooling towers.

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