Are you still doing this...

And ending up with this?

Call on the Screening Experts

Replace your existing bar screens on line, without any basin modifications with our unique, continuous screening

Vari-Flow SS Series
Traveling Sump Screen

Traveling Sump Screen

The Vari-Flow SS Series Traveling Sump Screen is custom fabricated to easily replace stationary screens while your unit stays in full operation. The screens can be automated and are available in more than 20 different screen-mesh sizes. The Traveling Sump Screen is patented, manufactured and distributed by Industrial Cooling Tower Services. Let the experts handle your equipment screening needs with this easy-to-use, cost efficient solution.

Industrial Cooling Tower Services, Incorporated
(225) 387-5664 • www.ictssinc.com
Contents

Feature Articles

8 AEP’s Experience With Failure Modes In Fiberglass Cooling Towers
   Bob Cashner, Dr. Hota GangaRao & Mark Skidmore

28 Innovative Tandem Blade For High Efficency Colling Fans
   Carlo Gallina

36 Comparison Of Chlorination Monitoring Methods In Cooling Water Systems
   Trey Cook, Michael Dorsey and Matt Walker

44 Premature Failure of Open and Closed Recirculating Cooling Water and Fire Water System Piping and Equipment – Are You Responsible?
   Robert J. Cunningham

58 Review and Comments in the CTI Publication PTG-143: Technical Issues and Challenges Encountered During On-site Testing
   Peter Holkers

66 Advanced Cooling Solutions for Water Conservation
   Jean-Pierre Libert, Jennifer Hamilton and Tom Bugler

74 Sustainability In Cooling System Operation
   Roy A. Holliday, Shereif Alsayed

Special Sections

82 CTI Certified Towers
89 CTI Licensed Testing Agencies
90 CTI ToolKit

Departments

2 Multi Agency Press Release
2 Meeting Calendar
4 View From the Tower
6 Editor’s Corner

© 2015 by The Cooling Technology Institute, PO Box #681807 Houston, Texas 77268. Periodicals postage paid at Houston, Texas.

MISSION STATEMENT
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和支持 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.

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

SUBSCRIPTIONS
The CTI Journal is published in January and June. Complimentary subscriptions mailed to individuals in the USA. Library subscriptions $45/yr. Subscriptions mailed to individuals outside the USA are $45/yr.

CHANGE OF ADDRESS Request must be received at subscription office eight weeks before effective date. Send both old and new addresses for the change. You may fax your change to 281.537.1721 or email: vmanser@cti.org.

PUBLICATION DISCLAIMER
CTI has compiled this publication with care, but CTI has not investigated, and CTI expressly disclaims any duty to investigate any product, service process, procedure, design, or the like that may be described herein. The appearance of any technical data, editorial material, or advertisement in this publication does not constitute endorsement, warranty, or guarantee by CTI of any product, service process, procedure, design, or the like. CTI does not warrant that the information in this publication is free of errors, and CTI does not necessarily agree with any statement or opinion in this publication. The entire risk of the use of any information in this publication is assumed by the user. Copyright 2015 by the CTI Journal. All rights reserved.
Step up to the “Vari-Flow” Distribution Valve

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

Maintenance Free Operation
Manufactured from 304 stainless steel and UHMW plastic, which eliminates corrosion and maintenance concerns. Bushing assembly replaces easily from exterior, eliminating costly downtime.

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

The next generation of industrial fans for cooling towers and heat exchangers.

swifterfans.com
GLOCON INC • NJ USA • 973-463-7300

Swifter
Happy New Year to all. It is again time for the CTI Annual Technical Conference and I am looking forward to seeing each of you in New Orleans. The 2015 Conference is being held at the Sheraton on Canal Street; right across from the French Quarter. I am confident that everybody will enjoy the facility and fine restaurants and entertainment which is abundant in the French Quarter. The CTI office staff and Program Committee have put together another great program. There will be a diverse selection of technical paper presentations, seminars, panel discussion, Committee meetings and Table Top exhibits. The Owner/Operator Council also will have a closed meeting for only this category of conference attendees. There will be a short technical presentation during the Owner/Operator Council meeting but the majority of the time will be allocated for the owner operators to openly discuss topics and issues important to them. This is also an excellent forum for the owner operators to bring up items that need addressed by the CTI Engineering Standards & Maintenance, Performance & Technology and Water Treating Committees through revision and/or development of standards under their respective responsibilities.

The CTI Annual Technical Conference always provides significant educational value as well as great forum for networking with experts in all aspects of the cooling technology industry. A particular focus of mine is to facilitate continued growth in the owner/operator participation and first time attendees. New ideas, perspectives and experiences that folks bring to the CTI through networking and meeting attendance ensure that we are able to keep up with the world’s constantly changing cooling technology related issues and technologies. I am looking forward to seeing all of the regular attendees at the Annual Technical Conference and especially looking forward to meeting all or the new faces.

One of the events that occur at each Annual Conference is the retirement of three members of the CTI Board of Directors. This year Tom Toth of GEA and George Zubritsky of Cooling Tower Testing and Inspection Services are retiring. Please join me in thanking them for their service to CTI and for a job well done. Helene Troncin from EDF who was appointed to the Board to fill a vacancy on the Board in 2013 will be serving a full three year term as an Owner Operator representative. Many Thanks to Helene for her continued service to CTI. The other two new Board members are Brandon Rees of Cooling Tower Depot (Manufacturer representative) and Narendra Gosain of Walter P Mone and Associates (Supplier representative). I know all three new Board members will continue CTI’s interests and represent its membership for continued growth and wellbeing.

I am pleased to point out that the CTI going into its 65th year anniversary continues to grow as the leader of cooling technology by expanding our membership worldwide and through partnerships with organizations like Eurovent. The CTI also remains financially sound which is not the case with many other industry organizations these days.

As always, I wish to thank the dedicated CTI staff and multitude of members who volunteer their valuable time and expertise in making CTI a world class technical organization and making my time serving as your President enjoyable and rewarding.

Thanks,
Frank Michell
CTI President 2014 - 2015
Thinking...

inside the box.

Add new life to an old box.

Amarillo Gear Service™ is focused on keeping existing gear boxes,...existing. A gear drive that you may have thought was ready to be replaced, may now have the opportunity for a new life with quality, Amarillo parts and service. We are also manufacturing more and more gears to fit our competition’s old boxes, too.

(806) 622-1273
info@amarillogear.com
AmarilloGear.com

Contact us and let’s see if we can make your old gear drive smile again!
Dear Journal Reader,

2014 is an eventful year for CTI. After an exhaustive process, an agreement has been reached with CleanAir Engineering to provide Thermal Certification Administrator Services to CTI. This multi-year contract places Mike Womack as the Thermal Certification Administrator going forward, with support services being provided by CleanAir per the contract requirements. The thermal certification program has been growing rapidly, and this arrangement positions us well to accommodate the growth.

We are fortunate that Tom Weast, the longtime Certification Administrator has agreed to overlap with Mike Womack to provide as smooth a transition as possible. Tom’s company will also continue to provide the licensed thermal certification testing services. CTI is working to extend the licensed testing program for thermal certification testing to additional existing CTI Licensed Thermal Certification testers. Please take an opportunity to thank Tom Weast for his many years as CTI Thermal Certification Administrator, and also to thank Mike Womack and CleanAir Engineering for coming on with the Thermal Certification Program.

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

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

Best wishes for the New Year,

Paul Lindahl, CTI Journal Editor
KIMCO, The Altimate in environmental-friendly Cooling Tower!

KIMCO serves all kinds of cooling towers with numerous new options. Enjoy the benefits!

- Plume Abatement Design
- Super Low Noise Design
- Anti-Bacteria, Legion-Free Tower
- High Efficiency, Energy Saving Design
- Non-Corrosion FRP Structure Construction
- CTI Certified Models are Available: Dyna-Cool / CKL / Endura-Cool

COOLING TOWER KIMCO

www.kimcoct.com

FOR MORE INFORMATION, CONTACT
E-mail: kimco@kimcoct.com
AEP’s Experience With Failure Modes In Fiberglass Cooling Towers

Bob Cashner, P.E.
American Electric Power
1 Riverside Plaza, Columbus, Ohio 43215, USA

Dr. Hota GangaRao & Mark Skidmore, P.E.
West Virginia University - CFC
653 Engineering Science Building
Morgantown, WV 26506, USA

Abstract
There are a total of 15 hyperbolic and 31 mechanical draft cooling towers on the American Electric Power (AEP) system. These towers utilize a cross-flow or counter-flow thermal transfer design, and a majority of the cross-flow towers are treated wood structures. AEP replaced eight cross-flow, mechanical draft towers during the period of 2008 through May 2013. Two new counter-flow, mechanical draft towers were built for new generating units in 2009 and 2012. A counter-flow, mechanical draft tower (which was built around 2001) was finished and placed into service in 2011. A natural draft, hyperbolic tower had the heat transfer and water distribution areas converted from a cross-flow configuration to a counter-flow design in 2011. All twelve of these new towers used polyester or vinyl ester fiberglass structure from at least three different pultruders, and were designed and constructed by four different cooling tower companies. These twelve towers are the only fiberglass structure cooling towers on the AEP system.

The intent of this paper is to share information on how pultruded fiberglass members can fail or be structurally compromised. Failed or cracked fiberglass columns were found in five towers during construction or after 18 months of operation. The failed or cracked columns were attributed to misuse of fiberglass bearing pads or poor construction procedures. Several failed columns and horizontal members were also damaged from icing on the counter-flow, natural draft tower in January 2013. Surface blisters were noticed in two of the new towers after 2 to 18 months of operation. A summary of these events will be discussed in this paper along with the probable reasons and actions AEP is taking to prevent a reoccurrence.

CTI Paper TP11-19 was presented at the 2011 CTI Winter Conference and provides more details on four of the mechanical draft fiberglass towers constructed in the 2008 to 2010 time frame. A brief summary of the failed columns in those four towers are included in this paper.

Background
AEP is one of the largest electric utilities in the United States, delivering electricity to more than 5 million customers in 11 states. AEP ranks among the nation’s largest generators of electricity, owning more than 38,000 megawatts (MW) of generating capacity in the U.S., with individual unit ratings ranging from 25 MW to 1300 MW.

Tower Descriptions
Towers 1 and 3 are new replacement 14 cell, fiberglass structure, cross-flow, mechanical draft towers which were completed on neighboring 465 MW units in May 2008 and May 2009. Figure 1 represents the cross-flow structure for these towers and shows the ~40 ft columns (supplied in a single length with no splices) which support the 60” to 30” hot water distribution pipe on top of the hot water decks. There are six transverse bays in each cell with the transverse bents spaced every 6 ft, longitudinal bents spaced every 6 ft, and vertical elevations of 6 ft. The 3-1/2” pipe columns rest on elevated concrete piers which are at eye level. The pultruded polyester fiberglass columns are ¼” thick and originally designed to sit on a fiberglass/neoprene bearing pad.

Tower 2 is a new replacement 12 cell, fiberglass structure, cross-flow, mechanical draft tower which was completed on a 460 MW unit in May 2008. Figure 2 represents the cross-flow structure for the tower and shows the ~48 ft columns (supplied in a single length with no splices) which support the 66” to 30” hot water distribution pipe on top of the hot water deck. There are six transverse bays in each cell with the transverse bents spaced every 6 ft, longitudinal bents spaced every 6 ft, and vertical elevations of 6 ft. The 4” and 3-1/2” pultruded polyester fiberglass pipe columns are ¼” thick and originally designed to sit on a fiberglass/neoprene bearing pad which then rest on the cold water basin floor.

Tower 4 is a new 10 cell, back-to-back, fiberglass structure, counter-flow, mechanical draft tower which was constructed in 2009 and commissioned in early 2010 on a 550 MW unit. Two 30” hot water distribution pipes enter each of the west side cells to supply water to the east and west back-to-back cells. There are eight transverse bays in each cell with the transverse bents spaced every 6 ft, longitudinal bents spaced every 6 ft, and vertical elevations of 6 ft. Due to tight site constraints, the columns were “stick-built” or constructed of three separate pieces with two levels of splice blocks (designated by the red arrows in Photo 1). The four-bolt splice connections are comprised of a positioning tube inside of the column ends and flat plate on opposite sides. The 3” and 4” pultruded polyester fiberglass columns are ¼” thick and originally designed to sit on a fiberglass/neoprene bearing pad which then rest on the cold water basin floor.

Tower 5 is a hyperbolic cooling tower structure which was converted from a cross-flow to a counter-flow design in 2011 on a 650 MW unit. The cold water basin is roughly 385 ft diameter with the bottom of the concrete shell measuring 262 ft diameter. Photo

In Fiberglass Cooling Towers

Bob Cashner

American Electric Power

1 Riverside Plaza, Columbus, Ohio 43215, USA

Dr. Hota GangaRao & Mark Skidmore, P.E.
West Virginia University - CFC

653 Engineering Science Building

Morgantown, WV 26506, USA

Abstract

There are a total of 15 hyperbolic and 31 mechanical draft cooling towers on the American Electric Power (AEP) system. These towers utilize a cross-flow or counter-flow thermal transfer design, and a majority of the cross-flow towers are treated wood structures. AEP replaced eight cross-flow, mechanical draft towers during the period of 2008 through May 2013. Two new counter-flow, mechanical draft towers were built for new generating units in 2009 and 2012. A counter-flow, mechanical draft tower (which was built around 2001) was finished and placed into service in 2011. A natural draft, hyperbolic tower had the heat transfer and water distribution areas converted from a cross-flow configuration to a counter-flow design in 2011. All twelve of these new towers used polyester or vinyl ester fiberglass structure from at least three different pultruders, and were designed and constructed by four different cooling tower companies. These twelve towers are the only fiberglass structure cooling towers on the AEP system.

The intent of this paper is to share information on how pultruded fiberglass members can fail or be structurally compromised. Failed or cracked fiberglass columns were found in five towers during construction or after 18 months of operation. The failed or cracked columns were attributed to misuse of fiberglass bearing pads or poor construction procedures. Several failed columns and horizontal members were also damaged from icing on the counter-flow, natural draft tower in January 2013. Surface blisters were noticed in two of the new towers after 2 to 18 months of operation. A summary of these events will be discussed in this paper along with the probable reasons and actions AEP is taking to prevent a reoccurrence.

CTI Paper TP11-19 was presented at the 2011 CTI Winter Conference and provides more details on four of the mechanical draft fiberglass towers constructed in the 2008 to 2010 time frame. A brief summary of the failed columns in those four towers are included in this paper.

Background

AEP is one of the largest electric utilities in the United States, delivering electricity to more than 5 million customers in 11 states. AEP ranks among the nation’s largest generators of electricity, owning more than 38,000 megawatts (MW) of generating capacity in the U.S., with individual unit ratings ranging from 25 MW to 1300 MW.

Tower Descriptions

Towers 1 and 3 are new replacement 14 cell, fiberglass structure, cross-flow, mechanical draft towers which were completed on neighboring 465 MW units in May 2008 and May 2009. Figure 1 represents the cross-flow structure for these towers and shows the ~40 ft columns (supplied in a single length with no splices) which support the 60” to 30” hot water distribution pipe on top of the hot water decks. There are six transverse bays in each cell with the transverse bents spaced every 6 ft, longitudinal bents spaced every 6 ft, and vertical elevations of 6 ft. The 3-1/2” pipe columns rest on elevated concrete piers which are at eye level. The pultruded polyester fiberglass columns are ¼” thick and originally designed to sit on a fiberglass/neoprene bearing pad.

Tower 2 is a new replacement 12 cell, fiberglass structure, cross-flow, mechanical draft tower which was completed on a 460 MW unit in May 2008. Figure 2 represents the cross-flow structure for the tower and shows the ~48 ft columns (supplied in a single length with no splices) which support the 66” to 30” hot water distribution pipe on top of the hot water deck. There are six transverse bays in each cell with the transverse bents spaced every 6 ft, longitudinal bents spaced every 6 ft, and vertical elevations of 6 ft. The 4” and 3-1/2” pultruded polyester fiberglass pipe columns are ¼” thick and originally designed to sit on a fiberglass/neoprene bearing pad which then rest on the cold water basin floor.

Tower 4 is a new 10 cell, back-to-back, fiberglass structure, counter-flow, mechanical draft tower which was constructed in 2009 and commissioned in early 2010 on a 550 MW unit. Two 30” hot water distribution pipes enter each of the west side cells to supply water to the east and west back-to-back cells. There are eight transverse bays in each cell with the transverse bents spaced every 6 ft, longitudinal bents spaced every 6 ft, and vertical elevations of 6 ft. Due to tight site constraints, the columns were “stick-built” or constructed of three separate pieces with two levels of splice blocks (designated by the red arrows in Photo 1). The four-bolt splice connections are comprised of a positioning tube inside of the column ends and flat plate on opposite sides. The 3” and 4” pultruded polyester fiberglass columns are ¼” thick and originally designed to sit on a fiberglass/neoprene bearing pad which then rest on the cold water basin floor.

Tower 5 is a hyperbolic cooling tower structure which was converted from a cross-flow to a counter-flow design in 2011 on a 650 MW unit. The cold water basin is roughly 385 ft diameter with the bottom of the concrete shell measuring 262 ft diameter. Photo
Real experts, real results

The Best People
Experienced service engineers who live in your community

Results That Last
Extending asset life while minimizing chemical and water usage

Continuous Innovation
Delivering customized products with a full-service analytical lab and R&D group

Environmental Protection & Safety
Protecting your people, your brand, and the environment with our innovative solutions

Proven Treatment Technologies For:
- Cooling Systems
- Pretreatment
- Boilers
- Wastewater
- Membranes & RO
- Automation & Control

Phone number: 804-935-2000
Website: www.chemtreat.com
2 shows a sectional view of the new counter-flow tower design during construction. The heat transfer area, distribution pipes and drift eliminators are located about 35 ft above the cold water basin and are supported by a structure composed of pultruded vinyl ester fiberglass. The columns measure 5.2” square, 3/8” thick, and supplied in full height lengths (e.g. no splices). There are roughly 464 columns which are laid out on a 12 ft by 12 ft grid. All columns are designed to sit on a stainless steel bearing plate (without a neoprene pad under the plate) which rest on the cold water basin floor.

Design Issue Which Caused Failures

Towers 1, 2 and 3 were inspected after 9 to 18 months of operation. During the outages, approximately 90% of the fiberglass bearing pads had failed under the 3-1/2” pipe columns (reference Photo 3), and many pipe columns had cracked at the bearing pads. The cracked column bottoms had sections cut off ranging from 1 ft up to 6 ft with replacement fiberglass column splice sections, stainless steel pedestals or grout pads installed. In Tower No. 1, a total of 54% (90/168) of the pipe column bottoms failed, while 20% to 25% of the pipe columns failed in Tower Nos. 2 and 3. Photo 4 shows how the “cut” fiberglass bearing pad was forced up into the pipe column which then overstressed and cracked the column corners. Photos 5 and 6 represent the worst case column bottom failures.

From a collection of failed column sections pulled from the structures in Towers 1, 2 and 3, 80% of the cracks originated from the exterior surface while 20% originated on the interior surface. It was also observed that 70% of the cracks were located on the corners and roughly 30% of the cracks occurred on the face of the column. The failed pipe columns occur throughout the entire length of the tower, with about half of the failures occurring under columns supporting 66” or 60” pipes and the other half of the failures occurring under columns supporting 54” to 30” pipes, motors or fan gearboxes.

In Tower 4, the fiberglass bearing pads were replaced shortly after start-up by the cooling tower contractor with 304 stainless pads under the high load columns (3,000 lbs or higher). A total of 10 highly loaded 3” columns were found cracked where they rested on the fiberglass bearing pads. It is reported that none of the removed fiberglass bearing plates exhibited any damage or cracks. Three of the 18 ft high 3” columns were replaced, while seven other columns had 1” or 2” cut off the bottom and 304 stainless steel blocks installed under the columns.

A handful of failed fiberglass bearing pads were found during construction and replaced on the cross-flow tower Nos. 1 and 2. It was originally thought debris had been trapped under the bearing pad, or the pedestal surface was not smooth and caused a stress concentration. In hindsight, those bearing pad failures during construction were a warning as to what would happen after the towers were placed in-service.

Below is a summary of the probable failure mechanisms which caused the cracks in the fiberglass column bottoms.

- The shear capacity of fiberglass is 4,500 psi, so in order to maintain a 3 to 1 safety margin then the highest shear load should be 1,500 psi or less.
- The calculated applied compressive stress along the seating surface of a 4” x ¼” column (loaded to 13,043 lbs) and a 3-1/2” x ¼” column (loaded to 11,416 lbs) is 3,478 psi and 3,512 psi, respectively. When these compressive column stresses are applied perpendicular to the bearing pad, then the resulting shear stress greatly exceeds the design shear limit of 1,500 psi.
- Failed column and bearing pad assemblies indicate the column cut into the fiberglass bearing pad (like a cookie cutter), which then caused the bearing pad to become inserted into the column and impose an internal force which overstressed the corners (Reference Photo 4). The fiberglass/neoprene bearing pads have been replaced under the high load columns in all the towers with 304 stainless/neoprene bearing pads.

Towers 1, 2 and 3 have been inspected annually since they were installed and very few new cracked column bottoms have been identified after the stainless steel and neoprene bearing pads were installed.
It’s what’s inside that really matters.

Better components make better towers.

Since 1957, our primary business has been innovation!
We encourage inquiries for custom product solutions!

- PVC Coated Hanger Grids
- Stainless Steel Hanger Grids
- Gull Wing Splash Fill Slats
- V-Bar Splash Fill Slats
- Film Pack
- Drift Reduction Units
- Nozzles & Accessories

C. E. Shepherd Company, L.P.
2221 Canada Dry Street
Houston, TX 77023
Telephone: 713.924.4300
Fax: 713.928.2324
www.ceshepherd.com
sales@ceshepherd.com

Whether your project requires new construction or retrofit, standard products or custom solutions, Shepherd Tower Components are a perfect fit.
Installation Procedures Which Caused Failures

Over-Tightened Bolts Or Bolt Holes Not Lined Up

Several bolts on the stainless steel anchor clips were over tightened which drew in the bolted surface of the column (Photos 7 and 8). Cracks due to over tightening would occur on the interior surface and not be visible during construction inspections.

CTI Standard ESG-152 (2010), paragraph 2.3.2 currently states, “When bolting hollow members such as square tubes, a positive means shall be provided to prevent tube cracking or a means provided to ensure cracking does not exist with joint disassembly. If a crack is present, the member has failed and should be replaced.” This guideline states the Owner’s engineer is to decide if a minor crack (which is undefined) can be terminated (stop drilled) or if a repair is acceptable. Therefore, the burden is placed on the Owner’s
GENERATE

NEW ideas.

NEW connections.

NEW opportunities.

NEW resources.

SAVE THE DATE

APRIL 21-23, 2015

Donald E. Stephens Convention Center
ROSEMONT, ILLINOIS, USA

ELECTRIC POWER
CONFERENCE + EXHIBITION
Presented by POWER magazine
www.electricpowerexpo.com
engineer (not the cooling tower design company) to define what is acceptable, what “repairs” have proven effective or the risk of future failure.

If a bolt cannot be inserted through all the drilled bolt holes by hand, then construction personnel may pound the bolt through the holes versus threading it through. Bolts pounded through the bolt hole (from the back surface of the column) can fail the surface surrounding the bolt hole by tearing out a chunk (Photo 9). This would typically be covered over by a splice joint or horizontal girt, so it would only be caught by watching construction or randomly disassembling several joints.

Column Bottoms Not Cut Square

Tower No. 5 utilizes 5.2” x 3/8” thick vinyl ester columns on a 12 ft by 12 ft layout. The cooling tower company’s construction team used an 8” circular saw to cut the column bottoms to the proper length. However, the 8” diameter blade only cut 4” into the 5.2” column so the column bottom had to be cut from different sides which resulted in an uneven cut. The columns sat on stainless steel plates on the cold water basin floor.

Cracks started to occur on the column bottoms during the 3 month construction period. Figure 3 shows that approximately 178 of the 464 columns (38%) had to be modified at the bottom during construction and after a week of operation. The blue dots were cracked columns noted in Dec. 2011, and many of them had grout pads (green squares) or helper columns (black squares) installed before construction ended. The red dots are cracked columns found after the tower had been in operation for one week. The pink triangles represent cracked columns at the first girt elevation which is located 7-1/2 ft from the top of the cold water basin floor.

The cracked column bottoms were noted after the structure was assembled in the north half of the tower. The tower’s construction crew then started to apply epoxy under the cut column bottoms at the end of each day to provide a uniform bearing under the uneven cuts. A bead of sealant was used to act as a dam around the perimeter of the column bottom as the free flowing epoxy was injected into the interior of the column bottom. But in many cases the sealant was applied too close to the column (or pushed) under a portion of the column bottom’s perimeter cut edge. In the instances where the sealant was pushed under the column there was no epoxy to support the entire bearing area.
Right now while you’re at the CTI conference, Bedford has thousands of corrosion-resistant FRP profiles in stock, available immediately. You could place an order today, have it fabricated to your specs, and get it shipped faster than ever before. We’ve built up our inventory to deliver the industry’s shortest lead times — so you can deliver faster for your customers.

Call 800-377-3280 or visit bedfordreinforced.com/inventory.
The West Virginia University - Constructed Facilities Center (WVU-CFC) was contracted by AEP in 2012 to determine the failure mechanism of the cracked column bottoms. WVU-CFC gathered in-field data by load testing columns instrumented with strain gages, measuring column bearing area, infrared thermography analysis, digital tap hammering, and checking column plumb. WVU-CFC also conducted laboratory tests to verify material properties, compression testing to evaluate the effect of different bearing conditions and developed a Finite Element (FE) model of the 5.2” column cross section.

Six columns each had 16 strain gages installed from the column bottom up to the first girt elevation, and then the structure was lifted slightly at the first level girt to remove load on the column. This data showed the as-installed load of four columns was close to the design dead load value of 6,170 lbs. However two columns had lower loads which indicate uneven load distribution to surrounding columns. The average vertical strains collected during field testing correspond to a stress of 352 psi versus a theoretical stress of 852 psi for the design dead load. The horizontal strains measured during field testing averaged 70 psi. The design dead load of 6,170 lbs is roughly 25% of the maximum design operating load.

The amount of actual column bearing area was checked by removing the sealant around the bottom of 35 columns to determine if the epoxy had properly distributed under any uneven areas of the column bottoms. Sixteen of the 35 columns had nearly complete bearing (e.g. <15% missing bearing area), while 19 of the columns exhibited incomplete bearing (e.g. roughly 50% or more of missing bearing area as shown in Photo 10). The incomplete bearing fell into four categories which included C-shaped, diagonal, inner perimeter and undetermined as referenced in Figure 4.

A total of 36 columns were field inspected with an InfraCAM SD™ infrared camera and RD3 Digital Electronic Tap Hammer. This testing was done in February so a quartz space heater was used to warm the column bottom prior to capturing an infrared image of the FRP material with the infrared camera. The tests were conducted on 24 columns which exhibited no cracks, 1 column with the bottom caved-in, 6 columns with corner cracks less than 1”, and 5 columns with corner cracks greater than 6”. Only 1 column (crack > 6”) was conclusively noted to have an internal delamination, so these techniques may not be able to detect micro-level cracks or delaminations.

The manufacturer supplied material properties of the pultruded vinyl ester columns were verified via several tests including Differential Scanning Calorimetry (DSC), moisture content, fiber architecture based on burn out tests, 3 point bending of longitudinal coupons, 3 point bending of transverse coupons, and Izod impact test. All material properties were within the allowable limits as specified by the manufacturer or CTI. Laboratory evaluation revealed that surface cracks in the corners always occurred in resin-rich areas but not all resin-rich corner areas had cracks. The penetration of the surface cracks into the column cross section is unknown.

Compression tests were conducted on 1 ft high column sections, and the data showed that the ultimate load was significantly reduced with incomplete bearing area. Columns with a C-shaped or diagonal bearing areas failed at roughly 20% of the ultimate load capacity, while columns with an inner perimeter bearing area failed at approximately 31% of the ultimate load capacity. Testing of two column stubs (cut out from in-service columns including bearing plate and grout) behaved similarly in that they failed at 33% of the ultimate load capacity due to incomplete bearing areas.

The FE model validated the stress ranges collected from the laboratory and field testing along with theoretical calculations and showed good convergence. The C-shaped, diagonal and inner perimeter bearing conditions caused the axial stresses to increase up to 10 times higher than a fully supported column (Figure 5). The large increase in axial stresses is due to a combination of eccentric loading (due to poor bearing) and the 5.2” column size. The case of an inner perimeter support condition created the highest transverse stresses, increasing from near zero to a range of -5,564 psi to 2,071 psi. The transverse compressive stress of 5,564 psi exceeds the design value of 3,000 psi for compressive shear stress in CTI STD-137 (Fiberglass Pultruded Structural Products for Use In Cooling Towers).

The data collected by WVU-CFC in 2012 indicates the primary cause of column bottom cracking was due to poor bearing conditions created by uneven cuts and lack of grout under the columns. The lack of bearing led to the formation of stress concentrations at the corners during construction even when the structure was only experiencing dead loads of 25% of the maximum design operating loads. The stress concentrations eventually found a point of weakness in the resin-rich areas in the corners which then propagated through the column’s cross section.

AEP’s field inspection in Sept. 2013 found that only a few columns showed evidence of new cracks (< 1” long) at the column bottoms. The column bottoms will continue to be inspected annually.

**Installation Procedures Which May Cause Future Problems**

**Columns Installed Out of Plumb**

The WVU-CFC personnel field measured 50 columns in Tower No. 5 with a plumb bob in February 2012. The cooling tower contractor measured 436 columns for plumb in April 2012. AEP installed corner targets on 35 control columns in September 2013 at three elevations, and surveyed those columns from permanent monument pins surrounding the cold water basin.
Moore Sets The Standard In Axial Flow Fans.

Since 1940, Moore Fans has provided customers with high-efficiency, high-quality Axial Flow Fans for industrial applications worldwide. Operating in air-cooled heat exchangers, cooling towers, and radiators, Moore fans keep liquids cool in refineries, power plants, process plants, gas compressors and limitless other industrial settings.

**Special Design Features Of The Class 10000 Fan**

- **Resilient Blade Mounting** – For more than half a century, all Moore fan blades have been designed with a resilient blade mount, virtually eliminating all moment forces on the hub and shaft; improves durability; ideal under extreme operating conditions.
- **Chord Width** – Improve performance with fewer number blades for the same performance requirements, resulting in a lower overall cost.
- **Blade Angle Adjustment** – Blades are factory preset for specified performance conditions eliminating the need to set during field installation.
- **Adjustable Diameter** – Designed to permit fan diameter adjustment by as much as +1.5 inches (381 cm), greatly easing installation.
- **Ideal For Variable Speed** – With Moore’s resilient mount system, there are virtually no critical speeds to be avoided.
- **Available Blades** – Available in both odd and even number of blades, up to 16.
- **Ultra-Low Noise MAG Fan** – The Minimum Acoustic Geometry (MAG) fan is a low noise option to reach the most stringent noise objectives. Available in diameters of five feet thru 14 feet and in clockwise (RH) and counterclockwise (LH) rotation. The MAG is designed for both electric motor and engine driven applications.
- **Strengthened Design** – For engine drive and larger fan diameter applications from three to 24 feet.

Today, Moore Fans has some 175,000 fans in operation around the world. And with sales offices in North America and in Europe, Moore factory engineers and customer service representatives stand ready to help you analyze your air moving requirements; choose the right product, and provide reliable service and support, before and after the sale.

For more information on the Class 10000 Fans or any of the family of quality products from Moore Fans call 660-376-3575 or visit us online at moorefans.com.
The cooling tower contractor’s construction tolerance for column plumb is 3/16” over a 10 ft height but not to exceed 1”. The above 3 column plumb surveys did not directly correlate with each other, so it is unknown if the columns are moving or if the 2012 survey data is suspect. Based upon an overview of the 3 surveys, approximately 55% of the columns are within construction plumb tolerances, 30% are over the tolerance, and roughly 15% of the columns are out of plumb by more than twice the construction tolerance.

Approximately 20% of the column bottoms are anchored to the concrete cold water basin floor and there are a significant number of diagonal braces in the east-west and north-south directions. The cooling tower contractor provided no explanation regarding how so many columns were installed outside of their plumb tolerance, but from a structural perspective the large number of out of plumb columns is not expected to cause any long term problems.

AEP will survey the 35 control columns for out-of-plumb again in fall 2014 and see what changes occurred from AEP’s 2013 data.

**Surface Scratches From Transverse Bent Lift and Installation**

In many instances transverse bents are pre-assembled on the ground prior to the outage as shown in Photo 11. During construction of another mechanical draft tower (other than Towers 1, 2, 3 or 4 as previously described), the stainless bolts made deep scratches into the top surface of several columns (Photo 12) when the bent was lifted off the ground. Since these columns were lightly loaded it was agreed to field repair them by applying a surface epoxy with a mat layer.

**“Hanging Chads” From Unfinished Drilled Holes**

When bolt holes are shop drilled in fiberglass shapes, they are supposed to verify the hole is cleanly drilled. In some instances, the drill bit does not completely penetrate the entire cross section and a small piece of the veil on the bottom surface remains. If proper care is not exercised in the field to remove this “hanging chad” then a large area of surface veil could be removed or torn as shown in Photo 13.

**Contribution Of Pultrusion Process On Failures**

Folded reinforcement is inherent to the pultrusion process and has been observed in various degrees in products from all pultruders. Two distinct types of folded reinforcement in columns (or hollow tube shapes) include surface folds (Photo 14) and internal mat folds (Photo 15). If the surface folded reinforcement is not tightly folded on itself, then a large resin-rich pocket will occur on the surface which has a high risk for cracks.

Tests conducted by AEP and WVU-CFC show that folded reinforcement will reduce the material properties, but it is difficult to quantify because of the variations in location, shape and size of the folded reinforcement. The visual acceptance criteria for folded reinforcement has not been established by the pultrusion industry or ASTM. The 2013 revision of ASTM D4385 states that folded reinforcement does affect the strength of pultruded products, and
Giving you the ACTvantage you deserve!

ACF Series Induced Draft Counter Flow
- 86 single cell models ranging from 97 to 1043 nominal tons
- Over 250 multiple cell configurations
- CTI STD-201 certified
- ASHRAE 90.1 compliant
- Ideal for both new and replacement projects
- Flexible arrangements and configurations
- Wide range of options and accessories
- G-235 Galvanized steel construction
- Stainless steel 304, 316, or 316L options
- 5 Year mechanical / 1 year total product warranty
- Extended parts & labor warranties available

ACX Series Induced Draft Cross Flow
- 69 single cell models ranging from 102 to 1074 nominal tons
- Multiple cell configurations for any project size
- CTI STD-201 certified
- ASHRAE 90.1 compliant
- Integral drift eliminators and inlet louvers
- Wide range of options and accessories
- G-235 Galvanized construction
- Stainless steel 304, 316, 316L options
- 5 Year mechanical / 1 year total product warranty
- Extended parts & labor warranties available

American Cooling Tower, Inc. • 3130 W Harvard Street • Santa Ana, CA 92704
800-371-5959 • www.americancoolingtower.com
if folded reinforcement is of concern then the material properties have to be verified. AEP is currently limiting folded reinforcement of surface mats to no more than 20% of the cross section thickness on the face, while not placing a limit on folded reinforcement of internal mat layers.

Ice Build-Up Which Damaged/Failed Fiberglass Members

Tower No. 5 is a counter-flow structure consisting of many columns spaced on a 12 ft by 12 ft grid under the entire fill area along with 3 elevations of horizontal members connecting all the columns together (Reference Photo 2). When the tower was placed into service, a significant amount of water was dripping along the entire bottom perimeter of the fill area air seal wall and I-beams (Photo 16).

The first winter operating conditions for Tower No. 5 occurred in January 2013 when night time temperatures dropped to 10°F and day time temperatures were in the mid 20’s°F. Once the ambient temperature dropped below 32°F, ice started to develop on the perimeter horizontal members within hours and continued to develop and bridge between elevations and columns. The entire air inlet area was almost completely blocked off by ice after approximately 24 hours of winter conditions below 20°F (Photo 17). The plant undertook emergency actions of installing a submersible pump in the cold water basin (which had reached 100°F while the ambient temperature was in the 20°F’s) and spraying the warm water on the ice at the lower elevations. This established windows at the lower elevations which allowed ambient air to enter the tower and cool the circulating water temperature. The plant also raised and lowered the basin water level to melt ice at the water line and allow ambient air to enter the tower.

A total of 7 columns, 23 horizontal 5.2” tubes, and 77 horizontal 6” channels were damaged and replaced under warranty in Sept. 2013. The damage included localized bolts being pulled out (or plowed through) the ends of perimeter members (Photos 18 and 20), impact damage (Photo 19), and corner cracks on perimeter columns at the
A Complete Power Transmission Package to Keep You Cool.

Solutions for the Cooling Tower Industry

Cooling towers are one of the harshest environments for power transmission equipment. Moisture, chemicals, and minerals attack the equipment driving cooling tower fans, making durability, corrosion resistance and superior customer service a priority.

That's why customers choose Addax® Composite Couplings and Falk® Renew® Prager® repair and asset management services.

- Lower total cost of ownership — properly maintained, the cost-effective Addax Composite Coupling can last the life of the cooling tower, while its lower weight results in less wear on other system components
- Professional on-site inspection, evaluation, service and repair or replacement of gear drives, couplings and bearings
- Same-day, emergency delivery of gear drives and couplings for many applications are available to maximize your uptime
first girt elevation (Photos 20 and 21) from ice overloading the columns or ice impact on connecting horizontal members.

During an outage in September 2013, the cooling tower company installed a modification above the fill area along the entire perimeter which almost eliminated all water drips along the bottom fill area structure and seal wall. Winter operating conditions in December 2013 (when ambient temperatures ranged from 32°F to 10°F over a 2 day period) resulted in ice build-up as shown in Photo 22. So the modifications provided a dramatic improvement from January 2013 and appears to let the tower self-regulate itself regarding ice formation and build-up.

Surface Blisters

Surface blisters were found on cross-flow towers No. 1 and 2 after 18 months of operation. Approximately 20% of the columns in the cross-flow tower No. 2 had dime-size surface blisters which were usually on one face and linear as shown in Photo 23. Roughly 15% of the columns in the cross-flow tower No. 1 had pea-size surface blisters which were on multiple faces and located randomly. These blisters are located throughout the entire length of the towers and from the submerged cold water basin up to the fan deck. Almost all of the pipe saddle side plates (3/4" thick pultruded fiberglass) exhibited thumb-size surface blisters along the submerged area of the hot water deck as shown in Photo 24.

The make-up water sources for the cross-flow towers Nos. 1, 2 and 3 are a fresh water lake or river. AEP feeds 93% concentrated sulfuric acid continuously into the make-up water to control pH, and shock feeds 12.5% concentrated bleach hypochlorite once or twice daily (up to 50 minutes per event) to control biological growth. A PPA (polyacrylic acid) product or a HEDP (1-hydroxyethylidene-1, 1-diphosphonic acid) product is fed continuously to act as a dispersant (1 ppm) and scale inhibitor (5 ppm) year round. A non-oxidizing
Clean it Up and Keep it Clean!

BCP™ products provide organic deposit cleaning by penetrating and dispersing surface foulants in industrial cooling water systems. Applied with biocides, BCP™ products provide a highly effective Biofilm Control Program (BCP™), yielding improvements in biofilm, corrosion and scale control.

AMSA’s BCP™ Product Line

- BCP™ 1000 Classic DTEA II™
- BCP™ 2000 New Biofilm Control Program Products
- BCP™ 3000 New and Classic DTEA II™ Solid Products
- BCP™ 4000 All-in-One Formulations*
- BCP™ 5000 Specialty Products – Geothermal

*Please call us for more details

Before BCP™ 2000  After BCP™ 2000

Before BCP™ 2000  After BCP™ 2000

“
A Biofilm Control Program (BCP), based on the well-reputed DTEA II™ chemistry, results in a clean industrial water system."

Call Us Today!
To get the protection you need!
888 739-0377
A biocide (4% terbuthylazine) is dumped into the basin several times each week (in 5 gallon doses) at tower No. 2 during the summer months to control algae.

The blisters on a 3-1/2” column under the fan in Cell 8 of the cross-flow tower No. 2 were photographed in Nov. 2009 (Photo 23) and March 2010, and the photos show that the number of blisters increased over that 4 month period.

AEP conducted a warm bath immersion test from summer 2011 to December 2011 on different polyester fiberglass shapes from several pultruders. The edges of all pieces were sealed with a polyurethane sealant, while the bolt holes were left as-is. The parameters of the immersion test was a water bath generally maintained between 117°F to 130°F, chlorine levels of 5 ppm, and 8 to 9 pH. All the pultruded shapes were inspected after roughly 6 months, and blisters were found on flat plates and a column from first article samples from Towers 2 and 3. No definitive conclusions have been reached on the blister situation or whether the blisters will affect the long term structural integrity of the pultrusions.

At several AEP plants, we have found that the pH within a unit’s circulating water system can vary by up to 0.43 pH because of aeration and/or thorough mixing of the chemicals in the circulating water system. The circulating water pH range was determined by simultaneous measurements at the condenser, tower’s hot water distribution basin, and tower’s cold water basin. The pH monitor is typically located near the condenser which may be the low pH point in the circulating water system. As a result, the typical pH range of a unit’s circulating water system should be measured (e.g. at the condenser, hot water distribution basin and cold water basin). Then the alarm point of the pH measuring location can be properly set to keep the entire circulating water system below 9 pH which is the upper limit for polyester fiberglass components.

**Aep Lessons Learned**

Below is AEP’s current design philosophy for new fiberglass structure cooling towers based upon the above pultruded fiberglass structural failures, surface blisters, testing and recent lessons learned on the twelve new fiberglass cooling towers,

New fiberglass towers shall comply with CTI STD-137 “Fiberglass Pultruded Structural Products for Use in Cooling Towers”, and CTI ESG-152 “Structural Design of FRP Components”. All exceptions to these standards must be detailed in writing at the time of bid.

Minimum design stresses, water immersion correction factor and temperature correction factor, etc. are to comply with CTI STD-137. The structure’s design basis is to incorporate the cooling tower contractor’s published construction tolerances (i.e. column plumbness, cut end squareness, cross-sectional thickness, enlarged bolt holes, drilling tolerances, etc.). As a result, the reduction of a structural member’s load carrying capacity due to the contractor’s published construction tolerances shall not be covered by (or included in) the CTI service factors.

Any visually cracked structural member shall be replaced (at the expense of the cooling tower contractor) during construction and throughout the entire length of the warranty period. Any closed structural members (columns) which exhibit the surfaces being drawn together because of over tightened bolts shall be replaced (at the expense of the cooling tower contractor) even if no visual cracks are on the external surface. Contractor shall provide construction details to preclude over-tightening of bolts (e.g. use of torque wrenches, helical washers, lock nuts, etc.).

Fiberglass bearing pads are unacceptable. All columns are to have full bearing contact to the cold water basin (with no gaps between the column and concrete) prior to tower completion. If epoxy needs to be applied under column bottoms to obtain full bearing, then a “sealant dam” should be placed away from the column base to ensure the grout is able to seep out and support the entire column base. All column splice joints are to have full bearing contact between column ends.
Your stainless-steel fastener source.

- **20”-22” Plastic Strip Full Round Head, Screw-Shank Nails**
  - Type 304 and 316 stainless steel

- **Truss-Head Screws**
  - Type 303 stainless steel

- **Self-Drilling Hex-Washer Head Screw**
  - Type 303 and 316 stainless steel with EPDM sealing washer

- **Common Annular-Ring-Shank Nails**
  - Type 304 and 316 stainless steel

- **Spiral-Shank Nails**
  - Type 304 and 316 stainless steel with EPDM sealing washer

- **Self-Drilling Hex-Washer Head Screws**
  - Type 305 and 316 stainless steel

- **Ring-Shank Nails**
  - Type 304 and 316 stainless steel with EPDM sealing washer

- **Common Spiral-Shank Nails**
  - Type 304 stainless steel

- **Bugle-Head Wood Screws**
  - Type 305 and 316 stainless steel

- **Hog Rings**
  - Type 304 stainless steel

- **Fencing Staples**
  - Type 304 stainless steel

- **EPDM Sealing Washers**
  - Type 304 and 316 stainless steel

---

Simpson Strong-Tie is your source for fasteners for building and repairing cooling towers. Our wide selection of stainless-steel bulk and collated nails, screw/nail washer assemblies, and self-drilling screws are easy to install and provide superior results in wood, fiberglass and corrosive environments. Fasteners are available in 304, 305 and 316 stainless steel.

To learn more about the entire line of Simpson Strong-Tie® fasteners for cooling tower construction and repair, call (800) 999-5099 or visit [strongtie.com/fasten](http://strongtie.com/fasten).
The cooling tower company is responsible to provide all shop and field quality control and quality assurance requirements on all material, and set aside material not meeting this specification. Owner’s engineer will spot audit the material and reject all material not meeting this specification (even if it has been installed). The following visual acceptance criteria will be used during construction and the entire warranty period. The visual acceptance criteria for all fiberglass pultruded products shall comply with the latest version of ASTM D-4385 which was issued in December 2013, except for the columns which will have stricter requirements as noted below:

- Presence of any defects in excess of the following definitions shall be cause for rejection. Repairs will not be considered for these defects.
- Blister – Blisters are not allowed.
- Folded reinforcement – Folded near-surface reinforcement is not permitted along the straight edges if it exceeds 20% of the cross sectional thickness. Folded near-surface reinforcement is not permitted at the corners if it exceeds 25% of the cross section thickness.
- Insufficient cure – Insufficient cure is not acceptable.
- Internal shrinkage cracks – No more than two (2) internal shrinkage cracks on each face of a cut end. All internal shrinkage cracks are defined as oriented perpendicular to the internal ply or reinforcement. If an internal shrinkage crack penetrates any internal ply or reinforcement, then it is defined as a crack and the piece is rejected. Any cracks oriented parallel to the internal ply or reinforcement will be defined as a delamination and rejected.
- Resin-rich areas – Accept if material reduction thickness is not over 10% and the area width is 1/8” or less. May be continuous in length, but not more than one area on a face. Resin-rich areas on opposing surfaces are not permitted. Must satisfy dimensional requirements.
- Sluffing - Acceptable if material thickness reduction is not less than 0.85 of nominal wall thickness on columns. That is, material is rejected if wall thickness is less than 0.212” for ¼” material or less than 0.319” for 3/8” material. Sluffing is characterized by a depressed area with scales.

The stated thickness of the pultruded shapes shall not deviate by more than 10% of the nominal thickness.

All holes are to be drilled and shall not exhibit “splinters” or “gouges” on the backside. No punched holes are acceptable.

Conclusions
The cooling tower contractors have been responsive in performing warranty repairs to these cooling towers, and we are continuing to work with the cooling tower contractors to identify all of the failure mechanisms.

There are no current national standards which completely cover the design, fabrication and construction of fiberglass cooling towers. The individual owner/buyer needs to become extremely knowledgeable about pultruded fiberglass before the specification is submitted for bidding so the final product is acceptable to the owner for a 30 year operating life. AEP has offered several clarifications in this paper in relation to current CTI Standards with the expectation that a better pultruded product can be specified, provided and constructed.

It appears that all the failure mechanisms for pultruded products are not completely understood, and the pultruders, cooling tower contractors and tower owners will need to work together to prevent design and installation errors.

Acknowledgements
M. Durner (AEP Director of Mechanical Engineering)
J. Horvath (AEP Plant System Owner)
D. Lee (AEP Region Engineer)
F. Michell (AEP AE&BOPME Section Manager)
A. Moore (AEP Engineer)
J. Newell (AEP Plant Senior Specialist)
D. Rathburn (AEP Engineering Production Superintendent)
B. Robinson (AEP Process Supervisor)
R. Snyder (AEP Structural Section Manager)
U. Halabe (WVU Professor)
R. Liang (WVU Research Assistant Professor)

Appendices

Figure 1 – Transverse Cross Section of Cross-Flow Towers 1 & 3 with 3-1/2” Pipe Column on Elevated Concrete Pier (circled in red).
Figure 2 – Transverse Cross Section of Cross-Flow Tower 2 with 4” & 3-1/2” Pipe Columns on Cold Water Basin Floor
Figure 3 – Summary of Cracked Column Bottoms in Tower No. 5

- Cracked column bottom noted 12/19/11
- Cracked column bottom noted 2/22/12
- Helper columns instaled with cracks of > 3" remaining
- Grout pads installed to remove cracks < 3" at bottom
- Cracked columns at 1st girt elevation

Figure 4 – C-shaped, diagonal and inner perimeter bearing areas (from left to right)

Figure 5 – FE Model with eccentric loading on 5.2" column causing high compressive stresses (in blue)
Innovative Tandem Blade For High Efficency Colling Fans

Carlo Gallina
COFIMCO Srl, Via Gramsci 62, Pombia, ITALY

SUMMARY
Nowadays, the main goal of all modern heat exchangers is to increase performance and reduce costs. In typical applications such as Cooling Towers, Air Cooled Condensers and Process Air Coolers, axial fans play a key role in achieving these targets. As an example, recent Directive 2009/125/EC has defined a list of minimum efficiency requirements for each fan type. As a consequence, the improvement of fan efficiency and corresponding reduction in power consumption become the most important parameters in new airfoil development and solutions that can satisfy these requirements.

Extensive research, the application of aerodynamic concepts to fan blades through Computational Fluid Dynamic analysis (CFD simulation) and laboratory tests have resulted in the development of a new innovative design: the Tandem Blade.

Scope of the present study is to examine aerodynamic concepts which determine fan blade efficiency and then show how a new design can lead to improved fan performance by increasing lift and reducing vortexes generated by the blade.

AERODYNAMIC BASIS AND FAN BLADE EFFICIENCY DEFINITION
Axial fans are used in applications like heat exchangers where a high air volume is required to cool a fluid (water or oil) or steam. Typical applications are Cooling Towers, Air Cooled Condensers and Process Air Coolers.

In detail, the aim of a fan is to generate air flow through obstacles present in the heat exchangers (i.e. fin tubes, grids). In order to overcome the resistance given by the obstacles, the fan has to produce a static pressure. From an aerodynamic point of view, it means that a lift has to be produced, similar to airplane wings. As the wings, the blades of axial fans produce vortexes which are a necessary condition to have a lift in air.

Computational Fluid Dynamic analysis (CFD simulation) allows to look in more detail at the air speed around the airfoil (Figure 2.1).

From this picture it is possible to notice that the air speed on top of the blade section is higher than the speed on the bottom as per the different colors representing the air flow lines.

According to the Bernoulli Principle, the static pressures are different on top and bottom of the airfoil having different air speeds. Consequently, there is an aerodynamic force having 2 components: (1) drag, in the same direction to flow and (2) lift, in the transverse direction. This mechanism is shown in Figure 2.2 by CFD analysis.

Drag is basically determined by the shearing of air into two layers at the trailing edge and by the resulting generation of vortexes.

Hence, it is possible to state that the amount and dimension of these vortexes determine the fan blade efficiency and as a consequence, the blade drag and fan power absorption.

The lift generated by the blades determines the air volume provided by the fan, directed on the opposite side. Lift is a function of the angle between the airfoil’s reference line (chord line of an airfoil) and the oncoming flow (called angle of attack). Therefore, lift increases with the angle of attack.

However, beyond a certain point, the lift begins to suddenly decrease. This point is called the critical or stall angle of attack and the airfoil working condition is called stall. Above the stalling angle of attack, the flow lines “separate” from the airfoil and large vortexes and turbulence are generated.

The blade working conditions for a progressive increase in the angle of attack are shown in terms of air speed vectors in Figure 2.3.
At HUDSON, we understand there is more to the design and production of fan blades than patented technology. We understand that there is more than establishing the highest standards in a manufacturing process, and we understand that there is more than providing the highest quality products and services to our clients – we understand that Hudson has a history.

A history developed over many years of producing the finest fan blades in the industry. We once again raise the standard with the introduction of the latest member of our famous Tuf-Lite® lineage.

With a history of fan blade production since 1955, Hudson continues to push the limits of axial flow fan technology.

For more information on this or any other product, please contact:

HUDSON PRODUCTS CORPORATION
9660 Grunwald Road, Beaasley, Texas 77417-8600
Phone: (281) 396-8300
Fax: (281) 396-8388
1-800-634-9160 (24 Hours)
E-Mail: hudsonproducts@hudsonproducts.com

HUDSON Products Corporation
A Subsidiary of Hudson Products Holdings, Inc.

www.hudsonproducts.com
In fan applications, it means the air volume provided by fan blades noticeably decreases for angles of attack higher than the stalling point.

In aerodynamics, the application of a slotted airfoil has the scope of delaying airflow separation from the airfoil surface so that the stalling angle of attack is increased. Simultaneously, vortexes at the trailing edge are reduced.

Delay of airflow separation follows the Bernoulli Principle. The flow speed around the airfoil in correspondence to the slot is very high and a local low pressure area is generated as shown in Figure 2.4. As a consequence, the airflow on the top side of the “1st airfoil portion” is sucked by the low pressure area (slot) and drawn on the bottom side of the “2nd airfoil portion”. Simultaneously, the air flow trying to separate from the bottom of the “1st airfoil portion” is also sucked and reattached to the bottom of the “2nd airfoil portion”.

Figures 2.5 and 2.6 show the results of Computational Fluid Dynamic analysis in terms of air speed and pressure.

Therefore, the application of a slotted airfoil leads to an increase of the stalling angle of attack. In addition, the lift for the same angle of attack improves.

A general relation between Lift Coefficient (CL) and the angle of attack is shown in Figure 2.7 for a traditional and slotted airfoil. Being the Lift Coefficient is proportional to lift, the above mentioned increase in stalling angle of attack and lift is evident.
Vortex reduction is evident comparing the path of air speed vectors at the trailing edge of slotted airfoils (Figure 2.8) with traditional ones (Figures 2.9).

In fan applications, the use of slotted airfoils means that the required air volume can be provided with smaller or fewer blades because the lift generated for the same angle of attack is higher than traditional airfoils and blades can be set at higher angles of attack. Simultaneously, the reduction of vortexes at the trailing edge result in higher blade efficiency and as consequence, lower drag and fan power absorption. These features provide a strong technical basis that can be used to improve fan performances and reduce costs. In addition, considering the high stalling angle of attacks for slotted airfoils, fan blades can provide the required air volume at very low speeds, generating lower noise as a consequence.

**TANDEM BLADE FEATURE**

Based on the additional values slotted airfoils provide in terms of higher aerodynamic efficiency and stalling angles of attack over traditional airfoils, the innovative Tandem Blade has been developed for axial fan applications.

By means of Computational Fluid Dynamic analysis (CFD simulations) and wind tunnel tests of scaled prototypes, the optimal airfoil combination and setting have been identified. Final aerodynamic profile produced in extruded Aluminum alloy has been designed to guarantee an elevated resistance to the fatigue stress introduced by fan working conditions.

The resulting Tandem Blade shown in Figure 3.2 is the combination of 2 airfoils held together with special tip and root caps. The shape and size of all blade components have been determined by means of FEM analysis along with extensive laboratory tests (Figure 3.3) to reflect the highest loads which might act on the blades while also taking in account the influence of temperature, humidity and aging.

Both tip and root caps are assembled to the airfoil by means of structural rivets. Considering the profiles are produced in extruded Aluminum alloy, the first airfoil (larger section) is fixed by means of bolts to a blade shaft which allow for a secure blade to hub connection.

**TANDEM BLADE PERFORMANCE**

Performance of fans equipped with Tandem Blades tested on a 14ft test rig show the following improvements compared to traditional
Delivering
“Objectivity & Reliability on Quality”
For Value With Trust!

India’s No.1 FRP Cooling Tower, with over 18,000 Satisfied Customers

3 Decades of Excellence!

CTI
CERTIFIED

Save up to 10% on electricity bills for Chillers

India’s First Cooling Tower with CTI (USA) certification for ‘A-SERIES’ Towers.

15000TR (Hyderabad) 4000TR (Gurgaon) 3000TR (Bangalore Airport)

Upto 1500 TR available in single / multiple cell.

Introducing 100% non-corrosive, pultruded fibreglass structure.

Conforms to the standards & specifications for Green Buildings.

Advance GRP Cooling Towers Pvt. Ltd.
405, ‘Span Centre’, R.K. Mission Marg, Santacruz (W), Mumbai - 400054. INDIA
Tel: 2600 1067 Fax: 2600 0303. E-mail: sales@advance2020.com
Branch Offices: • Bangalore: 09900521598 • Delhi: 09953658971 • Chennai: 09445155645

www.frpcoolingtowers.com
Tandem Blades can provide the same air volume as larger traditional blades (15-20 % larger) at the same angle of attack.

Total and Static efficiencies increase due to the corresponding lower fan solidity and vortexes reduction at the trailing edge.

Fan speed can be reduced to 20 m/s tip speed resulting in a reduction in noise.

In following Figure 4.2, the performance measured on a 14ft fan equipped with 8 Tandem Blades are compared to same sized traditional blades at the same speed (Figure 4.1).

By reducing the Tandem Blade size in order to superimpose the fan operating curves of the two 14ft fans in object, their efficiencies can be directly compared for each pitch angle as shown in Figure 4.3.

Depending on the fan operating point, an increase of up to 25% in the fan total efficiency is measured comparing data from Tandem Blades to traditional blades. The above stands for a corresponding saving in fan power absorption.

As an additional value, Tandem Blades can perform at 20 m/s tip speed without stalling. Traditional fan performance generally becomes unpredictable at lower tip speeds.

According to the below general law, the blade tip speed influences the PWL:

\[ PWL = const + 10 \cdot \log (P_s \cdot V \cdot \rho) + 30 \cdot \log (V_{tip}) - 5 \cdot \log(\phi) \]

Where:
- \( P_s \) = fan static pressure
- \( V \) = Air Volume
- \( \rho \) = air density
- \( V_{tip} \) = tip speed
- \( \phi \) = fan diameter

Tandem Blades can provide the required airflow at lower tip speed, generating lower noise as a consequence.

**CONCLUSIONS**

The theoretical and practical analysis show an increase in performance and efficiency when using Tandem Blades on axial fans. Thanks to the lower vortexes generated at the trailing edge, a reduction in fan power absorption is realized compared to traditional airfoils.

The higher lift provided by slotted airfoils allows to reduce blade dimension keeping the same air flow. Finally, the higher stalling angle of attack allows the fan to operate as slow as 20 m/s, which produces a reduction in noise.

In conclusion, the new Tandem Blade design represents a great innovation in improving axial fan performance and as a consequence, increased cooling efficiency.
Model **ST**: Prevailing wind directions will not affect cooling performance due to the unique circular design on the cooling tower. Lightweight and compact to eliminate heavy support and space requirement. Finally, a cooling tower provides quick and easy installation.

Model **LRC-H**: A crossflow cooling tower features lighter operational weights and reduces space requirements. Future expansion is achievable with adaptation to the existing towers. Multi-cells designed to accommodate seasonal cooling needs.

Model **LHC**: A crossflow cooling tower specifically designed to serve industrial application which demands dependability and durability of the towers.

Contact information: www.amcot.com

Amcot Cooling Tower Corporation 350 N. Ponderosa Avenue, Ontario, California 91761
Phone (909) 390-2598 Toll Free (800) 444-8693 Fax (909) 390-1098 Email amcot@aol.com
Comparison Of Chlorination Monitoring Methods In Cooling Water Systems

Trey Cook and Michael Dorsey, Dupont
Matt Walker, Design Controls

Abstract
Free chlorine residual is one of the most difficult chemistry parameters to control in a cooling water system. There are various technologies available for measurement, each with advantages and disadvantages. This paper compares the application of oxidation-reduction potential and potentiostatic free chlorine instruments for monitoring and control of free chlorine in industrial cooling water systems.

Introduction
Free chlorine residual is one of the most difficult chemistry parameters to control in a cooling water system. This is primarily because chlorine biocides are strong oxidants and are continuously being consumed unlike other water treatment chemicals. Sunlight, organic molecules, and other water treatment chemicals all react with chlorine depleting the residual.

Maintaining a free chlorine residual in a cooling water system controls microbiological growth. Without some type of biocide, cooling water systems would quickly foul with biofilm. This growth can reduce cooling tower efficiency due to plugged fill and can impede heat transfer in heat exchangers throughout the system. Biocide feed is also important because the warm and oxygenated water in cooling towers is an excellent environment for Legionella bacteria, which can cause Legionnaires’ disease.

It is important to maintain good control of chlorine feed to maintain system reliability. Underfeeding will result in excessive microbiological growth while overfeeding will cause increased corrosion rates. Overfeeding can also oxidize and, therefore, reduce the effectiveness of other treatment chemicals like scale inhibitors. A good chlorine treatment program will maintain just enough free chlorine residual to control microbiological growth but not so much that it affects the rest of the treatment program.

Usually chlorine demand in a system changes constantly throughout the day due to changes in temperature, sunlight, microbiological activity, and organic loading. This makes it very difficult to maintain the target free chlorine residual without automation. Fortunately, there are various technologies available to both monitor free chlorine residual continuously and automate chlorine feed. This document seeks to compare two of these technologies and their application in two industrial cooling tower systems. The methods compared are oxidation-reduction potential (ORP) monitoring and potentiostatic free chlorine monitoring.

Background
Free chlorine and total chlorine residual are both measures of the concentration of chlorine biocides in water. When chlorine is added to water, it forms hypochlorous acid (HOCI) and hypochlorite ion (OCl-). This form is called free chlorine because it is unreacted and has a strong oxidizing potential. As free chlorine reacts with ammonia and nitrogen containing organics in the water, they form chloramines. These molecules are called combined chlorine and still have some oxidizing power but substantially less than free chlorine. Total chlorine is the sum of the free chlorine and the combined chlorine concentrations.

N, N-diethyl-p-phenylenediamine (DPD) Method
DPD is a reagent that is oxidized by chlorine to form a compound known as Würster dye which creates a magenta color. The DPD Würster dye color can be measured photometrically at wavelengths ranging from 490 to 555 nanometers (nm). The DPD test is one of the most commonly used methods to manually measure concentrations of both free and total chlorine in cooling water systems. The DPD method is economical, quick and relatively repeatable however there are potential interferences and the results can be significantly affected by operator technique. Another issue is that the free chlorine measurement can be affected by high combined chlorine levels. This effect is called monochloramine breakthrough. The DPD free chlorine measurement relies on free chlorine reacting faster than monochloramine which is part of the combined chlorine. If enough time elapses, the combined chlorine will react and increase the measured free chlorine residual.

Oxidation Reduction Potential (ORP) Method
ORP is probably the most used method for automating chlorine feed to cooling water systems. Free chlorine is a very strong oxidant and can be measured very easily using an ORP sensor. ORP sensors generate a small voltage that is a direct measurement of the oxidation potential of the water. As chlorine is increased the oxida-
Your tower represents a **HUGE** investment...

Isn’t it worth investing a small amount to keep it “in the Pink” by preservative spraying the wood structure?

**PREVENTION IS ALWAYS THE RIGHT SOLUTION!!!**

*Decay Prevention & Slime Control with PROVEN RESULTS*

**Nationwide Since 1964**

*Also Featuring:*
- Fill Cleaning
- Fan Deck UV
- Protective Coating
- Dry Mothballing
- Wood Analysis
- Structural Inspections
- Spray-In Basin Linings

**Spraying Technician applying red dye colored preservative.**

**COOLING TOWER SOLUTIONS by Spraying Services, Inc.**

Phone: 713.941.1944 • Fax: 713.941.2545

www.sprayingervices.com
tion potential of the solution increases and therefore the generated voltage from the ORP sensor increases. ORP sensors are generally rugged, reliable, and relatively inexpensive. The problem with ORP occurs when trying to correlate ORP measurement to free chlorine residual. Due to the many factors that affect ORP, the comparisons are rarely repeatable. The largest problem with controlling free chlorine residual with ORP is that the relationship between ORP voltage and free chlorine is non-linear and is significantly affected by pH.

**Figure 2: ORP versus free chlorine residual and pH**

**Potentiostatic Method**

The potentiostatic free chlorine probe used in this paper consists of two platinum electrodes and a reference electrode and requires a constant sample flow rate. Free chlorine reacts at the electrode and the amount of current generated by the reaction is proportional to the free chlorine residual in the water. The measuring cell is controlled by a potentiostat integrated into the measuring amplifier. An exactly defined potential of the working electrode is retained by means of the third electrode (reference electrode). This results in a linear response for the measuring cell as well as a stable zero point for the measurement.

**Method**

To compare these three methods of testing for halogen, the team equipped two cooling towers in southeast Texas chemical plants with monitoring instruments. An ORP probe and a potentiostatic free chlorine probe were both placed in a flow cell to measure the cooling tower return water. Both probes were alternately connected to a controller to automate chlorine feed.

Data loggers were used to record measurements from the ORP meter and the potentiostatic free chlorine meter overtime. Manual measurements were also taken several times to compare the different chlorine measurement methods. Manual readings were taken using a conventional DPD free chlorine test kit and an amperometric test kit. The amperometric test kit is a proprietary electrochemical test which gives both free chlorine and total chlorine residuals readings in one test. It is US Environmental Protection Agency approved for chlorine measurement.

**System 1 = Chemical Plant 1 along the Texas Gulf Coast**

This system is a medium size 2 cell cooling tower with a 15,000 gpm recirculation rate in a Texas Gulf Coast chemical plant. It uses a combination of 10% sodium hypochlorite (NaOCl) bleach and 20% sodium bromide (NaBr) for disinfection. The two chemicals are fed into a carrier water dilution stream at a 20:1 NaOCl to NaBr ratio. This solution is injected into the back of the cooling tower basin opposite the suction pumps. An on/off controller was used for chlorine control on this system.

**System 2 = Chemical Plant 2 along the Texas Gulf Coast**

This system is a large 5 cell cooling tower with a 60,000 gpm recirculation rate in a Texas Gulf Coast chemical plant. It uses a basic chemical feed program consisting of NaOCl bleach for microbiological control, sulfuric acid for pH control and a corrosion inhibitor for corrosion control. A dispersant and a defoamer are also used periodically. A PID controller was used for chlorine control on this system.

**Results and Discussion**

**Potentiostatic Free Chlorine Probe Automatic Control**

The free chlorine residual was tightly controlled in system 1 while using the potentiostatic free chlorine probe for automatic control at a 0.4 ppm setpoint. Interestingly, the ORP oscillated by approximately 25 mV over time (Figure 3). A clear correlation can be seen when ORP is compared to a temperature measurement inside the instrument box (Figure 4). Note that water temperature was relatively constant. Because the instrument box is outside, the authors suspect that the correlation is actually with outside air temperature and/or time of day.

On system 2, the free chlorine was controlled at set point effectively using the potentiostatic free chlorine probe for automatic control. Similarly to system 1, the ORP oscillated by approximately 50 mV throughout the day (Figure 5). The authors observed that the ORP reading would consistently be highest in the late afternoon to early morning hours and lower during the day. The authors suspect that the background ORP potential of the water changes throughout the day, thus, influencing the relationship between free chlorine residual and ORP.

Over time, the free chlorine reaction occurring at the electrode caused the potentiostatic free chlorine probe electrode to discolor. This process lowered the measured free chlorine residual and required the probe to be cleaned and recalibrated. The rate of discoloring depends on the water, but the probe in system 1 lasted 2 to 4 weeks between cleanings/calibrations.

**Figure 3: System 1 under automatic on/off control using a potentiostatic free chlorine probe (setpoint of 0.4).**
COOLING TOWER

PROTECTION

No Special Training Needed
Easy To Apply By Hand
Non-Toxic & No VOC’s

Wet/dry cycles and constant temperature changes create cooling tower horror stories of corrosion. Now there’s a safe, simple solution. Denso Tape Systems provide protection for piping, conduit, electrical boxes, hangers, valves, flanges, and sprinkler systems.

FOR MORE INFORMATION
CALL: 281-821-3355
FAX: 281-821-0304
E-MAIL: INFO@DENSONA.COM

www.densona.com
Figure 4: Same system and timeframe as Figure 3.

Figure 5: System 2 under automatic PID control using a potentiostatic free chlorine probe.

**ORP Probe Automatic Control**

In system 1, variation in free chlorine residual was higher when controlling with ORP than when controlling with the free chlorine probe (Figure 6). Free chlorine was out of the desired 0.2 to 0.5 ppm range frequently and appeared to shift after a period of being relatively steady.

The PID controller on system 2 allowed for tighter control of ORP than on system 1. Variation appeared to be smaller, but similarly to system 1, the free chlorine residual would remain steady for a period and then shift significantly (Figure 7). Also, note that the free chlorine spikes visible on the first 6 days occur at approximately 3 PM each day. This further suggests that the relationship between free chlorine and ORP changes cyclically day to day.

Figure 6: System 1 under automatic on/off control using ORP probe (set point of 385 mV).

Figure 7: System 2 under automatic PID control using ORP probe.

**Manual Measurements**

Manual measurements of free chlorine using the DPD test kit and free and total chlorine using the amperometric test kit were taken on system 1. During the first measurement period, the DPD free chlorine measurement was significantly higher than both the potentiostatic free chlorine probe and the amperometric free chlorine measurements (Figure 8). The authors took manual measurements again on a different day and observed that the DPD free chlorine readings were much closer to the amperometric free chlorine measurements (Figure 9). The total chlorine residual during the first measurement period was much higher than on the second measurement period. The authors suspect that the high total chlorine residual caused monochloramine breakthrough on the DPD test, which elevated the free chlorine measurement on the first day. Only measuring DPD free chlorine would have suggested that the free chlorine probe needed calibration.

Figure 8: System 1 manual chlorine measurements period 1.

Figure 9: System 1 manual chlorine measurements period 2.
The NEW Walchem W600 Series Controller gives you complete control of chemical metering pumps and valves in a broad range of water treatment applications. With easy, icon-based programming on the large touchscreen display, the W600 can be configured to control up to six complex functions. The universal sensor input permits exceptional flexibility to utilize almost any type of sensor including pH/ORP, conductivity, disinfection, fluorescence and flow meter input. Internet connectivity option lets you maintain control via remote access.

Take control today and connect with the best!
Conclusion

Controlling chlorination with the ORP probe or the potentiostatic free chlorine probe both showed a daily cycle in the relationship between ORP and free chlorine. Even though water temperature and pH remained relatively constant, the ORP would swing by as much as 50 mV over a 24 hour period correlating well with the ambient air temperature. This suggests that the background ORP level of the water cycles up and down day to day. This may help explain some of the difficulty in correlating ORP with free chlorine.

The significant difference between the DPD and amperometric free chlorine measurements observed demonstrates the difficulty of measuring chlorine. The authors suspect that the total chlorine was high enough to cause monochloramine breakthrough in the DPD test during the first measurement period but not high enough in the second period. This could cause inaccuracy when controlling free chlorine using the DPD test and total chlorine is high enough to cause monochloramine breakthrough. As demonstrated in system 1, the total chlorine can change significantly in one system and can be high enough to affect the DPD free chlorine test. Most system operators only perform a DPD free chlorine test to monitor and control chlorination, which may be hiding inaccuracies caused by high total chlorine levels.

Overall, acceptable control was possible with both the ORP probe and potentiostatic free chlorine probe. Controlling with the ORP probe required regular changes to the setpoint as the relationship to free chlorine residual changed. The potentiostatic free chlorine probe required regular cleaning and calibration. The potentiostatic free chlorine probe reading is easier to understand than the ORP for system operators when control limits are for free chlorine residual. Problems can occur when calibrating the potentiostatic probe with the DPD free chlorine test because the DPD test is affected by total chlorine while the probe is not. The linear relationship between the potentiostatic free chlorine probe and chlorine feed allowed for tighter control with fewer excursions than when using the ORP probe.

Various factors, including reactant concentrations, pH, temperature, salinity and sunlight are constantly affecting the relationship between free chlorine, total chlorine, and ORP. Each measurement method have potential errors and interferences that will affect the accuracy of free chlorine control and prevent them from matching each other reliably. Despite these complexities, acceptable control of free chlorine is possible with both the ORP probe and the potentiostatic free chlorine probe.

Looking To Strike Out On Your Own?

QualiChem can help you make the leap to owning your own water treatment business.

We understand your needs and will provide expert support every step of the way:

- World-class manufacturing and custom formulations
- Private labeling
- Unparalleled technical support
- Business planning and sales development strategies

Contact us to learn more on how we can help your business grow.

540.444.5819
watertreatment@qualichem.com

www.qualichem.com

An ISO 9001:2008 Company
Paharpur has designed and supplied cooling towers for green buildings with approach as low as 1°C, making the air-conditioning plants of these buildings more energy efficient and reducing their energy consumption during the peak Indian summer-monsoon months to lower-than-ever levels.

In addition to reducing the building’s carbon footprint, these cooling towers are also more cost-efficient in the long run. The higher price of these towers is more than offset by the saving in air-conditioning plant energy consumption, in less than 12 months in most cases. And after the payback period, these savings accumulate to the owner for the rest of the plant’s life.

So, if you are looking to take your building to the next level of energy efficiency without compromising on life-cycle costs, look to the leader in cooling tower technology – look to… Paharpur.
In recent years there have been a relatively large number of unexpected, premature failures of system water piping associated with HVAC, Process Cooling, and Fire Water systems in modern buildings designed for commercial, residential, health care, governmental, and manufacturing occupancy. Facilities designed to provide long term service life are failing due to severe corrosion resulting in complete penetration of circulating water piping as a result of severe pitting type attack. This severe corrosion is occurring on the water side in both galvanized and un-galvanized carbon steel and copper piping. It is not uncommon to encounter systems where complete penetration has occurred within 4 to 8 years after initial commissioning, even though it appears to the building management team, right up until the leaks start to flow, that an appropriate water treatment program is in place. These premature failures are now finding their way into the courts, as attempts are made to determine responsibility and to seek compensation for these failures, resulting in severe reduction in asset value, excessive legal cost, and disruption of occupants.

In reviewing a number of such instances it is becoming clear that the root cause of these failures is a failure to provide clear, unequivocal specifications providing for a continuous process of outlining who is responsible for quality control during each phase of the process of validating proper design; materials selection and fabrication; construction; pre-service testing; removal of construction debris, foreign fabrication compounds, and corrosion products; and to provide for appropriate continuous and timely water treatment to carry the system(s) safely from construction to full occupancy and routine maintenance. During this critical time period, which can extend for several years after construction is largely completed, it must be recognized by all parties that the newly constructed system is very prone to suffering an initial corrosion process that, if not properly addressed, will likely condemn the system to exactly the types of failures that we are witnessing.

Corrosion is a naturally occurring process in which the fabricated metallic elements of the system, influenced by time, temperature, moisture, air exposure, and the presence of electrical fields, each try to return to their natural lower energy state of existing as oxides of the metals in question. This process can be greatly accelerated by improper alloying and fabrication techniques during manufacturing (wrong metallurgy, improper rolling, re-heating, forming, welding, etc.). Corrosion starts to occur the minute the pipe hits the storage area before shipping, and it continues throughout shipment and storage at the job site. During storage and shipping, and job site storage, the pipe is exposed to rain, high humidity, temperature variations, dust, dirt, etc. All of these influences contribute to a process in which the surface of the pipe begins to rust, or corrode. As this process continues, corrosion products and foreign debris accumulation can lead to the accumulation of deposits of varying composition, thickness, and moisture content. The presence of any deposits on the metal surface, especially deposits with variable thickness, composition, and porosity, can lead to an accelerating corrosion process known as “under-deposit corrosion”, during which differences in moisture and oxygen concentration under the deposits on the metal surface can lead to localized initiation of current flow, and ensuing “pitting type corrosion”.

During construction, the inappropriate joining of dissimilar metals can create galvanic couples and ensuing corrosion. In addition, the added presence of cutting oils, metal fragments, welding slag and flux, and stresses that are applied during construction, can all lead to additional accumulation of substances contributing to deposit formation, and these can lead to further acceleration of the corrosion process. The deposits formed by the accumulated corrosion products, mud, silt, oil, metal fragments, and miscellaneous debris provide a variety of ideal niches for the various micro-organisms found in the air and water to metabolize, grow, and multiply. Many of these organisms thrive under anaerobic conditions, secrete slime forming biomass, and generate acidic, corrosive metabolic byproducts that can greatly accelerate the corrosion processes already operating. These organisms can directly metabolize many of the active ingredients of the corrosion inhibitors. In addition, their metabolic byproducts can react with inhibitor and microbicide ingredients to deactivate them. The encapsulating biomass further complicates the process by retarding migration of fresh inhibitor and microbicide ingredients across these barriers.

After construction of the piping system is complete, a sub-contractor will conduct one or more “hydro-tests”, during which the piping system is filled with water and pressurized to some appropriately specified “over-pressure”, in order to test for leaks before insulation is applied. This is the point where the corrosion process must be stopped, the hydro-test water chemistry itself must be adjusted by the addition of a high level of chemical corrosion inhibitors during the entire hydro-test process. Immediately following hydro-testing, the system must be cleaned of corrosion products and foreign substances, the system cleanliness verified, and the exposed metal surface must be chemically “passivated”, to insure 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 and after hydro-testing and cleaning, the addition of water kick starts the microbial proliferation and the ensuing corrosion acceleration.

Hydro-testing should be delayed until all equipment in the recirculating system is installed. Hydro-testing should be conducted over a time period long enough to insure that all necessary equipment is also hydro-tested. Ideally, this phase of the process should be coordinated to the point where the same contractor, acting in conjunction with a chemical cleaning and passivation expert, performs the hydro-testing with inhibited, filtered water, and then immediately performs the cleaning process during which the cleaning chemical solutions are circulated for a specified time, and analyses of the cleaning solution are done to determine when the cleaning is complete. The last step of the cleaning process should incorporate the circulation of oxidant in sufficient concentration and duration to minimize the presence of micro-organisms, followed by removal of the excess oxidant to preclude additional corrosion due to the oxidant.
A History Built on Innovation

Since 1973, Brentwood has worked to meet the ever-increasing demands of the cooling tower industry and drive innovation. With over 100 million cubic feet of plastic media supplied, we continue to develop products and process enhancements that optimize cooling and maximize tower performance.

BRENTWOOD

www.brentwoodindustries.com +1.610.236.1100
When things heat up, call Aggreko.
Aggreko Cooling Tower Services (ACTS) is the world’s largest provider of rental cooling tower solutions. For over 20 years, we have successfully helped customers solve their cooling water limitations - under any circumstances.

From the planning stages to the turnkey installation of convenient modular cooling towers, ACTS has the solutions to help you keep your cool, 24/7/365.

ACTS provides proven rental cooling tower solutions to:

- Overcome thermal discharge temperature limitations
- Minimize post-disaster downtime
- Maintain cooling capacity during partial or complete tower repair
- Lower cooling water temperatures and reduce turbine back-pressure
- Add cooling water capacity with no capital commitment

Contact Aggreko today for all your rental cooling tower needs. Call us at 866.215.7963 or visit us online at www.aggreko-cooling-tower-rentals.com.
The success of the cleaning process should be verified by removing and visually inspecting “pipe spools”, or multiple short segments of the pipe fabricated into the piping system using pipe that was identically exposed during storage and fabrication. Ideally these spools should be installed in locations where maximum deposition is expected, i.e., at the lowest levels in the piping system. Pipe spools should be supplemented by exposure of corrosion coupons fabricated of the same metals as the system, and exposed to the cleaning solutions at the same linear fluid velocity and temperature as the piping experiences. Finally, it is very helpful to conduct a fiber-optic inspection of representative sections of system piping before and after cleaning, with photographs. At this point any exposure of the cleaned pipe to air must be minimized in duration, and followed immediately by the next step, which is “lay-up”.

In order to make sure that the corrosion process is greatly retarded from this point forward, it is necessary to insure that the environment of the pipe surface is in a continually protective condition. This must be done during the period of the “hydro-testing”, “pre-cleaning”, and “inspection” phases to the “system start-up” phase. This time period can be referred to the “lay-up period”. Recognize at this point that if there will be a significant need for on-going periodic circulation of water through the piping in order to test the function of any equipment added after the piping has been hydro-tested, cleaned, and passivated, then either the system must be retained intact and full of inhibited water, or the system must be re-treated each time that it is emptied. There are excellent “lay-up” corrosion control products and techniques available that involve draining and drying of the piping followed by application of vapor phase inhibitors (typically organic amine compounds), followed by sealing up the treated piping. Alternatively the system can be maintained full of water containing corrosion inhibitors and microbicides that are appropriate for the conditions to be encountered during any lay-up period. The choice of “lay-up” corrosion control technique must be made after a complete assessment of the projected need for repeated entry into and use of the piping system during the “lay-up” period.

During the “lay-up” period, if chemical corrosion inhibitors are used in conjunction with a water filled piping system, it is important that the circulating system water be periodically recirculated in conjunction with inhibitor testing, chemical feed, and corrosion and microbial monitoring, in order to insure the maintenance of sufficient levels of inhibitor and to prevent stratification of the circulating water. The circulation schedule should be determined in conjunction with the passivation expert, and will depend on the circulation time needed to insure thorough mixing of the water from all parts of the system, as well as on the choice and concentration of the corrosion inhibitor and microbicide. It is important to equip the circulating system with a surge tank at the top of the circulating piping loop to insure that the system is completely full of water at all times. This tank should be designed to minimize air contact with the treated water. Corrosion coupons should be appropriately exposed and monitored in all water systems during the “lay-up” period. In addition, routine monitoring for sessile and planktonic organisms should be conducted.

In the case of once through domestic hot and cold water systems, a lay-up period may not be practical. It must still be recognized that these systems will be subject to stagnant conditions and to low flow conditions during the transition period from final construction and hydro-testing until normal building occupancy and normalized flow conditions are realized. During this time period careful attention to both corrosion control and to microbial control must be exercised, and a water treatment chemical treatment and monitoring system appropriate to domestic potable water systems should be implemented. This will probably require the use oxidants such as chlorine, combined with a phosphate/zinc based corrosion control program coupled with routine sampling, testing, and data logging, and supplemented with the use of corrosion coupon and test spool monitoring.

When the time occurs where the buildings non-potable equipment must be periodically operated for a long enough time period that the choice of corrosion inhibitor will be affected (ex: high level nitrite in an open cooling loop), then the system treatment must be transitioned over to the on-going water treatment program. This time period is also a very significant time with respect to difficult corrosion control, especially in open loop systems (water exposed to air over a cooling tower, evaporative condenser, or closed circuit cooler). This is often a time when, due to low occupancy, there is only very low heat rejection on the system, calling for very little evaporation, make-up, or for the necessary ingredients of the chemical treatment program. In addition, there may be only infrequent recirculation of the water needed due to limited heat rejection requirements.

During this time period it is absolutely necessary to recirculate the system water for a significant period of time often enough to maintain a sufficient level of all chemical ingredients at all points in the piping system to provide the desired protection. In most systems this will involve recirculating the open loop cooling water throughout all of the water contacted equipment for at least two hours a day at design linear fluid velocity, with supplier specified maximum levels of the needed chemical ingredients, including corrosion inhibitors, scale inhibitors, dispersants, and microbicides. Your water treatment supplier may want to use a different program for this time period, in order to provide additional corrosion and microbial control, using highly stable ingredients, during this time when blow down will be at a minimum and system retention time will be extended due to low load.

Performance of the chemical program must be frequently monitored using equipment inspection, corrosion coupons, electronic corrosion probes, appropriate microbial testing (including bio-film and Legionella monitoring), and deposition monitoring, including heat rejection equipment inspection, individual component equipment heat transfer measurement, and possibly “deposition monitors”. The chemical service program must include frequent comprehensive chemical testing, including inhibitor product active ingredient testing: (phosphonate, phosphate, zinc, silicate, polymer, copper corrosion inhibitor), microbicide active ingredient monitoring; in addition to standard water tests such as pH, conductivity, cycles of concentration, chlorine, hardness, calcium, alkalinity, silica, chloride, and sulfate. It should be stressed that during these periods when decomposition and deactivation of treatment chemical ingredients is probable, the individual ingredients should be tested frequently. Depending on a “tracer” ingredient at this time is an invitation for unwanted complications.

During this time period some equipment may not be needed. It may be necessary to operate only one small chiller, one cooling tower, one compressor, etc. If this is the case, it may be appropriate to maintain the excess equipment on either a dry “mothball status” using vapor phase inhibitors and isolation, or a closed loop basis, using plenty of high level anodic inhibitor (nitrite and copper inhibitor with non-oxidizing microbicides). If you do this, remember that this equipment must be periodically recirculated, maintained completely full of water, properly treated, sampled and tested. The maintenance of un-needed equipment in a “lay-up” mode should incorporate a means of bypassing this equipment and isolating it from the main recirculating system. In this case, the equipment subject to lay-up must incorporate a means to periodically recirculate the system water at a frequency selected for the inhibitor and microbicide program selected.

Some facilities (hospitals, data centers, military facilities, etc.) maintain redundant equipment (spare chillers, spare cooling towers, emergency generators, spare compressors, etc.) that is not normally needed. This equipment is necessary to insure reliable continuous operation in the event of an equipment or power failure. If such equipment is not routinely operated it must also be protected on an on-going basis using proper moth-ball, lay-up, or stand-by procedures and the incorporation of appropriate bypass and recirculation piping, valves, and pumps. In order to insure preservation of our assets and infrastructure, a comprehensive set of specifications ensuring that the process of bringing new buildings on line without the severe corrosion problems being
The Industry’s Most Trusted Source in Components!

Dynamic Fabricators

We are known for providing dynamic solutions resulting in quality advantages and competitive pricing. Providing excellent customer service is our #1 priority. It's what keeps our customers coming back.

Your Complete Cooling Tower Supply Source with Locations in Wapato, WA & Elmore, AL.

- Header, Bypass, Riser and Lateral Distribution Syst.
- Fan Stacks, Fan Ring, Inlet Bells, FRP Basins.
- Fiberglass Pipe Saddles, Tanks, Access Hatches, Doors, Molded Stairs & Distribution Splash Boxes.

Your dynamic partner in cooling tower components...

Dynamic Fabricators

Toll-Free 877.604.6525
www.dynafab.net • Email us at: sales@dynafab.net
currently observed is needed. These specifications should specify the appropriate sampling, testing, and data collection points and parameters with specified control limits, as well as who is responsible for collecting and reviewing this information to insure compliance. If the lay-up period is going to be extensive, then the specifications should call for repeat periodic inspections to verify program performance.

There is currently too much focus today on the first cost of the water treatment chemical program as a commodity, without recognizing the needed practices, chemicals, controls, and on-going service that is really needed to be put in place and carefully verified before routine water treatment is inaugurated in an occupied and normally functioning facility. At the present time the water treatment supplier is penalized if they recommend products and work steps that are not called for in the spec. This has led to focus on first cost, and is condemning our piping systems to premature failure.

Over the last 30 years environmental constraints have severely limited the choices that water treatment and chemical passivation companies have available. Our arsenal of available chemicals used to include very cost effective materials, such as chromate and chromate/zinc formulations, often applied in conjunction with continuous chlorination and with acid based pH control. While these materials certainly were surrounded with environmental and safety concerns and the debate over their use was over-due, they are still very effective, their use may still be possible and desirable in some cases with appropriate safe guards, and they are resistant to degradation and were themselves biostatic. Today our replacement chemicals, while effective if properly applied, are more expensive, subject to degradation, require more rigorous system control and testing, and they contain phosphorous, nitrogen, and carbon – all bug foods.

**ILLUSTRATIONS:**
GAIENNIE LUMBER COMPANY
Industrial Products Division
Located in Opelousas, LA with quick shipping to all Gulf Coast points. 800-326-4050

Huge Stock Vinyl Ester-Fastec!  Redwood, Fir, and Fir Plywood  Stair Treads, Tread Covers and Pultruded Grating, All Sizes
Molded Grating, All Sizes  Huge Inventory Polyester Frp-Fastec!  Our New Fabrication Facility!

Also: Stainless Fasteners and All Thread Fire Rated and GP FRP Siding, All Sizes

Highest Quality Fabrication And Products!!! Lightening Fast Customer Service!!! Highly Competitive Pricing!!!

Call Or Email Us Today. Email: ct@gaiennielumber.com

Jim Elder 337-849-6309 (24/7)  Victoria Nall 318-664-5380  Joe La Bove 337-290-9006  Camille O’Kelley 337-948-3067

Visit us at gaiennielumber.com
CARBON FIBER COMPOSITE DRIVE SHAFTS / COUPLINGS FOR COOLING TOWER APPLICATIONS
Already installed in India, Indonesia, Thailand, Turkey etc.
Approved & Supplied to NTPC (India).
ATEX (CE) Certified

UV Stabilized
Easy Installation
Superior Fatigue Life
High Misalignment Capability

North Street Cooling Towers Pvt. Ltd.
Email: nsctpl@nde.vsnl.net.in / sales@nsctpl.in
Website: www.nsctpl.com
Phone: +91-120-2788571 / 72
Fax: +91-120-2788574

Member
ISO 9001:2008 (QMS), 14001:2004 (EMS)
& OHSAS 18001:2007 Certified Company
Figure 1: The biofilm life cycle [1]. 1) Free-floating bacteria could anchor to a surface within minutes of encounter, and start to produce slimy extracellular polymeric substances (EPS); 2) Self-organized, highly-structured 3D biofilm community could appear within hours of encounter; 3) Dynamic evolution of biofilm community via intercellular interaction and signaling, as well as interaction with environmental stimuli. Clumps of cells are released to colonize new surface.
3 REASONS TO CHOOSE IMI MECHANICAL VIBRATION SWITCHES

1. Superior control over trip sensitivity (Linear adjustment)
2. Economical (including special OEM pricing)
3. Remote reset options available (including Int’l configurations)

To learn more, visit www.imi-sensors.com/VibrationSwitch to download our ultimate guide to “Understanding Vibration Switches”.
BIBLIOGRAPHY:
Illustration credits (all illustrations from www.bing.com)

- G.S. Frankel, The Ohio State University, Metals Handbook, Pitting Corrosion Chapter
- Little, B.J., and Lee, J.S. Microbiologically Influenced Corrosion, John Wiley and Sons, Inc.
Midwest Cooling Towers, Inc

Leading the way in quality, service, and value.

Announcing a new name for the same great company you’ve always known.

We’re now Midwest Cooling Towers, Inc.
Same place. Same people. Same quality, service and value.

Midwest Cooling Towers leads the way for you with a full range of cooling tower products and services for your project. We are a complete cooling tower supply company. Our skilled and experienced team can support you in every step — design, fabrication, installation.

Contact us today and see how much value we can bring to your cooling tower project.

- Crossflow & countercflow cooling towers with wood or FRP structures
- Custom lumber fabrication and treating
- Fiberglass fan stacks and water distribution systems
- Non-skid fiberglass fan deck and hot water basins
- Corrugated FRP casing and louvers
- Fans, gears, drive shafts, motors, supports
- Flow control valves, nozzles, grommets
- Fill and drift eliminators
- Hardware, brace connectors, base anchors
- Replacement parts for all models and manufacturers
- Budget optimization and thermal upgrade studies
- Complete engineering services
- Reconstruction and thermal performance upgrades
- Maintenance and service contracts
- Emergency response and repair

WWW.MWCOOLING.COM
Midwest Cooling Towers, Inc. · PO Box 1485 · Chickasha, OK 73023 · Tel 405 294 4622 · Fax 405 294 4629
Sales Offices in New Jersey, Florida, Missouri, Texas & California. Representative Offices throughout the country
Review and Comments in the CTI Publication PTG-143: Technical Issues and Challenges Encountered During On-site Testing

Peter Holkers, Howden

Introduction
The primary function of a cooling fan is to provide cooling to an industrial process by generating an air flow through some form of heat exchanger system. The most common types of heat exchanger systems in which cooling fans are used are:

- Air cooled heat exchanger
- Air cooled condenser
- Cooling tower

The amount of cooling is directly related to the amount of air flow as can be seen from the general equation for heat transfer.

\[ q = m \cdot c_p \cdot \Delta T \]

- \( q \) Rate of heat transfer [W]
- \( m \) Mass flow rate [kg/s]
- \( c_p \) Specific heat of the air flowing through the cooling application [J/kg K]
- \( \Delta T \) Temperature difference between the application and the cooling medium [K]

It is therefore no surprise that cooling tower owners and operators are mainly focused on the air volume flow rate when it comes to the air side performance of their cooling tower or the performance of their fans. To determine this air volume flow rate CTI publication PTG-143 “Recommended practice for air flow testing of cooling towers” [1] provides detailed information on how to perform an air volume flow rate test in the field. When the outcome of such an air flow test matches the expected or desired air flow, all is well. However, when the fan is generating less air flow than expected or when there is a desire for more cooling capacity, and thus higher air flow, more detailed information regarding the performance of the fan is required.

This paper aims to expand on CTI publication PTG-143 by discussing the air volume flow rate measurement in the broader context of on-site industrial cooling fan performance testing. First some basics regarding cooling fan performance and system resistance are discussed. Next various measurement methods applied during an on-site fan performance test are discussed. Last some practical issues frequently encountered during on-site testing are discussed and some practical advice is given on how to avoid problems when preparing or conducting a fan performance test on-site.

Fan performance
Cooling fans are normally used in either an induced draught or a forced draught configuration, with the heat exchanger positioned either at the inlet or at the outlet side of the fan. Figures 1, 2 and 3 show some typical examples of cooling fan applications.

The aerodynamic performance of a cooling fan is characterized by three main variables:
1. Air volume flow rate
2. Fan pressure rise
3. Fan shaft power

These performance variables are typically presented as fan performance curves or “fan curves” as shown in figures 4a and 4b.

Scaling of fan performance
A fan curve is specific to a given fan (fan type, blade number, blade angle setting, etc.). The fan laws can be used to scale a fan curve based on:
1. Fan diameter
2. Fan speed
3. Air density

The fan laws essentially normalize the three main fan performance variables for fan diameter, fan speed and air density.

Dimensionless flow
\[ \pi_1 = \frac{Q}{\Omega D^3} \]

Dimensionless pressure
\[ \pi_2 = \frac{\Delta p}{\rho \Omega^2 D^2} \]

Dimensionless power
\[ \pi_3 = \frac{P}{\rho \Omega^2 D^5} \]

With:
- \( Q \) Air volume flow rate [m³/s]
- \( \Delta p \) Fan pressure rise [Pa]
- \( P \) Fan shaft power [W]
- \( \Omega \) Fan rotational speed [rad/s]
- \( \rho \) Air density [kg/m³]
- \( D \) Fan diameter [m]

One implementation of the fan laws is to use blade tip speed as the characteristic velocity. This implementation leads to the dimensionless pressure and flow coefficients shown below.
Flow coefficient

\[
C_f = \frac{Q}{\frac{\pi}{4} D_{fan}^2 v_{tip}}
\]

Pressure coefficient

\[
C_p = \frac{\Delta p}{\rho v_{tip}^2}
\]

Fan efficiency

\[
\eta = 100\% \frac{Q \cdot \Delta p}{P_{shaft}}
\]

These scaling rules can be used to select the best fan for a given duty, compare or predict fan performance at different fan speeds or to predict the effect of varying air density on the fan shaft power required to operate a fan.

System resistance

The heat exchanger forms a resistance to the air flow generated by the fan. This flow resistance, together with inlet or outlet losses and losses due to support beams and fan guards causes a pressure drop across the installation. This pressure drop is a function of the air volume flow rate. Typically this function is of the general form:

\[
\Delta p = K \rho \left(\frac{Q}{A}\right)^2
\]

The exact radii for the measurement locations are determined by dividing the net free surface area of the reference area into equal area bands. Measurements are then taken at the centers of these bands.

Fan selection and operating point

The operating point of a cooling fan in an installation is determined by the intersection of the fan performance curve and the system resistance curve (figure 6). The selection process of a cooling fan for a given installation essentially comes down to finding this intersection of the system resistance curve and the fan performance curve at a desired air volume flow rate. Most fan manufacturers provide their customers with fan selection software that will help to select the optimal fan for their application with regard to fan diameter, blade number, fan speed, fan shaft power, noise level, etc.

Fan performance testing in situ

Field performance tests on cooling fans can be conducted for a variety of reasons. Some of the most common reasons being:

- Site acceptance test
- Investigation to determine the possibilities for retrofit or upgrade
- Investigation to troubleshoot a fan performance issue

Typically an aerodynamic field performance test of a cooling fan will involve determination of the following variables:

- Air volume flow rate
- Fan static (or total) pressure rise
- Fan shaft power
- Fan speed
- Air density
- Blade tip angle
- Fan diameter

Apart from these variables the following items are also of importance and should also be part of an on-site fan performance test:

- Tip clearances
- Inlet shape
- Obstructions at the fan inlet and/or outlet
- Wind conditions during testing
- Air volume flow rate

As mentioned, [1] provides detailed instructions on how to perform an air volume flow rate measurement. The method described is based on determining the average air velocity over a reference area at either the fan inlet or outlet. The air volume flow rate is then determined as the product of the average air velocity and the reference surface area. According to [1] air velocities should be measured at 5 radii of the reference area in four quadrants. For fans larger than 20ft. 10 measuring points per quadrant should be considered.
The best choice of reference area for a given air flow measurement depends on the application. Accessibility is often an important factor with regard to this choice. Generally speaking it is recommended to measure at the inlet side of a fan since air velocities at the fan inlet side will typically be more stable and more uniform. At the outlet side of a fan flow conditions will typically be much more turbulent, axial air velocities will be non-uniform and air velocities will also contain a tangential component (often referred to as swirl).

It is possible to measure at the fan outlet but to obtain the axial air velocity component, needed to calculate the air volume flow, jaw angle corrections have to be made on the measured air velocities. An example of this jaw angle correction for a measurement using a vane anemometer is shown in figure 7. The anemometer is equipped with a diffuser or if there are flow obstructions present, the pressure loss associated with the obstructions needs to be taken into account as well.

With regard to pitot tubes it should also be noted that in wet conditions water droplets can block the holes of the pitot tube which will cause measurement errors. For measurements under wet conditions it is therefore recommended to use a pitot tube with sufficiently large holes.

### Fan static pressure

The term fan static pressure is a deceptively named variable. There is good reason why R.A. Wallis [2] referred to it as “clearly a misnomer” and suggested to replace the term fan static pressure by fan inlet total pressure for induced draught installations and by fan total pressure for forced draught installations. Nevertheless fan static pressure is still a widely used definition and can still be found in the latest revisions of all relevant standards regarding fan performance testing [3, 4]. By definition the fan static pressure is equal to the total pressure rise over a fan minus the velocity pressure at the fan outlet.

$$FSP = \Delta p_{total,fan} - p_{dynamic,fan outlet}$$

This is equal to:

$$FSP = p_{static,fan outlet} - p_{total,fan inlet}$$

For induced draught installations this leads to:

$$FSP = -p_{total,fan inlet}$$

For forced draught installations this leads to:

$$FSP = p_{static,fan outlet}$$

In induced draught installations the fan static pressure can be determined by determining the total pressure at the fan inlet. The total pressure at the fan inlet can be measured by inserting a Pitot tube through a hole in the casing. Alternatively the fan static pressure can be determined by measuring the static pressure at the fan inlet and adding the dynamic pressure calculated from the air flow measurement (note that for induced draught applications the static pressure at the fan inlet is below atmospheric). If the outlet of the fan is equipped with a diffuser or if there are flow obstructions present at the fan outlet the diffuser recovery or the pressure loss associated with the obstructions needs to be taken into account as well.

In forced draught installations the fan static pressure can be determined by measuring the static pressure in the plenum chamber. It is important to choose a measurement location where air velocities are as low as possible, typically the corners of the plenum chamber. Alternatively the static plenum pressure can be measured using static

For cases where the inner diameter can be set to zero the previous formula simplified to:

$$r_i = \frac{1}{2} \sqrt{(2l - 1) \frac{D_{out}^2}{2n}}$$

Note that for induced draft cooling towers, adjacent fan stacks often create accessibility issues with regard to these measurement locations.

The measured air velocities are then averaged and multiplied by the reference surface area to obtain the air volume flow.

$$\bar{v} = \frac{1}{k} \sum_{i=1}^{k} v_i$$

$$Q = \bar{v} A_{ref}$$

$v_i$ Average air velocity $[m/s]$

$k$ Measured air velocity at position $i$ $[m/s]$

$k$ Total number of measuring points $[-]$

$Q$ Air volume flow rate $[m^3/s]$

$A_{ref}$ Reference surface area $[m^2]$

The term fan static pressure is a deceptively named variable. There is good reason why R.A. Wallis [2] referred to it as “clearly a misnomer” and suggested to replace the term fan static pressure by fan inlet total pressure for induced draught installations and by fan total pressure for forced draught installations. Nevertheless fan static pressure is still a widely used definition and can still be found in the latest revisions of all relevant standards regarding fan performance testing [3, 4]. By definition the fan static pressure is equal to the total pressure rise over a fan minus the velocity pressure at the fan outlet.

$$FSP = \Delta p_{total,fan} - p_{dynamic,fan outlet}$$

This is equal to:

$$FSP = p_{static,fan outlet} - p_{total,fan inlet}$$

For induced draught installations this leads to:

$$FSP = -p_{total,fan inlet}$$

For forced draught installations this leads to:

$$FSP = p_{static,fan outlet}$$

In induced draught installations the fan static pressure can be determined by determining the total pressure at the fan inlet. The total pressure at the fan inlet can be measured by inserting a Pitot tube through a hole in the casing. Alternatively the fan static pressure can be determined by measuring the static pressure at the fan inlet and adding the dynamic pressure calculated from the air flow measurement (note that for induced draught applications the static pressure at the fan inlet is below atmospheric). If the outlet of the fan is equipped with a diffuser or if there are flow obstructions present at the fan outlet the diffuser recovery or the pressure loss associated with the obstructions needs to be taken into account as well.

In forced draught installations the fan static pressure can be determined by measuring the static pressure in the plenum chamber. It is important to choose a measurement location where air velocities are as low as possible, typically the corners of the plenum chamber. Alternatively the static plenum pressure can be measured using static

For cases where the inner diameter can be set to zero the previous formula simplified to:

$$r_i = \frac{1}{2} \sqrt{(2l - 1) \frac{D_{out}^2}{2n}}$$

Note that for induced draft cooling towers, adjacent fan stacks often create accessibility issues with regard to these measurement locations.

The measured air velocities are then averaged and multiplied by the reference surface area to obtain the air volume flow.

$$\bar{v} = \frac{1}{k} \sum_{i=1}^{k} v_i$$

$$Q = \bar{v} A_{ref}$$

$v_i$ Average air velocity $[m/s]$

$k$ Measured air velocity at position $i$ $[m/s]$

$k$ Total number of measuring points $[-]$

$Q$ Air volume flow rate $[m^3/s]$

$A_{ref}$ Reference surface area $[m^2]$

The best choice of reference area for a given air flow measurement depends on the application. Accessibility is often an important factor with regard to this choice. Generally speaking it is recommended to measure at the inlet side of a fan since air velocities at the fan inlet side will typically be more stable and more uniform. At the outlet side of a fan flow conditions will typically be much more turbulent, axial air velocities will be non-uniform and air velocities will also contain a tangential component (often referred to as swirl).

It is possible to measure at the fan outlet but to obtain the axial air velocity component, needed to calculate the air volume flow rate, jaw angle corrections have to be made on the measured air velocities [1]. An example of this jaw angle correction for a measurement using a vane anemometer is shown in figure 7. The anemometer is aligned with the air velocity vector as shown in figure 7 and the axial velocity component is then calculated from the measured air velocity and jaw angle.

$$v_{axial} = v_{meas} \cos \theta$$

$v_{axial}$ Axial air velocity component $[m/s]$

$v_{meas}$ Measured air velocity (containing swirl component) $[m/s]$

$\theta$ Jaw angle $[deg]$

In practice this jaw angle can be very difficult and often even impossible to measure during an on-site test. From practical experience it is recommended to choose a reference surface in the cylindrical part of the fan casing just upstream of the fan. This measurement location provides a clearly defined circular reference area where air velocities are normally reasonably uniform and free of swirl and outside influences due to wind are as low as possible.

Various instruments can be used to measure the air velocity. The two most commonly used instruments are:

- Prandtl type pitot tube
- Vane anemometer

Using a Prandtl type pitot tube to determine air velocity, the dynamic pressure is measured and used to calculate the air velocity.

$$v_{air} = \sqrt{\frac{2p_{dyn}}{\rho}}$$

$p_{dyn}$ Dynamic pressure $[Pa]$

$\rho$ Air density $[kg/m3]$

Other types of pitot tubes such as an S-pitot or for measurements in difficult flow conditions, various types of multi-hole probes (3-hole, 5-hole etc.) can also be used to measure air velocity. However, it should be noted that compared to a Prandtl type pitot tube or a vane anemometer these types of instruments require much more extensive calibration and are a lot less straightforward in their use.

The best choice of reference area for a given air flow measurement depends on the application. Accessibility is often an important factor with regard to this choice. Generally speaking it is recommended to measure at the inlet side of a fan since air velocities at the fan inlet side will typically be more stable and more uniform. At the outlet side of a fan flow conditions will typically be much more turbulent, axial air velocities will be non-uniform and air velocities will also contain a tangential component (often referred to as swirl).

It is possible to measure at the fan outlet but to obtain the axial air velocity component, needed to calculate the air volume flow rate, jaw angle corrections have to be made on the measured air velocities [1]. An example of this jaw angle correction for a measurement using a vane anemometer is shown in figure 7. The anemometer is aligned with the air velocity vector as shown in figure 7 and the axial velocity component is then calculated from the measured air velocity and jaw angle.

$$v_{axial} = v_{meas} \cos \theta$$

$v_{axial}$ Axial air velocity component $[m/s]$

$v_{meas}$ Measured air velocity (containing swirl component) $[m/s]$

$\theta$ Jaw angle $[deg]$

In practice this jaw angle can be very difficult and often even impossible to measure during an on-site test. From practical experience it is recommended to choose a reference surface in the cylindrical part of the fan casing just upstream of the fan. This measurement location provides a clearly defined circular reference area where air velocities are normally reasonably uniform and free of swirl and outside influences due to wind are as low as possible.

Various instruments can be used to measure the air velocity. The two most commonly used instruments are:

- Prandtl type pitot tube
- Vane anemometer

Using a Prandtl type pitot tube to determine air velocity, the dynamic pressure is measured and used to calculate the air velocity.

$$v_{air} = \sqrt{\frac{2p_{dyn}}{\rho}}$$

$p_{dyn}$ Dynamic pressure $[Pa]$

$\rho$ Air density $[kg/m3]$

Other types of pitot tubes such as an S-pitot or for measurements in difficult flow conditions, various types of multi-hole probes (3-hole, 5-hole etc.) can also be used to measure air velocity. However, it should be noted that compared to a Prandtl type pitot tube or a vane anemometer these types of instruments require much more extensive calibration and are a lot less straightforward in their use.
SAVE THE DATE
The Largest and Longest Running Ethanol Conference in the World!

June 1-4, 2015
Minneapolis, MN

31st ANNUAL INTERNATIONAL
FEW
FUEL ETHANOL WORKSHOP & EXPO

PROMOTING INNOVATION
CONNECTING THE INDUSTRY

Networking Opportunities
All Ethanol Facilities Receive 2 Free Passes
866-746-8385 service@bbiinternational.com
Follow Us: twitter.com/ethanolproducer

Produced by: Ethanol PRODUCER MAGAZINE
pressure taps on the plenum casing. Note that this procedure contains the underlying assumption that the fan inlet is at atmospheric pressure \( (p_{\text{total, fan inlet}} = 0) \). This assumption is not always valid. If there are obstructions at the fan inlet or if the fan being tested is part of a large array of fans, the total pressure at the fan inlet can be below atmospheric pressure.

**Fan shaft power**

For on-site measurements, the fan shaft power is typically determined from the motor shaft power \( P_{\text{shaft,motor}} \) and the drive efficiency \( \eta_{\text{drive}} \) (for cooling fan applications, the drive is usually either a gear box or a belt drive system). Although this method is not ideal with regard to accuracy, it is almost always the only feasible option for an on-site test.

\[
P_{\text{shaft,fan}} = \eta_{\text{drive}} P_{\text{shaft,motor}}
\]

The shaft power delivered by the electric motor \( P_{\text{(shaft,motor)}} \) can be calculated according to:

\[
P_{\text{shaft,motor}} = \eta_{\text{motor}} U I \sqrt{3} \cos \phi
\]

The nominal operating voltage \( U \) and current \( I \) and power factor \( \cos \phi \) can be found on the motor tag plate. Fortunately, the nominal shaft power \( P_{\text{nominal,shaft}} \) is often stated on the motor tag plate as well. The actual shaft power can then be calculated from the measured motor current \( I \):

\[
P_{\text{shaft,motor}} = \frac{I}{I_{\text{nominal}}} P_{\text{nominal}}
\]

Note that these methods assume that the motor efficiency and power factor remain constant. For most electric motors, this assumption remains valid as long as the motor is operated at nominal voltage and between 75% and 100% of nominal load [5]. At lower loads, both the motor efficiency as well as the power factor will decrease. These effects should be accounted for when a fan performance test at lower motor loads is required. If the purpose of the test allows, it is always recommended to carry out a fan performance test at the highest possible fan speed.

**Air density**

The air density can be determined by measuring the air temperature, absolute pressure, and relative humidity at the fan inlet.

\[
\rho_{\text{air}} = \frac{p_{\text{d}}}{R_{\text{d}} T} + \frac{p_{\text{v}}}{R_{\text{v}} T}
\]

- \( \rho_{\text{air}} \): Air density \([\text{kg/m}^3]\)
- \( p_{\text{d}} \): Partial pressure of dry air \([\text{Pa}]\)
- \( p_{\text{v}} \): Partial pressure of water vapour \([\text{Pa}]\)
- \( R_{\text{d}} \): Specific gas constant of dry air \([\text{J/kg K}]\)
- \( R_{\text{v}} \): Specific gas constant of water vapour \([\text{J/kg K}]\)
- \( T \): Temperature \([\text{K}]\)

The partial pressure of dry air and water vapour can be determined from the measured air temperature, absolute pressure, and relative humidity using the Mollier diagram. Alternatively, air density may be determined directly by standard psychrometric charts or the CTI toolkit.

**Fan speed**

The fan speed can be measured using a tachometer or strobe light. Alternative methods to determine fan speed are to measure vibrations on the fan casing to obtain the blade passing frequency or to mount an induction sensor on the fan shaft. Although determining the fan speed with a strobe has the major benefit of not having to stop the fan, this method can be difficult to perform due to visibility problems, especially when the fan is exposed to direct sunlight.

**Blade angle**

In most cases, the blade angle can be measured directly at the blade tip using an inclinometer. For some fans, especially fans with complex blade shapes, this approach cannot be used. The manual supplied with the fan should provide information on how to determine the blade angle in such a case. The blade angle of every blade on a fan should be determined to ensure that there is no variation in blade angle between blades. Significant differences in blade angle setting between blades can lead to unstable operating conditions.

**Tip clearances**

Evidently, some tip clearance will always be required to avoid blades hitting or rubbing against the fan casing during operation. Typically, tip clearances of a cooling fan will be between 0.5 and 1.5 percent of the fan diameter. Excessive tip clearances will lead to increased tip leakage flow which will have a negative influence on the performance of a fan. Large tip clearances can also cause increased fan noise levels. The fan manual will typically contain information regarding the recommended tip clearances for a given fan. Tip clearances can be measured using a tape measure. It is advisable to measure the tip clearances of each blade at several locations inside the casing.

**Inlet shape and flow obstructions**

A proper elliptic bell mouth inlet will ensure optimal flow conditions at the inlet of a fan. Other inlet shapes such as radius, conical, or flat flanged inlets will have an unfavourable effect on flow conditions at the inlet of the fan which can lead to some degradation in fan performance. Figure 8 illustrates the effect of a non-ideal inlet shape. Obstructions at the fan inlet or outlet can also impact the flow conditions experienced by the fan. Support beams and safety grids etc. can create wakes of turbulent flow, swirl, or areas of lower air flow that can lead to reduced fan performance, increased noise levels and increased loading and vibration.

A very useful and simple method to check flow conditions at the fan inlet and outlet is to use a thin wire attached to a stick. By observing the behaviour of the wire at various locations at the inlet and outlet of the fan, one can quickly determine the presence of any areas of high turbulence downstream of obstructions or of flow separation issues around the fan inlet.

**Wind conditions**

Wind conditions can also have a significant effect on the performance of a fan, particularly on fans installed in a forced draught configuration. It is therefore advisable to determine and record the wind speed and direction during a fan performance test. Most sites will have a weather monitoring system and in such cases, wind conditions can be obtained from this system. If such a monitoring system is not in place, the wind velocity and direction can be measured using a handheld anemometer.

**Practical issues regarding fan performance**

The previously discussed fan laws reveal some fundamental and very useful characteristics regarding the performance of a cooling...
A fan is a constant volumetric device. This means that a given fan operated at a given blade angle and fan speed will generate a constant air volume flow. This means that an increase in air density will lead to an increase in air mass flow but will not affect the air volume flow. The fan pressure rise is linearly dependent on air density. A 5% increase in air density (which corresponds to a reduction in air inlet temperature of about 14 °C) will lead to a 5% increase in pressure which will in turn lead to a 5% increase in fan shaft power. This relationship is important when selecting a fan drive for a fan application.

**Practical issues regarding fan performance testing on-site**

Conducting a fan performance test on-site can pose quite a few practical problems. Most of these problems are related to access, permission and safety issues. Nearly all of these problems can be avoided by proper preparation and by discussing the details of the measurement with the site owner or operator well in advance. Ideally, all details regarding a fan performance field test should be the measurement with the site owner or operator well in advance.

1. Safety first! Proper safety procedures and protocols should always be followed. Health and safety procedures form a layered system of safety and removing even a single layer will greatly increase the risk of accidents.

2. Allow sufficient time to perform the measurements. Rushing to complete a measurement will often lead to measurement errors and mistakes.

3. During the preparation phase of a fan performance field test, communication will likely occur by phone and/or email and sometimes not with the person who will be the contact on-site. It is very important to check that the on-site contact is aware of the relevant details regarding the measurements.

4. It is not uncommon in the industry to arrive on site to find out that the fan to be tested is in full operation and cannot be stopped. This means that measuring tip clearances and blade angles etc. is not possible. This scenario can (and should) be avoided by proper preparation.

5. Determining the fan shaft power of a fan will typically require a measurement of the motor current. Most sites will not allow such a current measurement to be taken at the motor terminal box due to safety concerns, even if the test engineer in question is certified to perform such a current reading. Most sites are however able to provide the motor current from the control room.

6. Whenever traveling abroad language barriers can pose issues with regard to communication. Ensure that it is possible to communicate effectively with the on-site contact. Language barriers can also lead to serious safety issues.

7. Taking Pitot tube readings at the inlet of a fan may require drilling access holes in the casing. If this is the case this has to be discussed with, and approved by, the site owner and/or operator prior to the test. Provisions should also be made to seal off the access holes once the performance test has been completed.

8. Performing an on-site fan performance test is a time consuming affair, especially on larger fans. It is important to make sure that during the test, tower operating conditions remain constant with regards to thermal load and fan speed.

9. It is helpful to have some photographs and/or dimensional drawings of the installation when preparing for a test. This can be extremely helpful in choosing the measurement method(s) best suited for the test and to identify possible issues with regard to accessibility.

10. Check your data during the measurement. Despite all efforts occasional mistakes can and will occur. Unlike a lab test an on-site test cannot be easily repeated. It is therefore important to keep checking obtained data for anomalies during the test. That way mistakes can be identified and corrected immediately.

11. It is important to check equipment thoroughly; it should be ensured that all equipment is calibrated and working properly prior to departure but also upon arrival; especially when traveling by plane. It may even be advisable to bring some backup equipment and to check if there is a local supplier near the site, just in case.

12. Before taking any pictures on any site it is highly advisable to verify whether taking pictures is allowed. Especially in certain parts of the world one can get themselves in serious trouble when taking unauthorized pictures on-site.

13. When working in humid conditions, bring a pencil. This seems like a silly issue but ball point pens will usually not function properly in a damp, humid environment.

**Reference**

[1] CTI PTG-143 “Recommended practice for air flow testing of cooling towers”, 1992


Figures

Fig. 1 Cooling fan application: Induced draught cooling tower

Fig. 2 Cooling fan application: Induced draught air cooled heat exchanger

Fig. 3 Cooling fan application: Forced draught air cooled condenser

Fig. 4a Fan curve air flow vs. fan static pressure

Fig. 4b Fan curve air flow vs. fan static efficiency
Fig. 5 Typical system resistance curve.

Fig. 6 Operating point

Fig. 7 Jaw angle correction

Fig. 8 Illustration of the effect of a non-ideal inlet shape (exaggerated for illustrative purpose)

The best sheaves for the worst environments!

Ideally suited for the most aggressive atmospheres, unusual conditions, such as weight requirements and installation problems, Bailsco lightweight all-aluminum cast V-belt sheaves have been in the field for over 15 years.

Full range of sizes available up to 38” diameter, larger sizes available upon request. Special designs to meet OEM requirements.

Design, molding, casting, machining, heat treating and balancing are all done “in-house”.

BAILSCO
POWER TRANSMISSION PRODUCTS

BAILSCO BLADES AND CASTINGS, INC.
Box 6093, Shreveport, LA 71136-6093 U.S.A.
Phone 318.861.2137 FAX 318.861.2953
www.bailsco.com
email: bailsco@bailsco.com
Trends in Water and Energy Use

There is a relationship between energy usage and water consumption often described as the “Energy-Water Nexus”. As the worldwide population grows, the demand for energy and potable water increases as well. The International Energy Outlook 2013 (IEO2013) projects that world energy consumption will grow by 56 percent between 2010 and 2040. Total world energy use rises from 524 quadrillion British thermal units (Btu) in 2010 to 630 quadrillion Btu in 2020 and to 820 quadrillion Btu in 2040.

Likewise, according to the Food and Agriculture Organization of the United Nations (FAO) and UN-Water, while the population has been growing by approximately 80 million people a year, water use has been growing at more than twice the rate of population increase in the last century. Per the Global Environment Outlook GEO4 report for the United Nations Environment Programme by the year 2025, water withdrawals are predicted to increase by 50 percent in developing countries, and 18 percent in developed countries.

In a recent Position Statement, the American Society of Mechanical Engineers (ASME) Board of Government Relations (BGR) and the Center for Research and Technology Development (CRTD) recommend the development of a national policy that addresses the interdependencies of reliable sources and efficient uses of energy and water. Internationally, policies are needed as well because worldwide demand for energy and water continue to grow. As stated by ASME, trends in energy and water supplies indicate that threats and concerns to energy production as well as quantity and quality of water within the U.S. could reach a crisis situation within the next 10-15 years.

According to a 2013 Congressional Research Service (CRS) Report for Congress, available projections estimate that by 2030 U.S. water consumption will increase 7% above the level consumed in 2005; 85% of this growth is attributed to the energy sector. While agriculture dominates US water consumption (71%), the energy sector (including biofuels, thermoelectric and fuel production) is the second largest water consumer at 14%, and domestic and public uses are third at 7%.

Typical Power Plant Cooling

More than 80% of U.S. electricity is generated at thermoelectric facilities that depend on cooling water; these facilities withdraw 143 billion gallons of fresh water per day (541 million cubic meters). The two most common cooling methods for thermoelectric power plants are once-through cooling and evaporative cooling. Most once-through cooling is either found at power plants located in the eastern United States and is associated with older facilities, or is at coastal facilities using saline waters. Newer facilities and those in more arid regions generally use evaporative cooling. Each type of cooling has its pros and cons:

- Once-through cooling, while largely non-consumptive, requires water to be continuously available for power plant operations. This reduces the ability for this water to be put toward other water uses and can make cooling operations vulnerable to low flows. Environmental factors such as heating of the water and fish kill must be remediated. The rate of evaporation of the heated water is also increased.
- Evaporative cooling withdraws much smaller volumes of water for use in a cooling tower or reservoir, where waste heat is dissipated by evaporating the cooling water. Evaporative cooling consumes more water at the facility than does once-through cooling.

Driven by water availability, costs and increasing water use regulations, more and more power plants are exploring additional cooling technologies that consume less water or use degraded water supplies to reduce freshwater use. These options include dry cooling, hybrid dry-wet cooling, cooling with fluids other than freshwater (e.g., brackish groundwater, produced waters), and other emerging technologies.

In order to better understand the water savings and energy benefits of newly developed hybrid dry-wet cooling technologies, it is best to start with the basic equations that describe the heat and mass transfer between water and air within an evaporative cooling tower.

Heat and Mass Balance in Evaporative Cooling Towers

In a typical evaporative cooling process, hot water from the power plant condenser flows from a network of pipes and low pressure spray nozzles vertically by gravity over the cooling tower fill. The cooling air travels through the fill either vertically up in counter flow cooling towers as shown in Figure 1, or horizontally in cross flow cooling towers as shown in Figure 2.
The warm water is cooled mostly by evaporation in contact with ambient air; the cooling air leaves the cooling tower saturated or nearly saturated. The heat balance for this process is:

\[ \text{heat}_{\text{in}} = \text{heat}_{\text{out}} \]

\[ c_p \dot{m}_{\text{water},1} T_{\text{water},1} + \dot{m}_{\text{air}} h_{\text{air},1} = c_p \dot{m}_{\text{water},2} T_{\text{water},2} + \dot{m}_{\text{air}} h_{\text{air},2} \]  

Where:
- \( c_p \) = specific heat of water \([\text{J/kg/K or BTU/lb/F}]\)
- \( \dot{m}_{\text{water},1}, \dot{m}_{\text{water},2} = \) mass flows of water entering (subscript 1) and leaving (subscript 2) cooling tower \([\text{kg/s or lb/hr}]\)
- \( T_{\text{water},1}, T_{\text{water},2} = \) temperatures of water entering and leaving cooling tower \([°C or °F]\)
- \( \dot{m}_{\text{air}} = \) mass flow of air \([\text{kg/s or lb/hr}]\) constant throughout the tower
- \( h_{\text{air},1}, h_{\text{air},2} = \) enthalpies of air entering and leaving tower \([\text{J/kg or BTU/lb}]\)

The difference between \( \dot{m}_{\text{water},1} \) and \( \dot{m}_{\text{water},2} \) is the evaporation (E) due to mass transfer:

\[ \dot{m}_{\text{water},1} - \dot{m}_{\text{water},2} = m_{\text{w}} (w_2 - w_1) = E \]  

\( w_1, w_2 = \) humidity ratios of moist air entering and leaving tower \([\text{kg moist air/kg dry air or lb m.a./lb d.a.}]\)

Combining equations (2) and (3):

\[ c_p \dot{m}_{\text{water},1} (T_{\text{water},1} - T_{\text{water},2}) = \dot{m}_{\text{w}} (h_{\text{air},2} - h_{\text{air},1}) - c_p \dot{m}_{\text{air}} T_{\text{water},2} (w_2 - w_1) \]  

Then rearranging to find \( h_{\text{air},2} \):

\[ h_{\text{air},2} = h_{\text{air},1} + c_p \frac{\dot{m}_{\text{water},1}}{\dot{m}_{\text{air}}} (T_{\text{water},1} - T_{\text{water},2}) + c_p T_{\text{water},2} (w_2 - w_1) \]  

(5)

In equation (5), the properties of the leaving air (subscript 2) are unknown. To find \( h_{\text{air},2} \) and \( w_2 \), we need to solve by trial and error. Assuming that the leaving air is saturated, that is to say its relative humidity is 100%, the trial-and-error solution is easy. But to compute the more exact conditions of the leaving air, we must integrate on both \( h_{\text{air}} \) and \( w \) to solve the equation. The method of integration proposed by Poppe allows resolving this equation mathematically by carrying out a double integration. This is complicated and can be time consuming; therefore a simplified method is shown below.

Assuming the leaving air relative humidity is 100%, a trial-and-error solution is easy. A first estimate of the enthalpy of the air leaving the cooling tower can be derived from the simplified heat balance assuming the evaporation is zero so the term \((w_2 - w_1)\) in equation (5) is equal to zero, leaving us with the following simplified equation below:

\[ h_{\text{air},2} = h_{\text{air},1} + c_p \frac{\dot{m}_{\text{water},1}}{\dot{m}_{\text{air}}} (T_{\text{water},1} - T_{\text{water},2}) \]  

(6)

The parameters on the right side of equation (6) are all known. From the first estimated value of \( h_{\text{air},2} \) and assuming again that the relative humidity of the leaving air is 100% we can determine a value for \( w_2 \) (from psychrometric tables or equations) and use it in equation (5) to find a new value of \( h_{\text{air},2} \) that can be used then to compute a new value of \( w_2 \) and so on. The iteration converges quickly.

**Evaporation and Make-Up in Evaporative Cooling Towers**

To compensate for the water evaporating from the cooling tower, it is necessary to add water to the system to keep the volume constant. The added water is generally called the make-up (M). As water evaporates the concentration of dissolved solids increases and the water quality changes. To control water quality, it is necessary to discharge water from the cooling tower to flush out these dissolved solids. The discharged water is generally called the blow-down (B) or bleed. Some of the water is also lost due to drift (D) losses from the cooling tower. The relationship between these items is:

\[ M = E + B + D \]  

(7)

The number of cycles of concentration \( n_{cc} \) is the ratio between make-up and blow-down:

\[ n_{cc} = \frac{M}{B + D} \]  

(8)

Combining equations (7) and (8), assuming D is negligible, and where evaporation has been determined in equation (3), the make-up flow rate is computed as:

\[ M = \frac{n_{cc}}{(n_{cc} - 1)} E \]  

(9)

**Energy Balance in Evaporative Cooling Towers**

Energy use is also an important part of evaporative cooling but is generally overshadowed by the unit’s water use. As shown in the equations above, the amount of water consumed in evaporative cooling is basically defined by the difference between the hot water
and the cold water temperatures and is constant regardless of unit design. Energy use for these units is substantially less than in dry cooling and can be managed by increases in overall surface area. Because of this fact, there is no set calculational method of energy use for evaporative cooling. Rather, the energy use is determined by available footprint and the customer’s first cost requirements.

**Typical 500 MWe Power Plant – Evaporative Cooling**

A May 2013 document from Electric Power Research Institute (EPRI) offers a power plant cooling system overview with typical design conditions for a wet field erected cooling tower in a 500 MWe thermoelectric power plant.

Under these typical conditions, the tower cools 250,000 GPM of hot water from the plant condenser at 102°F and returns it at 82°F cold water temperature. Atmospheric cooling air enters the tower at 75°F wet bulb temperature and 50% relative humidity. The power plant is assumed to be at sea level. The steam condensation temperature in the surface condenser is 109°F at 2.5”Hg backpressure (43°C and 85 mbar).

Using 100% evaporative cooling as an example, a counter flow design cooling tower using high efficiency film fill and high efficiency drift eliminators was selected. It has 18 cells in a back-to-back arrangement and an overall footprint of 490 feet long by 120 feet wide. At the design conditions it consumes 3,300 kW total electric power measured at the fan motor control center. The required mass flow of cooling air is 1,791,795 lb/min (13,546 kg/s) so the ratio of water mass flow rate to air mass flow rate (L/G) is

\[ \frac{m_{\text{water,1}}}{m_{\text{air}}} = 1.19 \]

At design conditions, the rate of evaporation is expected to be 1.79% of the circulating water flow rate or 4479 GPM (282.6 L/s) and the drift loss 2.5 GPM (0.2 L/s) or less. At 5 cycles of concentration, the make-up flow is expected to be 5,601 GPM (353.4 L/s) and the blow-down is expected to be 1,120 GPM (70.7 L/s).

**Energy Balance in Dry Cooling Technologies**

For customers looking for an alternative to the high water use of 100% evaporative cooling, dry cooling has been considered the most available option. Power plants that incorporate dry cooling in the form of Air Cooled Steam Condensers (ACC), offer significant water savings over power plants using traditional evaporative cooling technologies. State-of-the-art ACC feature single-row finned tubes installed in an A-frame steel structure. The steam from the turbine exhaust condenses as it is directly cooled by forced convection of the ambient air.

ACC reduce water consumption in combined cycle power plants by more than 97% when compared with wet cooling. They also eliminate the environmental impacts of plume, drift, and blow down associated with wet cooling. Lower water usage and environmental impact allows for faster permitting than wet cooling. However, ACC require a very large footprint and high energy consumption to drive the fan motors. In an ACC the condensation temperature of the steam is warmer than in a traditional surface condenser, resulting in a higher turbine backpressure and a less efficient thermal cycle.

**Typical 500 MWe Power Plant – Dry Cooling**

Using the same 500 MWe Power plant from the previous example, and instead operating with 100% dry cooling, an ACC was selected. The steam condensation temperature and pressure were raised to 125°F and 4”Hg (52°C and 135 mbar). The ACC selected has 60 cells and an overall footprint of 430 feet long by 270 feet wide. At design conditions it requires 8,450 kWe total electric power measured at the fan motor control center. The required mass flow of cooling air is 6,725,750 lb/min (50,850 kg/s).

**Hybrid Wet-Dry Cooling Technologies**

To answer the growing industry need for a compromise between the water use of evaporative cooling and the energy use of dry cooling, manufacturers are developing new types of wet-dry hybrid cooling technologies. These hybrid cooling technologies combine wet evaporative cooling with dry sensible cooling within the same unit to reduce both the amount of water required as compared to evaporative cooling and the energy use as compared to dry cooling.

Hybrid cooler cost, energy usage, water consumption and environmental impact can be represented in a graph like Figure 4 below where “wet” cooling is the left boundary of the x-axis and “dry” cooling is the right boundary. “Hybrid” wet-dry cooling is located anywhere between the two limits.
AHR EXPO 2016
ORLANDO
JAN 25-27
ORANGE COUNTY CONVENTION CENTER
THE WORLD'S LARGEST HVACR MARKETPLACE
AHREXPO.COM
The blue curve is Capital Cost which increases from wet to dry. Fan and pumping Power Consumption (kW) is the red line which increases from wet to dry. Water Use is the yellow line which decreases from wet to dry. Environmental Impact is the aqua line which decreases from wet to dry.

As shown by the graph, it is not unusual for hybrid cooling technologies to reduce water use by 20-50% as compared to evaporative cooling while at the same time reducing energy use by 30-60% as compared to dry cooling. The key for the customer is to select the technology that provides a proper balance between all factors, including footprint and capital cost for their particular jobsite.

Several commercially available hybrid cooling technology options are described below. Each technology is designed to meet a slightly different set of jobsite requirements. They are listed in order of increasing available water savings.

**Parallel Path Wet Dry Technologies**

One currently available hybrid technology is the PPWD (Parallel Path Wet Dry) arrangement as shown in Figure 5 below. This technology was developed primarily for plume abatement and provides a minimal amount of water and energy savings.

The PPWD arrangement adds finned coils above a typical counter flow cooling tower’s spray distribution system. The coils, typically tightly spaced aluminum fins on stainless steel tubes, are arranged so that a portion of the hot water to be cooled passes through the tubes prior to being sprayed over the cooling tower media. This provides some sensible cooling of the water while at the same time increasing the air temperature. This warm dry air is then mixed with the saturated air from the cooling tower below, thus reducing the visible plume from the unit. The water savings from this technology is realized in the sensible cooling of the coils.

This technology has been commercially available for some time with its main advantage being plume abatement. Water savings is minimal, ranging from 5-20% maximum. This is because the vertically oriented coils are limited hydraulically to 36 ft in height to prevent cavitation in the top header. These coils will typically require a vacuum system connected to the top header. The tower structure is also much taller than an equivalent evaporative cooling tower, driven by the height of the coils. This arrangement adds complexity with the requirement for mechanically actuated dampers, and the start-up priming top header vacuum system. The dampers are not air tight and typically leak air that must be accounted for in the fan power calculation leading to a potential power increase of 10-20%. Water treatment is approximately the same as for non-hybrid cooling towers. Capital costs depend on the amount of plume abatement required. PPWD towers have not typically been used in the past for water conservation.

**Wet/Wet-Dry Technology**

A new technology in the hybrid field erected cooling tower market is a wet/wet-dry technology. This design is capable of improved plume abatement and water conservation versus the PPWD design at reduced cost.

The wet/wet-dry tower starts with a typical counter flow cooling design and replaces some of the cooling media with coils made with widely spaced stainless steel fins on stainless steel elliptical tubes. The coils are installed in parallel, in both air-path and water-path, with the wet fill section in the center, as shown in Figure 6.

In the summer mode of operation, part of the recirculating water flows over the coils using the coils as fill. In plume abatement or water conservation mode (wet-dry) mode, part of the recirculating water flows inside the coil tubes while the coils are dry outside (no spray). In wet-dry mode, the ambient air flowing over the coils heats up and mixes in the plenum with the saturated air from the wet fill to abate the plume and conserve water like in the parallel path wet dry unit (PPWD) described above.

This technology is excellent for plume abatement and can be extended to provide water savings beyond PPWD levels. The amount of water savings is directly related to the surface area of coil in the unit. Because of the horizontal arrangement, there is no hydraulic limit to added coil surface, reasonably allowing a 20-30%, or more, reduction in water use with almost no impact to energy use. Because the wet/wet-dry system is all on one level, the structure is the same height, making seismic design easier and less complex while also keeping total pump head at about the same levels as a standard non-plume abated tower. Also, the parallel air flow through the fill and coils does not need to be controlled with dampers, since the coils act as fill when water is allowed to flow over them. The plume abatement or water conservation is controlled by controlling the water flow to the coils via simple valves. It is recommended that the fans be controlled with VFD’s. Water treatment is basically the same as for non-hybrid cooling towers. For comparable plume abate-
ment performance the capital costs should be less than the PPWD. However, some additional plan area may be required. Greater water savings can be accomplished with additional capital cost.

**Eco Hybrid Cooler Technology**

The Eco Hybrid indirect cooling system is a newly developed design that fills a previously open niche between plume abatement and all dry cooling. This technology is available commercially in factory assembled units and can be scaled up to field erected applications. A prototype unit is undergoing testing at the EPRI Water Research Center at Georgia Power Plant Bowen. These units can provide additional water conservation beyond that of the wet/wet-dry system. A flow diagram for the Eco Hybrid cooler unit is shown in Figure 7.

**Figure 7: Flow Diagram for Eco-Hybrid Technology**

Hot water is cooled in two coil systems (upper dry coil and lower wet coil). The hot water flows in series through the interior of both coil systems. The upper dry coil is constructed of stainless steel tubes with marine grade aluminum fins. The lower wet coil can be constructed of either carbon steel hot dip galvanized tubes and fins or stainless steel tubes and fins. Figure 8 shows a photo of the upper dry coil; Figure 9 shows a photo of the lower wet coils.

During operation, the hot water passes first through the upper dry coil and then through the lower wet coil. When the Eco hybrid cooler is operating in dry mode, cooling is only accomplished by sensible heat transfer by the fan pulling air over the dry exterior of both coils (Figure 10). When the Eco hybrid cooler is operating in wet mode, water is sprayed over the lower coil; latent cooling of the spray water provides enhanced cooling of the water in the interior of the coil (Figure 11). The water in the spray loop requires water treatment to prevent biofouling and inhibit corrosion and scaling.

Depending on the unit selected, this technology can achieve more than 60% water conservation in comparison to evaporative cooling. It accomplishes this by providing a significantly higher switchover temperature that enables totally dry operation for much of the time each year. Any time the ambient conditions are below the peak design wet bulb temperature, one or more cells can be switched to dry operation. Below the dry switch-over temperature, all cells may be operated in dry mode, even for part of the day.

Since each cell (or sets of cells) has its own circulating evaporative water system that is isolated from all other cells, cells can be individually drained and operated only dry without water treatment. Each cell can have its own water treatment system which can be shut off during drained times. Since this is a closed system, the inventory of treated water can be reduced to a fraction of what is normally used with open systems. Additionally, the steam condenser maintenance is greatly reduced, and condenser tube scaling is practically eliminated. Another operational benefit is that particulate emissions (environmental impact) are reduced significantly as cells are operated in dry mode. For all of the benefits of this system, the cooling system is higher first cost, but reduced operational costs of water
treatment, reduced water costs, and reduced condenser maintenance can make up some of the difference. This cooling system will also require increased plan area.

Figure 11: Eco Hybrid Operating in Wet Mode

Typical 500 MWe Power Plant – Hybrid Wet-Dry Cooling

In each of the three hybrid technologies above, the customer has many options regarding the amount of dry vs. wet cooling available within each unit design making an absolute comparison of units impossible to provide. The PPWD option can provide up to 20% water savings as compared to evaporative cooling with a 10-20% power use penalty. The wet/wet-dry system provides increased water savings over the PPWD design with no change to unit height and no impact to energy use. The Eco-Hybrid system has the most available water savings of greater than 60% but has a high first cost and footprint requirement.

Unit selection and results will depend on the site’s specific priorities including available footprint, first costs, and savings priority (water vs. energy) and percentage. Customers looking to save the most water will do so at the expense of first cost, footprint and energy use, while customers looking to save the most energy will use the most water. Interestingly, with both the wet-wet/dry and the Eco-Hybrid technologies, the end user can change from water saving mode to energy saving mode using his controls system depending on the availability of water at that time.

Controls

Once a best technology is selected, its operation will need to be closely monitored by a controls system capable of shifting operation from wet to dry and back again as appropriate. Building control systems have long been incorporated into the cooling process but advances in hybrid technologies require sophisticated systems for the cooling units themselves. Only when properly operated and controlled, can the cooling system provide the water and energy savings modeled in the selection and design process.

Conclusion

As water and energy consumption become more closely regulated, customers in the power industry are looking for cooling solutions beyond their typical once-through and straight evaporative cooling options. Manufacturers of cooling equipment are responding to the industry need for technological advancements through hybrid wet-dry cooling solutions. Now customers can select from a broad spectrum of cooling technologies to find the solution that most closely meets their needs as they juggle the competing priorities of first cost, plan area, water savings and energy savings.
SAVE THE DATE
DEC. 8 – 10, 2015
LAS VEGAS CONVENTION CENTER
LAS VEGAS, NV
POWER-GEN.COM

THE WORLD'S LARGEST
POWER GENERATION EVENT

POWER-GEN INTERNATIONAL

OWNED & PRODUCED BY
PennWell

PRESENTED BY:
POWER Engineering

SUPPORTED BY:
NPI, Hydro Review, HRW, Renewable Energy World, Electric Light & Power, PennEnergy

POWER GENERATION WEEK 2015
ABSTRACT
Several aspects of sustainability apply to cooling systems. These are related to the integrity and availability of the system from an operational standpoint, and impact upon the environment and ecological balance. This involves a multitude of factors, disciplines and operation, not only of the subject cooling system, but also of outside services and ecological systems. This paper presents and discusses various factors and topics that have an influence upon the sustainability of a cooling system, related to the operation and longevity of the cooling system, and, impact upon the environment, with a view to improving sustainability.

DEFINITION AND SCOPE
Sustainability, as related to a cooling system, can be defined in two ways.

- “The ability to be sustained”.
  - In this context, “sustained” refers to keeping the system operating and efficient as a “process”.
- “The quality of not being harmful to the environment”.
  - In this context, impact on the environment, depletion of natural resources and ecology are the pertinent factors.

These two simple definitions encompass a vast array of factors related to a cooling system. These include design, operation, treatment, maintenance and repair of the cooling system, and very much relate to a given cooling system as opposed to all cooling systems, although some may be regarded as general “Good Practice” guidelines. The impact and result of certain facets reach far outside of the subject cooling system, plant or site, and may not be immediately obvious.

A form of energy associated with cooling system operation is electrical energy, and a natural resource is the source of the water used as make up water. Although some facilities or sites have their own power generation plant, the majority of cooling systems use electricity supplied by outside private or public electricity generating plants. The pertinent generation plant will have an impact upon natural resources with respect to fuel used and source of water used in their operating plant, environmental impact related to CO₂ and other gas emissions in the case of fossil fuel plants, and, thermal, chemical and ecological impact on the environment related to effluent discharge from the Power Generation Plant.

Sustainability of natural resources not only includes the water used in the cooling system but also natural resources used to produce materials used in the construction of the system. Production of metals would involve a metal ore or compound, and production of plastics, rubber and elastomers would utilize a fossil fuel feedstock. The production of these materials used in the cooling system would generate CO₂ and other gas emissions, energy consumption, water, and other aspects related to environmental impact and ecology. In the past, wood was commonly used in the construction of a cooling tower. These days most cooling towers are made of fiber reinforced plastic. Sometimes galvanized steel, coated steel, or stainless steel may be used.

Chemicals used in the treatment of make up water, cooling water and/or effluent from the cooling system would originate from a naturally occurring substance or compound, and their production would involve energy consumption and elements of environmental impact mentioned above. Aspects of Environmental Health and Safety (EHS) are also involved when considering the handling, dosing and addition of treatment chemicals.

Proper design is one of the most important factors impacting sustainability of open evaporative cooling systems. Systems are typically designed providing the maximum possible efficiency and production throughput to the process stream without considering the impact on cooling water. This may result in a series of deficiencies that finally impact process output. Systems designed with high skin temperature, typically above about 60 or 70 °C, exhibit a high potential for deposition and/or corrosion. This may require special, and possibly expensive, water treatment chemicals or optimization of hydraulics, of the process and/or water stream, in order to enable more sustainable and “trouble-free” operation.

Large industrial open evaporative cooling systems can be more susceptible to fouling as opposed to smaller “Commercial and Institutional” systems which can be more prone to scaling. The magnitude of fouling may depend on the type of industry and location. Steel Plant cooling systems can be exposed to continuous airborne contamination of iron ore. Deposition of ore in the cooling system reduces system sustainability to mitigate corrosion. Similarly, systems operating in aggressive weather conditions, such as, sand storms would suffer from high suspended solids and increased deposition corrosion and deposition potentials. Accumulated material such as corrosion products, mud, sand and suspended solids in cooling tower basin may reach the recirculating pump suction inlet due to long lead times between successive shut down periods or unavailability of blow down facilities in the tower basin. Circulating fouling material will not only cause deposition and corrosion to downstream equipment, but also clogging of tower fill causing reducing temperature drop across the tower impacting plant cooling efficiency. These systems should be fitted with efficient side stream filtration systems enabling sustainable and continuous operation.

Design concepts should consider constraints imposed upon the design or operation of cooling water systems which may limit the ability to mitigate or control corrosion, deposition, and fouling, and subsequent sustainable cooling capacity to process streams.

It is obvious that sustainability in cooling systems is a very complex subject, making it difficult to precisely segment cooling system related items into defined or finite aspects of sustainability. As one starts to examine the individual parts in depth, there can be a commonality and cumulative effect on environmental impact and ecology. However, in practice “reality” or “practicality” replaces “ideal” and therefore it is only feasible to “improve” sustainability related to system integrity and availability, and to “minimise/environ-mental impact of cooling system operation. The main areas where improvement, minimization or optimization, and conservation can be realized are energy consumption, heat exchanger efficiency and life, and water. In many cases some of these may be inter-related.
One Call Does It All!

Full Service Fabrication & Supply
Quick Response + On-Time Delivery

“Exceeding our customer’s expectations for over 35 years”

FRP Grating & Shapes  Fabrication & Assembly  Fiberglass Casing
Hardware & All Thread  Decking & Platforms  Treated Lumber & Plywood

Our customers benefit with significant labor cost savings and improved safety when fabrication and assembly are done at our shops

2 Locations:
West Coast & Gulf Coast
800-245-8158
www.cooltower.com

“Our FRP and forest products are proudly made & fabricated in the USA”
HEAT EXCHANGERS

Obviously heat exchanger cleanliness and integrity is vital to efficient cooling and plant performance. Effects on energy consumption have been mentioned in previous sections. In most cases effective cooling water treatment programmes, and in some cases process side treatments, are used to maintain heat exchangers in a good efficient condition. Corrosion will reduce the life of a heat exchanger. For economic reasons low carbon steel is a “favorite” metallurgy, where applicable, for shell and tube and spiral plate heat exchangers. Sometimes the original economic reasons are not what they seem when the low carbon steel heat exchanger needs to be replaced before its expected lifetime because of corrosion. Although more expensive, where applicable, replacement of the failed heat exchanger with one constructed of a more corrosion resistant metallurgy can, in the long term, be economically viable. More corrosion resistant metallurgy and longer heat exchanger life improves sustainability of the integrity and availability cooling system and reduces the environmental impact of the process of manufacturing replacement heat exchange equipment by reduction in the frequency of replacement.

Systems designed with shell side cooling, vertical heat exchangers or elevated heat exchangers are other design forms that may limit system sustainability. Such designs can lead to low linear velocity of cooling water, which in turn increases the potential fouling of the heat exchanger, resulting in higher approach temperature which may impact plant production throughput. These systems typically need more frequent or unscheduled maintenance increasing operation cost and reducing production capability.

Tube cleaning systems can be installed to minimize scaling and fouling of heat exchangers, particularly surface condensers. Provided they are correctly operated and maintained these systems can reduce energy consumption by keeping heat exchangers clean. If not maintained or if cleaning balls, brushes or bullets are “lost” in tubes they can potentially have a negative effect.

COOLING TOWERS

There are numerous designs of cooling tower basically falling within the broad classification of Natural Draft and Mechanical Draft Towers.

Siting and orientation of a cooling tower can have an effect upon the cooling efficiency of the tower. This is primarily to avoid or minimize recirculation of warm exhaust air, either from the subject tower or other nearby cooling towers, recirculating back into the air intake. Since the recirculated air is warm and saturated with water vapor it has little residual cooling capacity, reducing the cooling efficiency of the tower and wasting fan power and electrical energy.

Cooling towers are very efficient air scrubbers so another important aspect of the location of a cooling is related to potential contamination of the cooling water by airborne matter. This would mainly be airborne particulate matter from stock piles or roads, industrial gasses from the process or combustion, or airborne microbes or droplets containing microbiological material. Therefore, cooling towers should be located upwind of stock piles and/or other dust producing features or processes, away from major traffic routes within the plant.

Scrubbing of industrial gasses from the atmosphere can have an effect upon the pH and chemistry of the cooling water. With this in mind, cooling towers should be located up wind or away from chimneys and other areas emitting industrial or process gases. Having said that some cooling tower manufacturers propose “Flue Gas Injection” where flue gas from a desulphurization plant is injected into the cooling tower, by concept a Natural Draft tower, above the cooling water distribution area. This can minimise the need and cost of a new chimney. It also has some environmental benefits in that the emission from the desulphurization plant is not affected or influences by wind direction, and it is better dispersed because of typically greater air flow and velocity from within the cooling tower than from the atmosphere.

With regard to fouling, similar considerations apply to air cooled heat exchangers and dry cooling towers. Fouling of the air side heat exchange surfaces reduces cooling efficiency and wastes fan power and electrical energy. Some industrial gases in the atmosphere may corrode and damage the air side heat exchange surfaces, particularly aluminum “radiators” in dry cooling towers, resultant corrosion products impeding heat transfer.

Traditional cooling towers can be Natural Draft or Mechanical Draft Towers. Wet cooling towers designed as Natural Draft and Induced Draft Towers can be of a cross flow or counter flow design, whereas Forced Draft Towers are counter flow design. Dry cooling towers would typically be of a Natural Draft or Induced Draft Tower design. There are “hybrid” tower designs, one of which combines Wet and Dry Tower principles and the other Natural Draft and Forced Draft tower principles. Plume Abated Cooling Towers are of an Induced Draft tower design fitted with “radiators” on the outside of the cooling tower between the wet section of the tower and the fan. The dry section, through which the cooling water return initially passes, cools the fully saturated air exiting the wet section, reducing the Relative Humidity, and no plume, caused by condensing water vapor in the warm air, is visible. Some designs are capable of eliminating visible plumes down to air temperatures of 5ºC (40ºF), consequently reducing the environmental impact of visible plumes emitted form cooling towers. Fan Assisted Natural Draft Towers are of a Natural Draft Tower design with fans installed around the base or air intake section of the tower, combining the concepts of Natural Draft and Forced Draft Towers. This allows reduction in the height of the tower structure and power savings compared to a conventional Mechanical Draft Tower, subsequently reducing environmental impact.

The type of tower fill installed in wet cooling towers will have an impact on relative cooling efficiency of a given cooling tower. Generally film packing is more efficient than splash packing and significant improvement in overall cooling efficiency of a tower can be obtained by replacing splash packing with film fill. However, film fill can be more prone to fouling than splash packing which subsequently reduces the cooling efficiency of the film packed tower, and wastes fan power and electrical energy. There are several designs of film fill elements based on optimizing efficiency and/or minimizing fouling. As usual one cannot have the “best of both worlds”. The designs with lower fouling risk are less efficient than the high efficiency designs, and vice versa, the high efficiency designs are more susceptible to fouling.

Tower fill selection is a critical factor impacting system sustainability. There are several factors to be considered when selecting the optimum tower fill. Systems with a high fouling potential because of the environment inside the plant or within the vicinity of the plant, susceptibility to process leaks, etc. and/or operating at high cycles of concentration, should avoid using tower fill that is very susceptible to fouling, in order to avoid frequent blockage and unscheduled shut down of the cooling system. Open evaporative systems that cool process streams in Refinery and Chemical Process Industries should be designed to accommodate possible process leaks. This would incorporate installing tower fill with high fouling resistance that can tolerate moderate fouling caused by process leaks.

Biomass is often associated with material that is fouling cooling tower fill. Biofilm may be the initial trigger for fouling of the fill or associated with other foulant material, adding to the foulant mass...
but invariably also acting as a binding agent. Cooling tower fill is available that is made from polymeric material impregnated with compounds that inhibit the growth of sessile organisms, typically bacteria, which could otherwise create or contribute to fouling of the fill. There are also coatings which it is claimed can be applied to cooling tower fill and internals to “prevent bacteria from growing in cooling towers”. As this is said to be sprayed on it is difficult to see how it is applicable to plastic film fill of a cooling tower. Even if splash packing or low fouling fill is used it must be understood that any degree of fouling, plus associated water, adds to the weight of the packing or fill which can cause deformation of the packing or fill and van ultimately lead to collapse of the tower or tower internals.

**ENERGY**

Electrical energy is used to drive recirculating pumps, and to drive fans in the case of mechanical Draft cooling towers or indirect air cooled heat exchangers, also known as fin-fan closed cooling systems, and dry cooling towers. Fouling of heat exchanger tubes, distribution pipework causing increased friction, back pressure or blockage will increase energy consumed circulating the water. Fouling in heat exchangers affects cooling efficiency which may in turn affect production. In the case of compressors this reduction in cooling efficiency also causes an increase in electricity consumption for the compression of gases.

Fouling of the cooling tower fill reduces cooling efficiency which means less effective use of the electricity used to drive fans, and as described above may have a knock on effect on electricity consumed in the production process.

Maintenance of fans and pumps is obviously important to minimise energy consumption. Maintenance and repair of cooling tower cladding and fill, can also affect cooling tower efficiency. Damaged or missing cladding, displaced or collapsed fill can create voids through which air will preferably travel, therefore not necessarily contacting cooling water and subsequently reducing efficiency of the tower. This can be as simple as not closing the door of a cross flow tower or panels below fan level in the cowling that are not refitted so as to facilitate maintenance.

The Liquid to Gas ratio (L/G) of a wet cooling tower is the ratio between the water and the air mass flow rates through a cooling tower. To obtain or maintain maximum cooling tower efficiency, seasonal or meteorological changes require adjustment and tuning of water and air flow rates, or L/G, to get the best cooling tower effectiveness through measures like adjustment of water flow over the tower, fan speed, and/or the angle of fan blades. These would require certain abilities to be incorporated in the design and construction of the cooling tower or retrofitting in an existing tower. Either way this is a costly approach, two speed or variable frequency fans are probably the best lower cost option.

In cold climates it is possible to switch off fans and/or take cells out of service in cold weather during winter. Reducing water flow over the tower could be an additional or alternative approach but one must take into account the potential detrimental effect of reduced water velocity in heat exchangers. In warm climates these options are less clearly predictable and special predictive software advisable to determine the feasibility of reducing water flow or number of fans in operation. The installation of a cooling tower bypass, allowing partial bypass of the tower and/or cells, is also beneficial for optimizing energy consumption during cooler atmospheric conditions.

Associated with cold climates is freeze protection. Where applicable freeze protection must be installed and used in order to protect the tower from frost damage and potential collapse. Freeze protection techniques consume energy so part of “good housekeeping” is to turn off the freeze protection when not required, which may be a manual or automatic operation.

**WATER**

In terms of reduced water consumption and subsequent conservation of natural water resources, a closed cooling system or dry cooling tower will yield more sustainability than an open evaporative cooling system. However, relative cooling efficacy is less since there is no cooling by latent heat loss. This can result in a larger footprint being required for a closed system, with subsequent increased environmental impact. Usage of chemicals is significantly less in a closed system than other types of cooling system, and discharge of treated water to the environment should be virtually zero, except when the system is drained for maintenance.

Use of an alternative source of make up water may reduce environmental impact and conserve a valuable or scarce natural water source. Reuse of water as total or partial make up to an open evaporative cooling system is an example. Where practical and applicable, reuse of industrial or municipal waste water or secondary treated sewage is an excellent means of conserving natural water resources, although more cooling water treatment chemicals may be required.

Make up water requirement to open evaporative cooling systems can be supplied from surface water, seawater, potable water, ground water, desalinated water or treated sewage effluent (TSE). Surface water usually contains higher suspended solids and organic matter, as opposed to ground water, imposing the need for full in line or side stream filtration and efficient microbiological control regimes. Weather conditions may impose additional constraints on chemistry, quality or acceptable cycles of concentration, increasing both make up and blowdown requirements and subsequent water and wastewater treatment costs. Unlike surface water, ground water has lower suspended solids and variable, but typically lower, organic content. Total dissolved solids are typically higher than surface water which would limit the operating cycles of concentration or impose the need for desalination or other modification of the water quality.

Potable water can be considered among the most preferred options as make up to open evaporative cooling systems. Its availability and economics impose challenges to ensure reliable and cost effective application. A 150 MW cooling tower operating at four cycles of concentration would require between about 300 and 400 m3/h (between about 1,320 and 1,760 gpm) make up water.

Seawater is an abundant source for cooling water supplies. It contains approximately 3.5% sodium chloride or “salt”, which makes it aggressive to most of the metallurgies, requiring the use of expensive corrosion resistant metallurgy and lined pipework. These systems can be prone to fouling which can either be caused by scaling, deposition or microbiological activities. Most of the seawater cooling systems are designed with electro-chlorinators fulfilling the demand of oxidizing biocide required to control microbiological populations, slime formation or algae proliferation. Non-oxidizing biocide(s) can be optionally or additionally used to enhance microbiological control practices and to prevent the ingress of macro-fouling species into heat exchange equipment. Effective scale inhibition is critical to the sustainability of seawater systems. Many once-through seawater cooling systems exhibit scale formation potential tendencies due to changes in operating conditions or seawater chemistry. Seawater chemistry can change with time due to evaporation, increased desalination plants reject or increased seawater temperature due to reduced velocity of local current pattern. Open evaporative seawater cooling systems are typically operating at low cycles of concentration in the range of 1.2 to 1.3 cycles. New deposit control agents have been introduced allowing
operating at higher than 1.3 cycles depending on seawater chemistry. Plant design and local environmental regulations would be the final factors influencing increase of cycles.

Some plants use desalinated water to fulfill cooling water make up requirements. Despite the corrosive nature of desalinated water, typically neither storage facilities nor critical plant equipment are constructed with corrosion resistant material. Desalinated seawater is inherently more aggressive than brackish desalinated water due to its higher chloride content. Re-mineralization is typically required to enhance corrosion inhibition, lime being among the most economic options. Its limited solubility in cooling water increases the risk of precipitation in cooling tower structure, filters, low flow areas and critical equipment.

Increasing the operating cycles of concentration of an open evaporative cooling system will reduce water consumption for make up to the system and reduce discharge of blowdown water and treatment chemicals to the environment. Where scaling is a limiting factor on the cycles of concentration at which a system can safely be operated, slight reduction of the pH of the cooling water by using acid as part of the treatment program may allow operation at higher cycles of concentration. In the example of the 150 MW cooling tower given previously, increasing the operating cycles of concentration from four cycles to six would halve the blowdown rate required to maintain the target cycles and save between 37.5 and 50 m³/h (between 165 and 220 gpm) of make up water and effluent from the tower, an overall saving of more than 300,000 to 400,000 m³ (more than 1.4 to 1.9 million gallons) of water and effluent per year.

COMMISSIONING AND START UP

Cooling systems are susceptible to corrosion and/or deposition before and during start up. Commissioning practices can significantly impact the subsequent on-going cooling water treatment maintenance program performance and consequently system sustainability. Leaving stagnant water in cooling systems for several weeks after hydro-testing is a common oversight. Even if heat exchangers are drained, distribution pipework, particularly those installed underground, may be difficult or impossible to drain. Uninhibited stagnant water is left in unlined low carbon steel pipework for a significant period of time, corrosion will inevitably occur and corrosion products can be in the form of “flakes of iron oxide”, similar in appearance to exfoliation. In time these flakes or “iron chips” can become dislodged and transportation around the system invariably results in blockage or partial blockage of heat exchanger tube inlets and/or cooling tower distribution systems. This phenomenon can persist for several years. Stagnant untreated water is also an ideal environment for microbial activity and resultant biofilm formation and Microbiologically Influenced Corrosion (MIC).

Passivation, often accompanied by pre-cleaning, will extend the life of equipment and typically produce better results obtained from the maintenance chemical treatment program. In the days when chrome was used as a cooling treatment component, it was established that equipment that was passivated during or before commissioning and after every shutdown, cleaning and start up had a longer life than that only passivated during or before commissioning, which in turn had a longer life than equipment that was never passivated.

Cooling systems are typically designed with make up and blow down flow pipework to fulfill the hydraulic requirements within the range of normal design operation. Designers do not necessarily take in consideration the high make up and blow down flow that may be required during cleaning and passivation. This can result in the filling or draining of the system to require days rather than a few hours resulting in scenarios akin to water stagnation and corrosion through uninhibited water. Draining can also be affected by limited influent capacity of a receiving wastewater treatment plant if it is commissioned. Gradual disposal with the limited capacity of 25 – 30 m³ trucks is another possibility but a very time consuming process and elements of water stagnation scenarios.

TREATMENT PROGRAMS AND CHEMICALS

Apart from protecting a cooling system from corrosion and fouling, choice of the cooling water treatment program can possibly allow an open evaporative cooling system to operate at higher cycles of concentration and as a result conserve make up water and reduce discharge of water from the tower in the form of purge or “blow-down”. Certain advancements in treatment chemical technology develop chemicals that can be used at lower active concentrations and/or have a lower impact upon the environment.

SUMMARY

Sustainability in cooling systems is a multi-faceted subject involving design, operation and materials of construction.

In the design of new plant proven concepts of sustainability should be taken into account and applied. An installation can often be influenced by economics and operating costs, which can quite easily be calculated on a short term basis. Certain elements of sustainability may be of a more implicit nature, yet sustainability may be a crucial factor for the long term life and acceptability of an operating cooling system.

Facing reality, normally one has an existing cooling system that may not have been designed with too much sustainability in mind. Design and materials of construction are already fixed, and these together with the source and chemistry of the make up water will dictate, or at least have an influence, on the operation of the system. Sustainability becomes more of an ongoing improvement plan, encompassing improved design, maintenance, repair, replacement, energy conservation, water treatment, and, monitoring and control equipment. Replacement or refurbishment of equipment, particularly heat exchangers, with one of optimized or improved design and use of a more durable or corrosion resistant material of construction can improve sustainability.

When appropriate, upgrade splash fill or replacing plastic fill to a higher efficiency higher efficiency plastic fill, but be aware of higher potential fouling with the most efficient plastic fill designs. Increasing the efficiency of the fill may allow for a volume of fill, decreasing the height of the fill and subsequently the elevation of the distribution system, may result in a significant reduction of the pumping head and therefore saving of electrical energy.

Above all maintenance, repair, good practice and basic common sense can go a long way to ensuring or improving cost effective operation, reliability and sustainability of a cooling system. In the long term, cutting costs for maintenance, repair and replacement is not a wise judgment.
Engineering Problems... Into Solutions

For over 20 years, Kipcon has been designing and inspecting cooling towers of all types.

You need it... We design it
Kipcon Inc. provides structural designs for new cooling towers and retrofits of existing towers, whether it be a cross-flow, counter-flow, wood, concrete, fiberglass, wet and/or dry system. This includes basin design and basin load tables.

You have it... We inspect it
Kipcon Inc. also provides complete cooling tower inspection services and can develop remedial plans of action for retrofitted towers.

You want drawings... We will draft them
Kipcon prepares drawing packages, including erection plans, connection and fabrication details.

Call us today to discuss your cooling tower needs.
Attention Owner/Operators of Heat Transfer Systems*

(*Water Cooling Towers, Air Cooled Condensers, Evaporative Condensers and Fluid Air/Evaporative Coolers)

Benefits of CTI Membership:

- Networking with industry peers/experts in all aspects of heat rejection equipment, including water treatment, mechanical equipment, structural design and testing/certification procedures.
- Exclusive access to the Owner/Operator Council which provides a forum to meet with other Owner/Operator’s to discuss problems and issues related to your specific operation.
- 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.
- CTI offers an opportunity to all members to participate in developing standards and guidelines for their industry.

Become a Member of the Cooling Technology Institute (CTI)
Visit www.CTI.org to Sign UP

At the Owner/Operator Council meeting an attendee told us: “it helped solve a recurring problem which saved the company over $100,000.”
44th Turbomachinery
31st Pump SYMPOSIA
GEORGE R. BROWN CONVENTION CENTER
HOUSTON, TX | SEPT. 14 - 17, 2015

The premier conference for Turbomachinery and Pump professionals
DEVELOPED FOR THE INDUSTRY, BY THE INDUSTRY.

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

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

The history of the CTI STD-201 Thermal Performance 
Certification Program since 1983 is shown in the follow-
ing graphs. A total of 41 cooling 
tower manufacturers are cur-
rently active in the program. In 
addition, 8 of the manufacturers 
also market products as private 
brands through other companies. 
While in competition with each 
other, these manufacturers ben-
efit from knowing that they each 
achieve their published perfor-
ance capability and distinguish 
themselves by providing the 
Owner/Operator’s required thermal performance. The 
participating manufacturers currently have 97 product 
lines plus 14 product lines marketed as private brands 
which result in more than 19,300 cooling tower models 
with CTI STD-201 Thermal Performance Certification 
for cooling tower Owner/Operator’s to select from. The 
following table lists the currently active cooling tower 
manufacturers, their products with CTI STD-201 Ther-
mal Performance Certification, and a brief description 
of the product lines.

Those Manufacturers who have not yet chosen to certify 
their product lines are invited to do so at the earliest op-
portunity. You can contact Virginia A. Manser, Cooling 
Technology Institute, PO Box #681807, Houston, TX 
77268 for further information.
CTI STD-201 THERMAL PERFORMANCE CERTIFICATION PROGRAM

NUMBER OF PARTICIPATING MANUFACTURERS

Through 12/31/2014

YEAR

NUMBER OF CTI CERTIFIED TOWER MODELS

Through 12/31/2014

YEAR
NUMBER OF CTI CERTIFIED PRODUCT LINES

Through 12/31/2014

- Private Brands
- Manufacturer Brands

YEAR

NUMBER OF CTI CERTIFIED PRODUCT LINES

ECC (Eurovent) Certification Activity

Through 12/31/2014

- CTI Ceris With ECC Endorsement
- ECC Ceris With CTI Endorsement

YEAR

ECC (Eurovent) Certification Activity
## Cooling Towers Certified by the CTI under STD-201

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

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product Line</th>
<th>CTI Certification Validation Number</th>
<th>Revision Number</th>
<th>Date</th>
<th>Tower Type</th>
<th>Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggeco Cooling Tower Services</td>
<td>AG</td>
<td>08-24-01</td>
<td>1</td>
<td>July 24, 2010</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td>Amcost Cooling Tower Corporation</td>
<td>R-LC</td>
<td>11-20-05</td>
<td>1</td>
<td>March 4, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>American Cooling Tower, Inc.</td>
<td>ACT</td>
<td>10-38-01</td>
<td>3</td>
<td>June 23, 2013</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>ACTX</td>
<td>13-38-02</td>
<td>0</td>
<td>July 30, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>ACME E&amp;C Corporation, Ltd.</td>
<td>ACT-C</td>
<td>C32B-08R01</td>
<td>1</td>
<td>October 1, 2014</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>ACT-R</td>
<td>C32A-08R03</td>
<td>3</td>
<td>October 1, 2014</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Baltimore Aircoil Company, Inc.</td>
<td>ACT</td>
<td>09-11-12</td>
<td>3</td>
<td>July 30, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>FXT</td>
<td>02-11-01</td>
<td>2</td>
<td>September 22, 2006</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>FXV</td>
<td>09-11-09</td>
<td>0</td>
<td>November 11, 2012</td>
<td>Closed Circuit</td>
<td>Combined</td>
</tr>
<tr>
<td></td>
<td>PCT</td>
<td>10-11-13</td>
<td>0</td>
<td>April 10, 2010</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>PF2</td>
<td>12-11-14</td>
<td>0</td>
<td>December 1, 2012</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>PT2</td>
<td>C11L-07R03</td>
<td>3</td>
<td>March 31, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td>Bell Cooling Tower Pvt Ltd</td>
<td>Series V Closed VF1 &amp; VFL</td>
<td>09-11-10</td>
<td>1</td>
<td>March 3, 2009</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>Series V Open VT1, VT1, VTL &amp; VTL-E</td>
<td>C11B-02R05</td>
<td>5</td>
<td>June 30, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>Series 1500</td>
<td>C11H-04R09</td>
<td>9</td>
<td>March 31, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>Series 2000 A, G, D, E &amp; Compass</td>
<td>C11F-02R14</td>
<td>14</td>
<td>August 19, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Cool Water Technologies</td>
<td>BCTI</td>
<td>C42A-12R02</td>
<td>2</td>
<td>August 25, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td>Delta Cooling Tower, Inc.</td>
<td>RTAI</td>
<td>C52A-12R01</td>
<td>1</td>
<td>November 14, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td>Decsa</td>
<td>TM Series</td>
<td>02-24-01</td>
<td>1</td>
<td>January 1, 2010</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td>Elesco Technology (Beijing) Co., Ltd.</td>
<td>RCC</td>
<td>C42C-14R00</td>
<td>0</td>
<td>February 26, 2014</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td>ELSW &amp; ESWB</td>
<td>ELH</td>
<td>12-50-01</td>
<td>0</td>
<td>January 30, 2013</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>ELOD</td>
<td>C55B-14R00</td>
<td>0</td>
<td>October 1, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Etaa, Inc.</td>
<td>AT Series</td>
<td>C13A-08R16</td>
<td>16</td>
<td>September 19, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>ATWB</td>
<td>09-13-06</td>
<td>5</td>
<td>December 11, 2013</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>EOSA &amp; ESWB</td>
<td>05-13-05</td>
<td>7</td>
<td>September 30, 2013</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>L Series Closed</td>
<td>09-13-07</td>
<td>1</td>
<td>September 17, 2010</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>L Series Open</td>
<td>05-13-03</td>
<td>3</td>
<td>April 17, 2012</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>LMTQ</td>
<td>10-13-09</td>
<td>0</td>
<td>September 17, 2010</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>LMTQ</td>
<td>10-13-08</td>
<td>0</td>
<td>April 19, 2010</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td>GEA Polacel Cooling Towers B. V.</td>
<td>CF Line</td>
<td>04-25-01</td>
<td>1</td>
<td>July 15, 2013</td>
<td>Open Circuit</td>
</tr>
<tr>
<td></td>
<td>XF Line</td>
<td>13-25-02</td>
<td>0</td>
<td>August 1, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td>E.W. GOHL GmbH</td>
<td>ecoTec</td>
<td>C52A-14R03</td>
<td>0</td>
<td>September 15, 2014</td>
<td>Open Circuit</td>
</tr>
</tbody>
</table>
## Cooling Towers Certified by the CTI under STD-201

CTI Certification Validation Number: [http://www.cti.org/certification.shtml](http://www.cti.org/certification.shtml)
Revised 12/31/2014

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product Line</th>
<th>CTI Certification Validation Number</th>
<th>Revision Number</th>
<th>Date</th>
<th>Circuit Type</th>
<th>Heat Transfer Type</th>
<th>Fan Type</th>
<th>Airflow Type</th>
<th>Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guangzhou Lesan Technology Development Company, Ltd.</td>
<td>HMK</td>
<td>C45A-12R02</td>
<td>2</td>
<td>November 7, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>LMB</td>
<td>12-45-02</td>
<td>1</td>
<td>December 28, 2013</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>9</td>
</tr>
<tr>
<td>Hunan Yuanheng Technology Development Company, Ltd.</td>
<td>YHA</td>
<td>C45A-11R03</td>
<td>3</td>
<td>October 1, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>72</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product Line</th>
<th>CTI Certification Validation Number</th>
<th>Revision Number</th>
<th>Date</th>
<th>Circuit Type</th>
<th>Heat Transfer Type</th>
<th>Fan Type</th>
<th>Airflow Type</th>
<th>Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC/R International, Inc.</td>
<td>Therflow Series TFC</td>
<td>C20B-09R01</td>
<td>1</td>
<td>October 10, 2014</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Therflow Series TFW</td>
<td>C20A-03R03</td>
<td>3</td>
<td>October 1, 2014</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>33</td>
</tr>
<tr>
<td>Jactr</td>
<td>KS</td>
<td>13-48-01</td>
<td>0</td>
<td>November 13, 2012</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Centrifugal</td>
<td>Forced-draft</td>
<td>24</td>
</tr>
<tr>
<td>Jiangsu Deyang Cooling Tower Co., Ltd.</td>
<td>HLT</td>
<td>C59A-14R00</td>
<td>0</td>
<td>August 22, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>36</td>
</tr>
<tr>
<td>Ji'nan ChinTtech</td>
<td>CTN</td>
<td>C91A-14R00</td>
<td>0</td>
<td>July 25, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>CTH</td>
<td>C91B-14R00</td>
<td>0</td>
<td>July 25, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>8</td>
</tr>
<tr>
<td>KIMCO (Kyung In Machinery Company, Ltd.)</td>
<td>CKL</td>
<td>C18B-03R03</td>
<td>3</td>
<td>October 15, 2014</td>
<td>Closed Circuit</td>
<td>Combined</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Eco-Elys Cool</td>
<td>C18C-09R01</td>
<td>1</td>
<td>November 7, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Endura Cool</td>
<td>C18A-03R07</td>
<td>7</td>
<td>November 7, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>33</td>
</tr>
<tr>
<td>King Sun Industry Company, Ltd.</td>
<td>HKB</td>
<td>09-35-01</td>
<td>2</td>
<td>March 16, 2013</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Centrifugal</td>
<td>Forced-draft</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>HKD</td>
<td>09-35-02</td>
<td>2</td>
<td>March 16, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>KC</td>
<td>11-35-03</td>
<td>0</td>
<td>January 3, 2011</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>4</td>
</tr>
<tr>
<td>Liang Chi Industry Company, Ltd.</td>
<td>C-LC</td>
<td>C20B-09R01</td>
<td>1</td>
<td>November 18, 2014</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>D-LC</td>
<td>C20F-14R00</td>
<td>0</td>
<td>January 2, 2014</td>
<td>Open Circuit</td>
<td>Counter-Flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>R-LC</td>
<td>11-20-05</td>
<td>1</td>
<td>March 4, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>U-LC</td>
<td>C20D-10R03</td>
<td>3</td>
<td>November 18, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>V-LC</td>
<td>10-20-03</td>
<td>0</td>
<td>July 4, 2010</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Centrifugal</td>
<td>Forced-draft</td>
<td>40</td>
</tr>
<tr>
<td>Aquatower Series</td>
<td>01-14-05</td>
<td>2</td>
<td>July 15, 2009</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AR Series</td>
<td>98-14-04</td>
<td>2</td>
<td>April 22, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>MCW Series</td>
<td>06-14-08</td>
<td>2</td>
<td>May 1, 2007</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>MD Series</td>
<td>08-14-11</td>
<td>2</td>
<td>November 14, 2012</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>222</td>
</tr>
<tr>
<td></td>
<td>MHF Series</td>
<td>C140-04R06</td>
<td>6</td>
<td>September 28, 2014</td>
<td>Closed Circuit</td>
<td>Combined</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>549</td>
</tr>
<tr>
<td></td>
<td>NC Series</td>
<td>C144-02R17</td>
<td>17</td>
<td>August 11, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>411</td>
</tr>
<tr>
<td></td>
<td>Quadrant</td>
<td>92-14-02</td>
<td>2</td>
<td>April 11, 2000</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>MCC Series</td>
<td>C200-12R02</td>
<td>2</td>
<td>November 26, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>MCF Series</td>
<td>12-26-08</td>
<td>1</td>
<td>December 1, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>MXL Series</td>
<td>12-26-08</td>
<td>1</td>
<td>December 1, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>MXR-MK Series</td>
<td>C20C-08R05</td>
<td>5</td>
<td>November 21, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>214</td>
</tr>
<tr>
<td>Munters Corporation</td>
<td>Oasis PFC</td>
<td>12-48-01</td>
<td>0</td>
<td>November 28, 2012</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
<td>Forced-draft</td>
<td>5</td>
</tr>
<tr>
<td>NIBA Su Sogutma Kuleleri San. ve Tic. A.S.</td>
<td>HMP-NB</td>
<td>C55A-14R00</td>
<td>0</td>
<td>July 11, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
<td>Induced-draft</td>
<td>23</td>
</tr>
</tbody>
</table>
# Cooling Towers Certified by the CTI under STD-201

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

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product Line</th>
<th>CTI Certification Validation Number</th>
<th>Revision Number</th>
<th>Date</th>
<th>Tower Type</th>
<th>Manufacturer Revision Number</th>
<th>Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nihon Spindle Manufacturing Company, Ltd.</td>
<td>KG</td>
<td>12-33-02</td>
<td>1</td>
<td>December 30, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>OTT Company Ltd.</td>
<td>OTTC</td>
<td>12-44-01</td>
<td>1</td>
<td>May 16, 2013</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>OTTX</td>
<td>12-44-02</td>
<td>0</td>
<td>October 9, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>OTT-C</td>
<td>C44C-1MR90</td>
<td>0</td>
<td>January 2, 2014</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>OTTX-C</td>
<td>C44D-1MR90</td>
<td>0</td>
<td>January 2, 2014</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>Palarpuri Cooling Tower Ltd.</td>
<td>CF3</td>
<td>C51A-1MR901</td>
<td>1</td>
<td>May 19, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>OX-30K</td>
<td>C51B-1MR900</td>
<td>0</td>
<td>March 12, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>Protec Cooling Towers, Inc.</td>
<td>FRS Series</td>
<td>05-27-03</td>
<td>2</td>
<td>October 5, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>FWS Series</td>
<td>04-27-01</td>
<td>5</td>
<td>September 27, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>HPC</td>
<td>10-22-06</td>
<td>2</td>
<td>December 8, 2011</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>HRF</td>
<td>04-22-03</td>
<td>2</td>
<td>August 6, 2011</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>C22D-13R02</td>
<td>2</td>
<td>December 23, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>SLRT</td>
<td>C22G-13R02</td>
<td>2</td>
<td>December 23, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>RSD Cooling Towers</td>
<td>RSS Series</td>
<td>08-32-01</td>
<td>0</td>
<td>April 28, 2008</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FCS</td>
<td>10-27-04</td>
<td>0</td>
<td>February 22, 2010</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FDC</td>
<td>11-27-05</td>
<td>0</td>
<td>October 1, 2011</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FRS Series</td>
<td>05-27-03</td>
<td>2</td>
<td>October 5, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FVS Series</td>
<td>12-27-06</td>
<td>0</td>
<td>October 5, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FWS Series</td>
<td>04-27-01</td>
<td>5</td>
<td>September 27, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>05-27-02</td>
<td>3</td>
<td>October 5, 2012</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Shanghai Bafeng Machinery Manufacturing Company, Ltd.</td>
<td>BTC</td>
<td>12-49-01</td>
<td>0</td>
<td>December 1, 2012</td>
<td>Closed Circuit</td>
<td>Combined</td>
<td>Axial</td>
</tr>
<tr>
<td>Shanghai Liang Chi Cooling Equipment Co., Ltd.</td>
<td>LCM</td>
<td>C62A-14R900</td>
<td>0</td>
<td>October 10, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>Shanghai Yacht Cooling System Co., Ltd.</td>
<td>TCC</td>
<td>C10A-04R900</td>
<td>0</td>
<td>September 15, 2014</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>Shanghai Wenchang Cooling Equipment Company, Ltd.</td>
<td>FBH</td>
<td>13-54-01</td>
<td>0</td>
<td>September 4, 2013</td>
<td>Closed Circuit</td>
<td>Combined</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CM0A-14R900</td>
<td>0</td>
<td>August 22, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Sinro Air-Conditioning (Fogang) Company Ltd.</td>
<td>CEF-A</td>
<td>C37B-11R932</td>
<td>2</td>
<td>November 26, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SC-B Series</td>
<td>C37C-11R932</td>
<td>2</td>
<td>November 26, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SC-H Series</td>
<td>C37A-11R932</td>
<td>2</td>
<td>December 19, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
</tr>
<tr>
<td>Ta Shin F. R. P. Company, Ltd.</td>
<td>TSS Series</td>
<td>08-32-01</td>
<td>0</td>
<td>April 28, 2008</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>The Cooling Tower Company, L. C.</td>
<td>TCE Series</td>
<td>06-29-01</td>
<td>1</td>
<td>January 3, 2011</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>The Cooling Tower Company, L. C.</td>
<td>TYH</td>
<td>C45A-11R933</td>
<td>3</td>
<td>October 1, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>Tower Tech, Inc.</td>
<td>TXL</td>
<td>C17F-68R94</td>
<td>4</td>
<td>July 5, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Product Line</td>
<td>CTI Certification Validation Number</td>
<td>Revision Number</td>
<td>Date</td>
<td>Tower Type</td>
<td>Fan</td>
<td>Airflow</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
<td>------------------------------------</td>
<td>-----------------</td>
<td>------</td>
<td>------------</td>
<td>-----</td>
<td>---------</td>
</tr>
<tr>
<td>Truwater Cooling Towers, Inc.</td>
<td>EC-S Series</td>
<td>12-41-01</td>
<td>2</td>
<td>December 31, 2013</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>EX-S Series</td>
<td>12-41-02</td>
<td>2</td>
<td>December 31, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>VXS</td>
<td>13-41-03</td>
<td>0</td>
<td>July 18, 2013</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>Wuxi Fangzhou Water Cooling Equipment Co., Ltd.</td>
<td>FKH</td>
<td>C64A-14R00</td>
<td>0</td>
<td>October 31, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>Yantai Ebara Air Conditioning Equipment Company, Ltd.</td>
<td>CDW</td>
<td>C53A-13R01</td>
<td>1</td>
<td>September 1, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>CXW</td>
<td>C53A-14R00</td>
<td>0</td>
<td>September 12, 2014</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>York (By Johnson Controls)</td>
<td>AT Series</td>
<td>C13A-09R16</td>
<td>16</td>
<td>September 19, 2014</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>ESWA &amp; ESWB</td>
<td>05-13-05</td>
<td>7</td>
<td>September 30, 2013</td>
<td>Closed Circuit</td>
<td>Counter-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>LSTE</td>
<td>05-13-03</td>
<td>3</td>
<td>April 17, 2012</td>
<td>Open Circuit</td>
<td>Counter-flow</td>
<td>Centrifugal</td>
</tr>
<tr>
<td>Zhejiang Jinling Refrigeration Engineering Company, Ltd.</td>
<td>JNC Series</td>
<td>C28B-09R01</td>
<td>1</td>
<td>October 1, 2014</td>
<td>Closed Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>JNT Series</td>
<td>C28A-09R03</td>
<td>3</td>
<td>October 1, 2014</td>
<td>Open Circuit</td>
<td>Cross-flow</td>
<td>Axial</td>
</tr>
<tr>
<td>Zhejiang Wanxiang Science and Technology Company, Ltd.</td>
<td>FBH</td>
<td>13-54-01</td>
<td>0</td>
<td>September 8, 2013</td>
<td>Closed Circuit</td>
<td>Combined</td>
<td>Axial</td>
</tr>
<tr>
<td>Participating CTI Certified Manufacturers</td>
<td>Product Lines</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MANUFACTURER’S PUBLISHED THERMAL PERFORMANCE IS CERTIFIED BY THE COOLING TECHNOLOGY INSTITUTE UNDER THE PROVISIONS OF STD-201(13)
For nearly thirty years, the Cooling Technology Institute has provided a truly independent, third party, thermal performance testing service to the cooling tower industry. In 1995, the CTI also began providing an independent, third party, drift performance testing service as well. Both these services are administered through the CTI Multi-Agency Tower Performance Test Program and provide comparisons of the actual operating performance of a specific tower installation to the design performance. By providing such information on a specific tower installation, the CTI Multi-Agency Testing Program stands in contrast to the CTI Cooling Tower Certification Program which certifies all models of a specific manufacturer’s line of cooling towers perform in accordance with their published thermal ratings.

To be licensed as a CTI Cooling Tower Performance Test Agency, the agency must pass a rigorous screening process and demonstrate a high level of technical expertise. Additionally, it must have a sufficient number of test instruments, all meeting rigid requirements for accuracy and calibration. Once licensed, the Test Agencies for both thermal and drift testing must operate in full compliance with the provisions of the CTI License Agreements and Testing Manuals which were developed by a panel of testing experts specifically for this program. Included in these requirements are strict guidelines regarding conflict of interest to insure CTI Tests are conducted in a fair, unbiased manner.

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

### Licensed CTI Thermal Testing Agencies

<table>
<thead>
<tr>
<th>License Type*</th>
<th>Agency Name</th>
<th>Contact Person</th>
<th>Telephone</th>
<th>Fax</th>
</tr>
</thead>
<tbody>
<tr>
<td>A,B</td>
<td>Clean Air Engineering</td>
<td>Kenneth Hennon</td>
<td>800.208.6162 or 865.938.7555</td>
<td>(F) 865.938.7569</td>
</tr>
<tr>
<td></td>
<td>7936 Conner Rd Powell, TN 37849</td>
<td><a href="http://www.cleanair.com">www.cleanair.com</a> <a href="mailto:khennon@cleanair.com">khennon@cleanair.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A, B</td>
<td>Cooling Tower Technologies Pty Ltd</td>
<td>Ronald Rayner</td>
<td>61.2.9789.5900</td>
<td>(F) 61.2.9789.5922</td>
</tr>
<tr>
<td></td>
<td>PO Box N157 Bexley North, NSW 2207 AUSTRALIA</td>
<td><a href="mailto:coolingtwttech@bigpond.com">coolingtwttech@bigpond.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A,B</td>
<td>Cooling Tower Test Associates, Inc.</td>
<td>Thomas E. Weast</td>
<td>913.681.0027</td>
<td>(F) 913.681.0039</td>
</tr>
<tr>
<td></td>
<td>15325 Melrose Dr. Stanley, KS 66221-9720</td>
<td><a href="http://www.cttai.com">www.cttai.com</a> <a href="mailto:cttake@aol.com">cttake@aol.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A, B</td>
<td>McHale &amp; Associates, Inc</td>
<td>Bernie Pastorik</td>
<td>865.588.2654</td>
<td>(F) 865.934.4779</td>
</tr>
<tr>
<td></td>
<td>4700 Coster Road Knoxville, TN 37912</td>
<td><a href="http://www.mchale.org">www.mchale.org</a> <a href="mailto:bernie.pastorik@mchale.org">bernie.pastorik@mchale.org</a></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

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

### Licensed CTI Drift Testing Agencies

<table>
<thead>
<tr>
<th>Agency Name</th>
<th>Contact Person</th>
<th>Telephone</th>
<th>Fax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Air Engineering</td>
<td>Kenneth Hennon</td>
<td>800.208.6162 or 865.938.7555</td>
<td>(F) 865.938.7569</td>
</tr>
<tr>
<td></td>
<td><a href="http://www.cleanair.com">www.cleanair.com</a> <a href="mailto:khennon@cleanair.com">khennon@cleanair.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>McHale &amp; Associates, Inc</td>
<td>Bernie Pastorik</td>
<td>865.588.2654</td>
<td>(F) 865.934.4779</td>
</tr>
<tr>
<td>4700 Coster Road Knoxville, TN 37912</td>
<td><a href="http://www.mchale.org">www.mchale.org</a> <a href="mailto:bernie.pastorik@mchale.org">bernie.pastorik@mchale.org</a></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CTI Toolkit Version 3.1
...now Windows 7 compatible

A great opportunity to upgrade your CTI Blue Book Version 1.0 and CTI Toolkit Version 2.0 Software

Key Features of CTI Toolkit Version 3.1:

- **Air Properties Calculator**: fully ASHRAE Compliant psychrometrics. Interactive.

- **Thermal Design Worksheet** in the “Demand Curve” Tab which can be saved to file and retrieved for later review. Now with printable and exportable graphs.

- **Performance Evaluator** in the “Performance Curve” Tab to evaluate induced draft or forced draft, crossflow or counterflow cooling tower performance. Now calculates percent performance or leaving water temperature deviation. Data can be entered manually or with an input file. Automatic Cross-Plotting. Now with printable and exportable graphs.

- **New and Improved Help Files** guide you through the software, explain performance evaluation techniques and offer tips for use.

Now works with Microsoft Windows 7 and all earlier Windows Operating Systems back to Windows 95

16 MB ram recommended, and 3 MB free disk space required.

*Upgrade Now! Only $25/per upgrade from 3.0 for CTI Members ($40 for Non-Members)*

To Order, Call (281) 583-4087 or visit CTI’s Website [www.cti.org](http://www.cti.org)
Order Today
Call 281-583-4087

“The Performance Curve method is widely recognized as a more accurate method of determining tower capability from measured test data. The new CTI ToolKit Tab Application provides a quick and easy method for anyone to evaluate a performance test using this more accurate method.”

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

Bill to: ________________________________________________________________

______________________________________________________________

Phone: ___________________________ Fax: ________________________________

Email Address: _______________________________________________________

Ship to: ______________________________________________________________

______________________________________________________________

Phone: ___________________________ Fax: ________________________________

Email Address: _______________________________________________________

Charges can be made to Visa, MasterCard or American Express

Card No.: ____________________________________________________________
Expiration Date: ______________________________________________________
Signature: ___________________________ CVV; CVC; CID Code:__________

<table>
<thead>
<tr>
<th>Product</th>
<th>Unit Price</th>
<th>Quantity</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTI ToolKit Version 3.1 (single user license)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI Member</td>
<td>$395</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-member</td>
<td>$450</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI ToolKit Version 3.1 (Upgrade from V1.0 and V2.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI Member</td>
<td>$95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-member</td>
<td>$120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI ToolKit Version 3.1 (Upgrade from V3.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI Member</td>
<td>$25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-member</td>
<td>$40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PerfCurv 3.1 (Stand alone Performance Curve application)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTI Member</td>
<td>$195</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-member</td>
<td>$240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipping for CD-Rom (from Texas):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Priority mail $6; 2nd Day Air $18; Overnight Domestic $28; International (DHL) TBA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Multi-user site licenses and educational institution pricing available on request

System Requirements:
Microsoft Windows® 95/98, 2000, XP, and Windows 7
Index of Advertisers

Advance GRP Cooling Towers Pvt Ltd (India) .......................................................... 33
Aggreko Cooling Tower Services ...... 46, 47
AHR Expo .......................................................... 69
Amarillo Gear Company .............. 5, IBC
Amcot ............................................................ 35
American Cooling Tower, Inc........ 19
AMSA, Inc .................................................. 23
BailSco Blades & Castings, Inc ........ 65
Bedford Reinforced Plastics .......... 15
Brentwood Industries ................. 45
ChemTreat, Inc ........................................ 9
CTI Certified Towers ........ 82-88
CTI License Testing Agencies ....... 89
CTI Owner/Operators .............. 80
CTI ToolKit ........................................... 90-91
Cooling Tower Resources .......... 75
Denso ........................................................... 39
Dynamic Fabricators ........ 49
Electric Power Conference/Exhibition .... 13
Fuel Ethanol ...................... 61
Gaiennie Lumber Company .... 51
Glocon ............................................................. 3
Hewitech ................................................. 6
Hudson Products Corporation .... 29
IMI Sensors ...................................... 55
Industrial Cooling Towers ............ IFC, 2
Kipcon ...................................................... 79
KIMCO .......................................................... 7
Midwest Cooling Towers .... 57
Moore Fans ............................................. 17
North Street Cooling Towers ....... 53
Paharpur ..................................................... 43
Power Gen ............................................. 73
Qualchem .................................................. 42
Research Cottrell Cooling .......... 72
Rexnord Industries ....................... 21
C.E. Shepherd Company, LP .... 11
Simpson Strong-Tie .............. 25
Spraying Services, Inc ............. 37
SPX Cooling Technologies ............ OBC
Strongwell .............................................. 31
Tower Performance, Inc ........... 27, 92
Turbo Machinery ................. 81
Walchem ..................................................... 41

Tower Performance, Inc.
Cooling Tower Specialists

Since 1964, Tower Performance, Inc., has been providing full service to the utility, cogeneration, chemical, petrochemical, and related industries by constructing new cooling towers and upgrading and repairing all makes and models of existing cooling towers.

New Cooling Towers: • Counterflow • Crossflow • Wood • FRP

Professional Services Include: • Cooling Tower Evaluations • Bid Preparations • Wood Analysis • Thermal Engineering

Field Services Include: • Repair & Overhaul • Scheduled Maintenance • Inspection & Evaluations • Emergency Service

Nationwide Service

New Jersey Office: Toll Free: (800) 631-1196
NJ: (973) 966-1116
NY: (212) 355-0746
Fax: (973) 966-5122
E-Mail: stefan@towerperformance.com

Arkansas Office: Ph: (501) 236-3629
Fax: (870) 852-2810
E-Mail: ctbowers@tpilco.com

Missouri Office: Ph: (816) 500-5296
Fax: (816) 501-3784
E-Mail: badeshong@towerperformance.com

Pennsylvania Office: Ph: (215) 778-8027
Fax: (215) 938-8900
smorris@towerperformance.com

Texas Office: Toll Free: (800) 324-0691
Ph: (713) 643-0691
Fax: (713) 643-0310
E-Mail: ctf@towerperformance.com

Parts Sales:
Toll Free: (800) 314-1695
Ph: (970) 593-8637
Fax: (970) 472-1304
E-Mail: jfhitz@towerperformance.com
OVER 95 YEARS QUALITY BUILT HERE

AMARILLO Gear Company has built a worldwide reputation for building quality gear drives and composite drive shaft assemblies during its 95 year history. While others farm-out and piecemeal, Amarillo still designs and manufactures its gears and builds them in Amarillo, Texas.

Amarillo is ISO 9001:2008 quality certified and stands behind their extensive line of right angle spiral bevel cooling tower fan drives, including single and double reduction models.

They also 100% manufacture the high quality A Series drives for drop-in replacement of other manufacturer’s models, complete with the backing of Amarillo’s warranty.


Want to know more? Please contact or staff of sales representatives or gear engineers for a quick response to your fan drive needs.

www.amarillogear.com (806) 622-1273
info@amarillogear.com
Sometimes you just can’t compromise.

The Marley® Geareducer

Getting a Geareducer from an industry leader in cooling towers will put you at an advantage from the start. Features including quality gears and bearings, lower maintenance costs and increased service intervals on input and intermediate shaft bearings will make you glad you didn’t compromise. And now, SPX is offering rebuilt Marley Geareducers, as well as OEM repair service for your well worn Marley Geareducer. Go to spxcooling.com/geareducer to find the Geareducer Solution that is right for you.

MarleyMobile - A Cooling Tower App From An Industry Leader!

Marley’s many tools are now available anytime, anywhere at your convenience! The app offers the ability to select an application appropriate tower, calculate system water usage and quickly reach a Marley Sales Representative with rapid, one-touch connect. Download your MarleyMobile cooling tower app from Apple™ today or visit spxcooling.com/marleymobile!