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For Immediate Release
Contact: Chairman, CTI
Multi-Agency Testing Committee
Houston, Texas
2-September-2018

Cooling Technology Institute, PO Box 681807, Houston, Texas 77268 – The Cooling Technology Institute announces its annual invitation for interested thermal testing agencies to apply for potential Licensing as CTI Thermal Testing Agencies. CTI provides an independent third party thermal testing program to service the industry. Interested agencies are required to declare their interest by March 1, 2019, at the CTI address listed.

Future Meeting Dates

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<tr>
<td>July 15-18, 2018</td>
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<td>San Antonio, TX</td>
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<td>February 9-13, 2020</td>
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<td>The Peabody</td>
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<td>Steamboat Grand</td>
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<td>Steamboat, CO</td>
<td>New Orleans, LA</td>
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I am honored and excited to be your new CTI President. Since February I have had the opportunity to better understand how the organization operates and even the opportunity to visit the CTI office to appreciate the large number of files and property, such as giveaways, that CTI maintains. I want to thank Vicky, Donna, and Angie for their generous hospitality during my visit and their hard work in keeping CTI operating smoothly.

As has been mentioned in other “View From The Tower” publications, the organization prospers with the vast support and expertise of dedicated volunteer members who work on the numerous committees that seem to run effortlessly. I have had more than a few conference calls, even conducting one from the conference room at the CTI Headquarters during my visit. These calls have covered various topics, including the General Data Protection Regulation (GDPR). If you are like me, I am receiving an increased amount of emails asking if I agree or consent to the privacy policy of the respective organizational websites. These emails are probably linked to GDPR, which is an European Union law enacted to protect Personally Identifiable Information (PII) and give us control over our data. If an organization has any association with a European entity, they must comply. This includes the CTI which has recently updated its Privacy Policy. Penalties imposed for noncompliance are steep with fines determined through a tiered system. In this data-driven climate, we must be diligent in protecting members’ privacy from data breaches. I will be discussing more about this topic at our Summer Workshop.

As I write this, summer is officially on the horizon and for some of us, it will be a welcome change to a wet and dreary Spring. Summer not only brings warmer and drier (hopefully not too dry) weather, but also the anticipation of the CTI Summer Workshop. This year it is being held at La Cantera, outside San Antonio, Texas July 15-19. I look forward to working with the Board of Directors, all committee chairs, and attendees. Please don’t hesitate to let me know your concerns and how we can continue the success of CTI. I hope I will see you at our annual conference in New Orleans February 10-14, 2019.

Stay cool,
Helen Cerra,
CTI President 2018-2019

---

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Dear Journal Reader,

Welcome to Helen Cerra as the new CTI President. Those of you who may not have met her yet will be pleased when you do. After missing the February meeting, it will be good for me to see a lot of you again in July.

The following are some updates on things new and old at CTI:

The DOE fan rule has gone into limbo, its future is uncertain. California, however, has taken it up and after input from CTI and other organizations has followed much of what was agreed in the term sheet by the interested parties who participated with DOE, including CTI. Heat transfer equipment has been excluded from the California rule as in the DOE term sheet.

Another issue emerged with a proposed change by ASME to remove the exemption to the Boiler and Pressure Vessel Code, that has led to small diameter tubing and equipment being designed to other standards for many years without adverse safety issues. This could have profound customer impact due to the cost to gain ASME code stamps. CTI, along with multiple other organizations commented on the proposed rule. ASME issue a blanket interpretation as a response to all the commenters that did not change anything, and proceeded to move forward with the change. CTI and other organizations have responded that they aren’t resolved by the ASME interpretation. We shall see what comes of this.

On the Legionella management front, the CTI and ASHRAE guidelines are moving toward completion. Another document by NSF International, Standard 444, is being developed for multiple building water hazards, including Legionella. Time will tell whether there are issues with conflicting information, but many are working to prevent that from happening.

The Pitot tip design resulting from the CTI funded research project has been utilized to create new Pitot tubes for use in CTI Thermal Certification testing, and will become the standard for all testing sometime this summer.

Note that the European privacy rule which came into effect recently will affect CTI as it has many US organizations, as our membership is international. Expect to see some changes in how things are done by CTI going forward.

As many of you know, various of you in our industry have been sharing old pictures and other information about the early history of cooling towers with me. I haven’t had much time for that recently, but am continuing to collect and hope to put together some (hopefully) interesting things to share in the future.

Respectfully,

Paul Lindahl,
CTI Journal Editor
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INTRODUCTION:
The use of windscreens has been utilized in the Industrial and Agricultural Markets to provide performance and maintenance improvement solutions for over 30 years.

Most recently, the focus has been on improving the performance of Cooling Towers, Fin Fan Air Coolers, and Air Cooled Condensers in Refineries, Petro-Chemical Plants, Power Plants, Hospitals, Universities and other manufacturing facilities.

This paper will identify performance and degradation problems associated with fill clogging and fouling, freezing and winterization, plume abatement, re-circulation and interference. Case studies will be provided to illustrate solutions for these problems.

The paper will conclude with discussion and photographs of the application of wind screens as industry leading solutions in preventing mechanical equipment failures and increasing performance on Air Cooled Condensers and Evaporative Cooling Towers.

SECTION 1: Debris Filters
The Problem
The addition of external filtration is always a topic that is open to discussion. Any obstruction in the airflow stream will increase the pressure drop into the system. From a thermal perspective, increasing the pressure drop into a cooling system will reduce the airflow into that system which is essential for the effective transfer of heat into the surrounding environment – the primary function of a cooling system.

However, allowing contamination to build up within a cooling system where it is harder to remove, will detrimentally reduce the performance of a system over time. So, is the introduction of a pre-filter more or less detrimental to ongoing performance of that equipment?

Air Filtration is common place on many different types of equipment that we would regularly use, such as air-filters on vehicles, extractor fans, tumble dryers, electrical equipment and so on, so the case to install these devices on larger equipment may have already been made.

For industrial and HVAC cooling solutions the following non-exhaustive list may offer some reasons to consider filtration:

1. Clogging and fouling of internal components, caused by airborne seeds, insects and debris, restrict the movement of air and decrease air cooling performance. Foreign materials can work their way deep inside the cooling tower fill and are difficult, time-consuming, and expensive to remove, clean and maintain. Increased levels of deep cleaning leads to longer downtimes and more interaction with the more delicate parts of your cooling system, leading to more regular replacement of internal components such as fill packs and drift eliminators.

2. Increased levels of biological contamination provide nutrients for bacteria to feed on and grow. These increased levels can create environments that are protected from the treatment chemicals in the water reducing the efficiency of the biocides introduced into systems to kill the bacteria.

3. Reduced efficiency of the biocides leads to higher dosage rates, which in turn can have detrimental effects on the materials of construction exacerbating the problem by increasing corrosion levels in a system.

The overall effects of higher levels of contamination are an increase in operating cost and a reduction in performance reducing generating capacity, or system efficiency. Output goes down, resulting in lower yield and higher operating costs long term.

We may therefore have created a really good case to install filtration on a wide variety of equipment, but the practical aspect of installing large debris filtration cost effectively may be somewhat of a challenge. Cooling equipment can be huge, and responsible for moving large amounts of air, so creating a range of solutions to meet the demands of larger systems takes a special range of products. These products may have been born out of a desire to improve the comfort of livestock, but offer an extremely capable solution to industrial challenges.

Case Study #1
A large counterflow cooling tower required debris filtration on the air inlets. The inlet opening measured 98ft long x 10ft tall. Using a single rolling system on each side of the tower, the complete air inlet face on both sides of the cooling tower was covered with a filter that can be manually rolled away for access by a single operator. The screen remains tightly contained so there is no risk that it could be blown into other equipment or damaged.

Solution and Results
1. Stopped airborne seeds, insects, leaves, pine needles, birds and debris.
2. It was easily cleaned with a soft brush or vacuum.
3. Simple and fast installation with minimal additional steelwork.
4. Simple replacement of filters which just slide into the fixing systems, means that a full 70m (230 feet) can be replaced in a short period of time.
5. Minimal amount of framing materials means that the reduction in air inlet area is kept to an absolute minimum.
6. ROI realized in reduced cleaning materials and lower chemical demand.
7. Designed to trap foreign material but maintain airflow with minimal pressure drop.
8. These rolling screens are available up to 70m wide (230ft) and 5m high (16ft). Having long screens with the minimal amount of mechanical devices for movement means that costs can be kept to a minimum.
9. These rolling screens were manual systems, but automatic or electrically actuated systems are also supported.
10. Hardware and mechanical equipment available in standard and saline specifications.
11. The fixing systems are based on a continuous support profile that evenly distributes the load of the screens along the full length of the filter removing stress points associated with point fixings. This allows the screens to be tightly tensioned to prevent them from being drawn into the system or flapping around during varying load conditions, improving the life of the filters.
12. The screens are held under tension along the full length using ratchets that are simply released if access is required into the system to carry out maintenance functions.

SECTION 2: Winterization

The Problem

Extreme cold weather presents its’ own problems when it comes to cooling.

Cooling equipment uses ambient air to cool a process or system by transferring the heat across a very efficient heat transfer surface into the surrounding environment, simple and effective.

In cooling towers, antifreeze cannot be used as a constant volume of water is removed from the system to drain, to maintain a manageable level of impurities in the circulating water. Wide spread freezing can occur even when the air moving equipment has been switched off but water still flows down the outside of the tower. Even though the temperature of the water increases due to the reduction of air flow, the water can still be below the freezing point. Once icing begins to accumulate on the air inlet, structural damage is inevitable. If the operator is not pro-active in preventing these accumulations of ice from occurring, icing will persist throughout the winter months. Installing automated winter protection screens will reduce the flow of air into a cooling system and help to contain the heat within the system to reduce or prevent the effects of extreme cold.

In air cooled systems maintaining enough heat within the tubes is essential to prevent tubes from freezing and often splitting as a result. Split coils are difficult to fix and often require replacement or the affected areas being isolated reducing the cooling surface and performance, or leading to extended down time to carry out repairs or replacements.

Typically, the medium used to cool the system or process will be water mixed with some antifreeze to prevent freezing in the colder months. However, in extreme climates where the temperature can fall to -25-degree F and below, then even the antifreeze additive may not be enough.

Case Study #2

- Rolling Doors were installed on an Air Cooler.
- Using a compact tube mounted, motorized rolling door connected to a temperature probe in the circulating fluid, solid rolling doors were installed to automatically deploy to protect the coils from the effects of freezing winds, removing the risk of freezing.
- Fitting these automated doors to the unit was a simple case of installing customized brackets and runners to the air cooler frame.
- Manual overrides offer additional protection in the case of unexpected power failure.

Solutions and Results

- Automatic deployment when circulating water temperature reaches a minimum temperature was installed.
- Manual override to allow emergency deployment was installed.
- Prevents damage to industrial equipment caused by freezing and icing.
- Improved performance was realized through lower glycol content.
- Rolling curtains were available up to 70m wide (230ft) and 5m high (16ft) in a single rolling system.
- Either manual or automatic systems could be used.
- Standard galvanized hardware and equipment was used but saline specifications which utilize stainless steel and aluminium are available.
Installation of automated winter protection screens.

Screens designed to automatically deploy if the system temperature falls below a minimum set point.

Huge ice loads can build up on structures sometimes with catastrophic effects leading to collapse.

The effects of ice build-up on timber structures can shorten the lifespan of the material.

Icing in splash filled towers, either cross-flow or counter-flow, can lead to widespread internal damage to the fill, and reduced performance as well as debris collecting in basins.

SECTION 3: Plume Abatement

The Problem

1. Evaporative cooling towers reject heat into the atmosphere in the form of warm saturated wet air. The larger the heat rejection, the more water will be rejected into the environment, and in the right conditions this water vapor will form visible clouds above the cooling towers. On a large scale this could be considered as a safety concern, where plume may ground near equipment creating wet and potentially icy surfaces. This can result in icing on other equipment and/or power lines. It can obscure visibility on roads or around airports and, from the public perspective, people associate it with pollution.

2. Historically plume abated cooling towers often considered two distinct modes of operation, full evaporative mode and plume abated mode. These two modes were usually seasonally changed with the coils being covered during the summer months of operation to achieve maximum cooling, and opened during the winter months to achieve maximum plume abatement.

3. In many climates pluming occurs around 70% of the time from evaporative cooling systems. Cooling tower designs have often been based on a dual design point, where the cooling tower is operated in plume abated mode all the time, while achieving the summer design case.

4. The failure to include plume control on cooling towers has been driven by a number of factors. The cost of installing coil doors is relatively high and operators often failed to use the plume doors properly. Plume design points became more stringent meaning two phases of operation were insufficient. Many coil door systems suffered from the limited use, becoming seized or requiring considerable maintenance.

5. Many cooling towers that have been designed without plume control have additional capacity which would be available if the coils could be covered during warmer conditions.

6. Automated proportionate control can unlock cooling potential year round.

7. There are also many cases where plume abatement control is fitted, but due to the infrequent use often becomes seized and inoperative forcing users to operate in only one of the two potential modes of operation, leading to either excessive pluming or lower thermal performance.
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Case Study #3

• Using manually operated rolling doors to vary the airflow into the cooling towers, it is possible to increase the plume abatement effect of the cooling towers seasonally, so maximum plume abatement could be achieved in the winter and maximum evaporative performance could be achieved in the summer.

• The system was installed onto the units using customized brackets, runners, and drive chains that allowed the operation of doors which were installed around 15 feet above the floor.

Solutions and Results

The site was located near a residential area so plume abatement was a requirement of the planning application. As a way of reducing the visual impact, a greater degree of plume control was achieved by installing air side dampers, which can vary the airflow into a cooling tower, reducing plume formation thus increasing thermal performance.

• The solution was cost effective.
• The solution was an easy and fast installation.
• There was minimal additional steelwork required.
• Screens were available up to 60 meters or approximately 197 feet.
• The Return on Investment was realized in increased generating capacity.

Automated rolling doors have a single moving part and positional control for maximum performance and availability.

Manually operated plume doors, are often rarely operated leading to units remaining open or closed.

Manual rolling doors on a small plume abated system, to improve seasonal performance.

Louver systems rely on many moving parts to be maintained often leading to them seizing and then not being used.

SECTION 4: Recirculation and Interference

A common problem in the Power Industry is the lack of real estate at the plant sites. Many times this lack of real estate results in the installation of evaporative cooling towers in close proximity of each other. Depending on the prevailing winds and the exit velocity of the fans, many times interference occurs. Interference occurs when the plume of a cooling tower is drawn into the air inlet of another. Recirculation occurs when the existing air from a cooling tower is drawn back into its own air inlet.

Recirculation/interference are most obvious when the wind is blowing, and humidity is high causing a visible plume. The negative impact on thermal performance is always present, with or without a visible plume. Financial impact on the plant is most severe in the summer months when cold water temperature and power value are both at their highest values of the year.
Due to limited space and/or improper placement of evaporative cooling towers, discharge recirculation and or interference likely occurs in practical applications. The air recirculation and or interference may adversely affect energy efficiency of the plants and increase the potential of visible plume around the towers. In the worst case scenarios, the plants will be forced to de-rate because of lack of performance of the cooling towers. This can be reduced and possibly prevented.

Discharge recirculation and interference from cooling towers can now be evaluated by CFD modeling. It has been used throughout Europe and in some USA Plants to study the adverse effect of recirculation and or interference on cooling tower performance and plant output. By means of simplified modelling of the flow field internal to the cooling tower, based on characteristic curves of the fans and the global system resistance, it is possible to resolve the full air velocity distribution in the plant area. In such a way both recirculation and interference may be highlighted already during the design phase, implementing solutions to avoid performance reduction (i.e. wind screens, improvement of fans, change in plant layout) when the costs of project modification are minimal. Furthermore this tool can be employed to predict plume trajectories and assess pollution/contaminant diffusion in the environment as well as its deposition on the ground.

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Obviously, the solution to this problem is to prevent the hot, moist discharge air from entering another tower or its own air inlet opening. One solution in the past is to increase the exit velocity to force the plume from the fans higher and over the adjacent towers. This method has had limited success and is very expensive.

Another method which is more cost effective and can be more easily retrofitted to existing systems is the use of windscreens. These can be modelled using CFD Modeling, and the best location can be determined to reduce the detrimental characteristics of high winds on a cooling system. The screens can be stationary or retractable, to either allow operators to move the screens if the screens reduce performance in low wind speeds, or if high wind speeds could be a risk to the screens themselves.

Windscreens provide an alternative solution which is definitely worth evaluating.

**SECTION 5: Air Cooled Condenser Solutions**

The use of wind screens on an ACC first started in 1998 when screens were installed on the Kings Lynn 360 MW C.C. Power Plant in the U.K. The objective of the installation was to reduce the extreme fluctuations in back pressure caused by the effects of wind on the performance of their ACC.

The O.E.M. supplier of an ACC, designs an ACC to meet performance when the wind does not exceed the speed specified in the current test code. Recent codes have changed this value to 5 m/s (11 mph). This latter change has caused several ACC suppliers to install screens with a new ACC while others will supply screens when specified. However, your customer’s site may experience wind conditions frequently above the test code speed, thus they may be interested in a wind screen option.

**Benefits of Wind Screens:**

1. Improve ACC performance in windy conditions.
2. Reduce fluctuations in the back pressure produced by an ACC in windy conditions.
3. Avoid turbine trips.
4. Reduce stress on fan blades which can lead to blade and bolt failures.
5. Increase gear reducer life.
6. Reduce variations in fan motor amperage.
7. Reduce fouling of fins from air borne pollen and debris.

The California Energy Commission’s did a 17 month study which they financed where the benefits of wind screens have been quantified. This has been done by extensive field testing, wind tunnel modeling at U.C. Davis and CFD modeling. This effort has finished and the results are published on the California Energy Commission’s website.
SUMMARY:
Local environment and weather has a huge impact on the design of cooling systems and their long term operation. The result of the environment on cooling can be seen in every system around the world. Some plants require more regular cleaning and have more stringent design requirements. These plants can benefit from seasonal and environmental protection.

Installing filtration systems and seasonal protection devices can help to prolong the life of the equipment, reduce downtime, and increase performance.

With the development of larger, more cost effective and user friendly systems it makes these add on devices more accessible for equipment of all sizes.

One size does not necessarily fit all so each and every system should be reviewed on its own particular situation to determine whether any protection is required. The use of wind screens can provide an alternative solution which merits evaluation.
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Underwater Robotic Technology for Online Tower Basin Cleaning

Randi Lee Morgan and Joe Leist
Scantron Robotics USA, Inc.

Introduction
Increasing safety in the workplace is often considered a leading motivator in the forward advancement of industrial technology. One such advancement, motivated by safety concerns, is in the field of industrial tank cleaning. A company in Houston, Texas has developed an innovative way to use robotic technology to clean water tanks, especially cooling tower basins, in which workplace safety is drastically increased and results are achieved without any interruption to the normal function of the tank. The purpose of this paper is to introduce online robotic cleaning technology and offer a comprehensive understanding of how its benefits are superior to those of traditional tank cleaning methods.

Definitions
Confined Space
A confined space is defined by OSHA as “a space which, by design, has limited openings for entry and exit, unfavorable natural ventilation which could contain or produce dangerous air contaminants, and which is not intended for continuous worker occupancy.”

A Permit-required confined space is defined by OSHA as “a confined space that has one or more of the following characteristics: contains or has the potential to contain a hazardous atmosphere; contains material that has the potential to engulf an entrant; has an internal configuration that might cause an entrant to be trapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross section; or contains any other recognized safety or health hazard.”

Industrial Water Tank
Industrial water tank is a broad term used to describe any large structure that holds water. For the purposes of this paper, the term industrial water tank (or sometimes referred to as water tank or tank) describes a permanent tank structure in an industrial facility that contains liquid that is not explosive or corrosive and is most often classified as a permit-required confined space, as defined above by OSHA.

Turnaround
A turnaround (also referred to in this paper as an outage) is a term used to describe a scheduled period of time in which an entire facility or unit within an industrial plant is removed from service to complete various tasks such as routine maintenance, repairs, inspections, and testing.

Current Industry Standards
Three of the most common methods used to clean industrial water tanks are vac trucks, divers, and offline robotics. These current industry standards involve dangerous confined space entries which risk the health and safety of workers; require facility wide turnarounds or outages that are chaotic in trying to complete many high priority tasks in a relatively short period of time; and have a higher overall cost when taking into consideration the money spent and productivity lost. These methods are explained in more detail below.

Vac Trucks
This method requires the tank to be completely removed from service; therefore, is always completed during a facility outage or turnaround. The liquid contents of the tank are drained and should be safely disposed of, which can incur costly fees, especially if the waste is environmentally hazardous. A permit-required confined space entry takes place and the worker enters the tank, often through a very narrow hatch and maneuvers himself to the tank floor. Once there, the worker uses an industrialized vacuum that is connected to a large truck located outside of the tank to suction the sediment from the tank floor. Once complete, the tank is refilled with water and chemically treated with whichever chemicals the process requires.

Divers
In recent years, the advancements in underwater technology has expanded to allow the use of divers to clean the sediment from an industrial tank. Some dive companies even boast the ability to clean a tank while it remains online - only turning off the pumps. This technique may save the client company from some of the inconveniences and costs associated with taking the tank out of service, but this method drastically increases the liability and safety risks of the job. Furthermore, undesired turbidity inside the tank becomes a significant concern with the diver method due to the action of swimming by the diver.

Offline Robotics
Robotic technology has already found its way into the field of industrial tank cleaning and it has had some success at reducing human exposure to confined spaces, however; its current offline methods have limitations. The robots used in offline robotic methods are non-submersible, which means that the cleaning must be done during an outage or turnaround and the tank must be drained of its liquid contents; are inefficient and often require confined space entry by vac truck workers to clean up any sludge left behind after
the robot is removed from the tank; and are cumbersome, weighing as much as 500 pounds, having the potential to damage structural elements of the tank. Although offline robotic methods are a great start to improving the safety in the field of industrial tank cleaning, these limitations drive up liability and costs, ultimately making this technique very expensive and do not offer the overall benefits that online robotic methods can provide.

Comparison

When we compared the average costs of every element of our cleaning services to those of a dive company, we proved to be significantly less expensive all while maintaining the productivity of the facility and eliminating confined space entry. The graph below represents information we’ve gathered regarding the average daily costs associated with the online robotic and diver methods of tank cleaning.

![Figure 1 - Tank Cleaning Methods Cost Comparison (Average Daily Cost $USD)](image)

Other than the obvious monetary comparisons discussed above, we noted the following non-monetized comparisons between online tank cleaning methods and other tank cleaning methods.

<table>
<thead>
<tr>
<th>Non – Monetized Cost Comparison</th>
<th>Online Robotic Cleaning</th>
<th>Other Cleaning Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Special Permitting</td>
<td>$0</td>
<td>$</td>
</tr>
<tr>
<td>Outage/Turnaround Planning</td>
<td>$0</td>
<td>$</td>
</tr>
<tr>
<td>Outage/Turnaround Execution</td>
<td>$0</td>
<td>$</td>
</tr>
<tr>
<td>Draining, Refilling, &amp; Chemically Treating New Tank Water</td>
<td>$0</td>
<td>$</td>
</tr>
</tbody>
</table>

![Figure 2 - Non-Monetized Cost Comparison Chart](image)

Online Robotic Tank Cleaning Method

Online robotic industrial tank cleaning was developed in 2010 to address the safety concerns associated with the traditional methods of tank cleaning. Inspired by industrial pool cleaner robots, the first online industrial tank cleaning robots were designed for the potable water industry. Despite bulky equipment, and inefficient methods, these robots showed success in removing sediment from potable water tanks while the tank remained online, and without the need for confined space entry by people. Since then, online robotic technology has evolved and can now accommodate a much wider array of tank applications and industries.

Process

Step 1: Deploy robot

The robot is carefully deployed into the tank by the use of a custom crane or by the use of a crane operated by the client facility. The robot is lowered to the tank floor and the on-board pumps are immediately engaged to avoid causing turbidity as it makes contact with the sediment.

![Figure 3 – Illustration of the online robotic industrial tank cleaning process](image)

Step 2: ROV operators navigate the robot throughout the tank

ROV operators use a control box to operate the robot, its auger, and pump. The live-feed cameras and lights attached to the robot frame are tools that operators use in order to help them navigate throughout the tank. In instances of low visibility due to poor water quality, operators will navigate the robot with the help of blueprints and measurements.

![Figure 4 - Robot being deployed into a tank using custom crane](image)

![Figure 5 - Online robotic tank cleaning operator](image)
Step 3: Auger breaks up tough sediment as it is pumped to dewatering site

Depending on the type of material that the sediment is comprised of, different augers will be outfitted to the front of the robot. Most often, a stainless steel auger will be used, but in instances where the tank has a liner, such as a rubber liner, a brush auger can be used as to avoid damaging the liner.

A powerful on-board pump that works to eliminate the creation of turbidity as the robot moves throughout the tank suck the water/sludge mixture through a series of hoses to the dewatering site. Turbidity is a major concern for most clients, therefore, careful consideration was taken in the placement of the pump on the robot. The footprint of the suction capability on the most current robot model extends approximately 2 feet in every direction from the base of the robot, further alleviating any potential for turbidity.

Step 4: Polymer Injection

A polymer can be injected into the system and can increase the speed at which the suspended solids fallout, ultimately increasing the efficiency of the remediation and dewatering process. Polymers are always discussed with the client company and approved prior to use in any system.

Step 5: Remediation and Dewatering

Most industrial water is chemically treated with expensive chemicals, such as chlorine or polymers, to help combat fouling or corrosion, and disposing of such liquid waste can incur costly disposal fees and negatively impact the environment. By separating the solids and liquid, clean water is recycled back into the tank and dry material is left for disposal. Disposal fees can be up to 7 times more expensive for liquid waste than dry waste; therefore, this step is essential to reducing the costs associated with waste disposal.

The sludge/water mixture is dewatered and remediated in preparation to return clean water back into the tank. Common methods of dewatering include one or a combination of plate/filter presses, dewater boxes, weir tanks, geo bags, centrifuges, and other filtering methods.

Step 6: Clean water is recycled back into the tank

Clean water is continuously pumped (recycled) from the dewatering site back into the tank which can drastically improve water quality throughout the duration of the project.
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Cleaning ROV’s
The current robot design was introduced in 2014 and has been so successful that it has not undergone any major change in design or cleaning technique since its introduction. Minor modifications have been made to accommodate challenges presented by varying structural elements that are present in different types of tanks. These modifications include interchangeable augers and tracks and various frame sizes to accommodate the smallest of hatches and the largest of projects. Robots can also be fully customized for tanks with unique obstacles or oddly shaped/sized access points. These robots range in weight from 100 to 300 lbs.

Safety
Based on statistics published by the Department of Labor, approximately 96 people die each year in confined space entry accidents. Of those fatalities, 61% occur during construction, repairing, or cleaning activities. Traditional cleaning methods, more often than not, require some form of confined space entry into the tank or cooling tower. However, robotic cleaning technology seldom requires the need for man to enter into dangerous confined spaces for necessary routine cleanings or inspections, therefore eliminating the potential for a worker to be injured or killed. Robots enter and exit the confined space by rigging set up outside of the tank access point. If something should happen inside of a tank that would require the removal of the robot, it can be quickly and easily removed by its tether without damaging the tanks structure. In the unlikely event that the robot is damaged in any way, it can be easily repaired or replaced; human lives aren’t so durable or replaceable. The safety concerns associated with this method are limited to general industrial precautions. Utilizing robotic cleaning services that do not require confined space entry reduces planning and preparation times, the coordination of permit required protocols, costs, and liability. Furthermore, online robotic tank cleaning does not have to expose humans to extreme weather conditions. Technicians can control the robot in the safety of a nearby trailer while the robot continues to work and endure extreme hot or cold temperatures. The only exception to this is if the temperature drops below freezing for an extended period of time. The image below is of an online cleaning robot when removed from a tank in sub-zero temperatures.

Other Useful Online Robotic Technology
Inspection Services
Online robotic technology is also available for in-depth tank inspection services. Instead of using divers or draining the tank for inspections, these smaller robots are fully submersible and are equipped with special cameras and lights, similar to those of the cleaning robots, to record the condition of the tank. The capability of these
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ROV’s include: a comprehensive hi-definition video recording of a tanks underwater structural elements and its related infrastructure, corrosion, and sediment build-up; API-653 certified inspections; and ultrasonic thickness testing.

Figure 13 - Inspection robot

Figure 14 - Inspection robot

Sediment Mapping Services

More often than not, sediment levels in a tank are inaccurately estimated, which results in inaccurate quotes with regard to length of services, rental equipment, and budget. Sediment mapping is a proprietary solution for measuring sediment levels in a tank and provides an extremely accurate representation of the landscape of the accumulated sediment. This information allows facilities to be more prepared than ever before for inspections, cleaning and remediation services, outages, and other maintenance needs.

The method used to map sediment levels throughout a tank involves the use of an imaging sonar attached to an underwater ROV that is programmed to swim in a grid pattern collecting data from intervals throughout the tank. As many as 500 data points are collected in an average sized cooling tower basin; this provides an adequate map of the sedimentation and can serve as a basis for the future cleaning of the basin.

Accumulated sedimentation measurements are calculated by the following manner: the imaging sonar unit measures the depth of the sediment from the water surface by the sonar as shown below.

\[ H_{\text{sediment}} = H_{\text{drawing}} - (H_{\text{measured}} + H_{\text{sonar}}) \]

- \( H_{\text{sediment}} \) = sediment height
- \( H_{\text{drawing}} \) = distance between water surface and tank floor, as measured from water level and basin diagram
- \( H_{\text{measured}} \) = Distance between sonar and sediment, as measured from sonar
- \( H_{\text{sonar}} \) = Height of sonar from water surface

A sediment heat map is created based on the data collected by the sonar, which provides a visual representation of the landscape of the sediment on the tank floor.

Figure 15 - Sediment Heat Map

Three dimensional topographic maps are also created using the information provided by the imaging sonar.

Figure 16 - 3-D Topographic sediment map
Conclusion – Setting The New Standard

Robots that replace humans in the workforce are often seen as a negative consequence of technological advancement; however, robots that replace humans in dangerous and deadly environments should become the industry standard and viewed as a technological win for everyone.

Although the use of online robotic technology is becoming a well-respected and widely used method, it has not yet become the industry standard. First and foremost, online robotic cleaning is a new approach and people are naturally more comfortable doing things as they've always been done before. Secondly, the total cost impact of the cleaning is often spread across several budgets, and those responsible for contracting for cleaning services should consider the entire cost of the cleanings and not just the specific portion of the budget that impacts their department. Overall, cost reductions can be achieved using this method, even though some individual line item costs may increase.

Due to the wide array of benefits using online robotic technology offers, as described in this paper, we feel confident that this method will soon become the standard of industrial tank cleaning.

References

Comparative Evaluation of Pitot Tube Designs for Water Flow Rate Measurements

By Ken Hennon, P.E. and David Wheeler, P.E.
Clean Air Engineering

Summary

The Cooling Technology Institute (CTI) has long supported accurate performance tests for evaporative cooling systems. Accurate water flow rate determination is critical to the performance characterization of any cooling system. Historically, this measurement has been made via the industry standard Simplex pitot tube. Because Simplex pitot tubes are difficult to obtain and have known accuracy problems in challenging settings, CTI contracted CleanAir Engineering to investigate alternative pitot designs. Two candidate designs, an elliptical pitot and a modified Fechheimer pitot, were evaluated in controlled hydraulic laboratories and contrasted to the Simplex pitot tube.

All three pitot tubes were initially calibrated at the TVA hydraulic laboratory in Norris, TN. Following the calibrations, the pitots were used to calculate flow rates when the measurements were made in pipe locations designed to have a disturbed flow profile. Comparison of the pitot based flow calculations versus the calibration flow standard was used to provide an estimate of the accuracy of each of the pitots in these challenging measurement locations.

All three pitot designs were found to provide accurate flow predictions when the measurement location was placed where the flow profile was well developed. The flow rate determined with the Simplex pitot tube has very high positive errors in the most disturbed flow situations, and the amount of error increases with the severity of the disturbance.

Based on the results of this study, it is recommended that the elliptical pitot design be adopted as the new standard measurement device for water flow measurements. The justifications for this recommendation are:

- The flow measurements made with the elliptical pitot tube are much less sensitive to flow disturbances than the Simplex pitot tube. The sensitivity to flow disturbance is similar to that of the Fechheimer pitot tube.
- The tip design of the elliptical pitot tube permits measurements closer to the pipe wall than the Fechheimer pitot tube.
- The pitot coefficient for the elliptical pitot tube showed a very low dependence on Reynolds number. This is a very desirable characteristic because it reduces the number of calibration points required to accurately determine the Reynolds number dependent pitot coefficient.
- The coefficient determined at each Reynolds number had the least deviation from the Reynolds number dependent calibration curve for the elliptical pitot tube as compared to the other pitot tubes.

Introduction

Overview

The Cooling Technology Institute (CTI) has long supported accurate performance tests for evaporative cooling systems. A critical parameter for performance characterization of any evaporative sys-

Figure 1 Simplex Pitot Tip

The coefficient determined at each Reynolds number had the least deviation from the Reynolds number dependent calibration curve for the elliptical pitot tube as compared to the other pitot tubes.
Pitot Tip Designs

Simplex Pitot Tube

The Simplex pitot tube is the industry standard design which has been used for cooling system measurements for decades. The design of the Simplex tip is illustrated in Figure 1.

Elliptical and Modified Fechheimer Tube Designs

Two candidate tip designs, the elliptical and the modified Fechheimer designs, were manufactured for this project. All three pitot tube designs; Simplex, elliptical, and Fechheimer; are equipped with a total pressure (impact port) and two static pressure ports. The elliptical design is illustrated in Figure 2. The modified Fechheimer design is illustrated in Figure 3.

For the elliptical tip design, the total and static ports are located 0.125 inches from the pitot tip. This is identical to the Simplex design. The two static ports on the sides of the elliptical tube are connected to tubes which run the length of the hollow circular extension tube. The differential pressure between these ports can be used to rotate the elliptical probe to align with the flow vector at each sampling station. The elliptical design is illustrated in Figure 2.

The elliptical and Fechheimer tip designs included a 1.125-inch cylindrical section beginning 2 inches from the end of the tube. The transition between the elliptical section and the cylindrical section is a 0.125-inch conical section. Brass was used to fabricate both tips.

Other Features

The elliptical and Fechheimer tips were attached to a 1-inch stainless steel tube (extension tube). The impact and static pressure ports were connected to 1/8-inch stainless steel tubes which pass through the extension tube to a tail piece which provides a connection point for the pressure lines. A packing gland to accommodate the 1-inch extension and a protractor plate (for determining the angle of rotation) were also fabricated.

Initial Calibration

Calibration Methodology

The initial calibration of each of the pitot tube was conducted at the TVA Norris calibration facility, which has an NIST traceable meter as a reference standard. Calibration runs were performed for each pitot tube at five velocities ranging from 3 to 20 ft/sec in a 14-inch pipe.

Two twenty-point traverses with the Simplex and the elliptical pitot tubes were conducted through perpendicular taps installed at the traverse location. Ten point traverses were conducted with the Fechheimer pitot tube because the distance from the end of the tube to the sensing ports restricts access to the far wall of the pipe. The traverse location for the calibration study was 24 feet downstream of the nearest flow disturbance. The measured internal diameter of the pipe at the traverse point was 13.19 inches.

Unheated water circulates through the TVA flow facility but, the temperature rises slightly during calibration runs due to heat added by the pumps. All calibration runs were done with water temperatures between 68 and 73ºF.

The static ports of the elliptical and Fechheimer pitot tubes were connected to a Tee upstream of the pressure transmitters. The differential pressure between the total and static ports was read by two Rosemount 3051D pressure transmitters calibrated immediately before the measurements to a tolerance of 0.1-inch over a 150 inwg range. The differential pressure was periodically read with an air-over-water manometer installed in parallel with the pressure transmitters to ensure transmitter accuracy. The analog output of the pressure transmitters was scanned a 2 second intervals for approximately 20 seconds at each measurement point.

Blockage

There is currently no consensus in the industry about the use of a correction for area blockage in the computation of pitot coefficients and field measurements. CTI STD 146 reflects this lack of consensus by allowing but not requiring corrections for blockage. For both of the new tip designs, the attachment rod is a 1-inch cir-
cular tube. For these tubes, area blocked by the pitot tube is much greater than that of the traditional Simplex design with the oval attachment tube. For instance, in the 14-inch pipe used for the pitot calibrations, the average blockage for the elliptical pitot tube was 4.1 percent of the total area of the pipe. For the 6-inch pipe used in the pipe diameter study, the average blockage area was 7.3 percent of the total area at the measurement location. The large blockage area for these tubes has the potential to significantly affect the flow profile and, therefore, the value of the pitot coefficient.

The effect of blockage on the apparent flow profile is illustrated in Figure 4.

![Figure 4 Flow Profile Elliptical Pitot Tube: 14-inch Pipe 12 ft/s](image)

In Figure 4, the square root of the measured differential pressure (proportional to velocity) is plotted against the relative radial position, which is the distance from the center of the pipe to the measurement location. The radii are numbered clockwise from the upper left. The differential pressure readings from radii 3 and 4 (those farthest from the tap) are considerably higher than those from radii 1 and 2. Since the velocity profile would be expected to be uniform at the calibration location, it seems likely that the pitot blockage is affecting the measured differential pressure readings. The differential pressure readings corrected for blockage are presented in Figure 5.

The blockage corrected square root of differential pressure at each measurement point was calculated by:

$$\sqrt{\Delta P_{bc,i}} = \sqrt{\frac{1}{\Delta P_{i}} A_t - A_{b,i}}$$

where

- $\Delta P_{bc,i}$ is the square root of differential pressure at measurement point $i$
- $A_t$ is the pipe area at the traverse location
- $A_{b,i}$ is the area blocked by the pitot tube at measurement point $i$

Blockage area was calculated based on the total cross sectional area of the tube at the measurement point. The log-linear fit is the expected profile for a pipe in well-developed turbulent flow. The corrected data fit the expected profile well except at the two points nearest wall.

Data for other velocities for the elliptical pitot tube and the Fechheimer pitot tube showed similar results. Based on this evidence, CleanAir decided to use the blockage adjusted coefficients when analyzing the data for the rest of the study.

### Simplex Pitot Tube Calibration

Calibration data for the simplex pitot tube is presented in Table 1:

<table>
<thead>
<tr>
<th>Flow</th>
<th>Avg AP in wg</th>
<th>Velocity</th>
<th>Reynolds</th>
<th>Calculated</th>
<th>Regression</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3528</td>
<td>4.80</td>
<td>8.59</td>
<td>4.4E+04</td>
<td>0.82</td>
<td>0.8217</td>
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<tr>
<td>2</td>
<td>5211</td>
<td>6.65</td>
<td>12.26</td>
<td>6.1E+04</td>
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<tr>
<td>3</td>
<td>6620</td>
<td>8.59</td>
<td>15.55</td>
<td>7.7E+04</td>
<td>0.7965</td>
<td>0.7894</td>
</tr>
<tr>
<td>4</td>
<td>8530</td>
<td>11.65</td>
<td>20.04</td>
<td>1.0E+05</td>
<td>0.7572</td>
<td>0.7661</td>
</tr>
</tbody>
</table>

Slope: -0.8105-97  Intercept: 0.8652

![Figure 5 Flow Profile with Blockage Correction Applied](image)

The calculated pitot coefficient was determined from the flow measured by the standard reference meter, the corrected area and the square root of the average measured differential pressure. A linear least squares fit was used to calculate the slope and intercept based on the calculated pitot coefficient and the Reynolds number. The regression pitot coefficient was calculated using the slope and intercept at the indicated Reynolds number. The percentage error was determined from the difference between the regression and the calculated pitot coefficient divided by the calculated coefficient. The root mean square error (due to lack of fit) was 1.1 percent.

The calibration point at 3 ft/sec presents significant challenges which affect the accuracy of the results. The average differential pressure at this velocity was 3 inwg. However, some of the differential pressure measurements at nearest the pitot tap were less than 1 inwg. For differential pressure in this range, the uncertainty of the pressure transmitters (0.1 inwg) represents a significant fraction of the reading.

The Reynolds number dependence of the Simplex pitot tube is illustrated in Figure 6.
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The pitot coefficient for the Simplex tube is highly dependent on the Reynolds number varying from 0.84 at a Reynolds number of 18,000 to 0.76 at a Reynolds number of 100,000.

**Elliptical Pitot Tube Calibration**

Calibration data for the elliptical pitot tube is summarized in Table 2.

<table>
<thead>
<tr>
<th>Pipe Diameter</th>
<th>13.1875 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Area</td>
<td>0.9485 ft²</td>
</tr>
<tr>
<td>Blockage Corrected Area</td>
<td>0.9098 ft²</td>
</tr>
<tr>
<td>Flow</td>
<td>Avg Air Velocity</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>1</td>
<td>1447</td>
</tr>
<tr>
<td>2</td>
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<td>4</td>
<td>6619</td>
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<tr>
<td>5</td>
<td>8525</td>
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</tbody>
</table>

The dependence of the pitot coefficient on Reynolds number for the elliptical pitot tube is illustrated in Figure 7.

Compared to the Simplex tube, the elliptical pitot tube coefficient shows very low dependence on Reynolds number; the pitot coefficient for elliptical pitot tube is practically constant over the range of calibration. The pipe flow conditions, velocity and temperature, were very close to those for the Simplex tube. The Reynolds number is calculated based on the diameter of the pitot tube perpendicular to flow. The minor diameter of the elliptical tube is 0.315 inches compared to a diameter of 0.625 inches for Simplex and Fechheimer pitot tubes.

**Fechheimer Pitot Tube Calibration**

Calibration data for the Fechheimer pitot tube is summarized in Table 3.

<table>
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<td>8587</td>
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</table>

The Reynolds number dependence of the coefficient of the Fechheimer pitot tube is illustrated in Figure 8.

Compared to the Simplex tube, the elliptical pitot tube coefficient shows very low dependence on Reynolds number; the pitot coefficient for elliptical pitot tube is practically constant over the range of calibration. The pipe flow conditions, velocity and temperature, were very close to those for the Simplex tube. The Reynolds number is calculated based on the diameter of the pitot tube perpendicular to flow. The minor diameter of the elliptical tube is 0.315 inches compared to a diameter of 0.625 inches for Simplex and Fechheimer pitot tubes.

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<tr>
<td>5</td>
<td>8525</td>
</tr>
</tbody>
</table>

The dependence of the pitot coefficient on Reynolds number for the elliptical pitot tube is illustrated in Figure 7.
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- **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

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Disturbed Flow Study

Disturbed Flow Study Description

All measurements performed under this task were made at TVA’s hydraulic laboratory in Norris, TN. As previously specified, this facility has the capacity to measure volumetric flow rate with a traceable standard with an uncertainty of less than 1 percent. Flow rate measurements were made by pitot tube traverse in a controlled setting designed to mimic locations typical of those found in field measurements. CleanAir collected data in three flow profiles that vary from ideal to significantly disturbed. Flow profiles were altered by changing the position of the pitot traverse relative to flow disturbances consisting of a 90 degree elbow and butterfly valve as well as butterfly valve manipulations. These configurations are detailed in Table 4.

<table>
<thead>
<tr>
<th>Pipe Configuration</th>
<th>Butterfly Valve Position</th>
<th>No. Pipe Diameters Between Elbow and Pitot Taps</th>
<th>Distance Between Elbow and Pitot Taps (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Wide open</td>
<td>3</td>
<td>54</td>
</tr>
<tr>
<td>B</td>
<td>40% Closed</td>
<td>3</td>
<td>54</td>
</tr>
<tr>
<td>C</td>
<td>Wide open</td>
<td>7</td>
<td>126</td>
</tr>
<tr>
<td>D</td>
<td>40% Closed</td>
<td>7</td>
<td>126</td>
</tr>
<tr>
<td>E</td>
<td>Wide open</td>
<td>10</td>
<td>180</td>
</tr>
<tr>
<td>F</td>
<td>40% Closed</td>
<td>10</td>
<td>180</td>
</tr>
</tbody>
</table>

Table 4 Pipe Configurations for Disturbed Flow Profile

Configurations C, D, E, and F are meant to represent flow profiles frequently encountered in cooling tower field measurements and meet the minimum requirements established in CTI Standard 146. Configurations A and B are worst case scenarios representing piping configuration which do not meet the requirements of CTI Standard 146. The flow profile represented by configuration E is typical of flow traverses conducted in a main line while the profiles associated with configurations C and D are more typical of riser flow measurements.

Flow measurements were made at three locations 60 degrees apart (i.e. top dead center, negative 60 degrees and positive 60 degrees) in a cross-sectional sampling plane. The axis of the butterfly valve is 45 degrees from vertical and at least 15 degrees away from all sampling planes. Figure 9 depicts the cross-section diagram of this setup.

Three sets of flow rate measurements (i.e. two traverses at three different measurement planes) were conducted to evaluate the “transferability” of the calibration from the lab to less-than-ideal applications in the field. Measurements were conducted with both of the alternate designs as well as the Simplex tube.

Flow rate measurements were conducted at two Reynolds numbers for each pipe configuration. Target Reynolds numbers were associated with circulating water flow at approximately 5 ft/s and 10 ft/s as depicted in Table 5.2. Differential pressure data points were recorded at each sampling point as follows:

The first flow measurements were conducted with the impact port of each pitot tube oriented perpendicular to the pipe. For the Fechheimer and Elliptical pitot tubes, an additional flow measurement was conducted with the impact port of the tube rotated into the flow such that the pitot tube static ports are balanced (i.e. zero differential pressure between the static ports) and the differential pressure between the impact and one of the static ports was recorded with the pressure transmitters. It was assumed that the differential pressure between the impact port and each static port are virtually the same. The angle of rotation was measured with a device with a maximum 2 degree uncertainty at each sample point.

<table>
<thead>
<tr>
<th>Velocity (ft/s)</th>
<th>Elliptical</th>
<th>Round Tips</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10,793</td>
<td>21,552</td>
</tr>
<tr>
<td>10</td>
<td>21,586</td>
<td>43,103</td>
</tr>
</tbody>
</table>

Table 5 Approximate Reynolds Numbers for Disturbed Profile

The flow associated with each set of traverses was calculated based on the pitot coefficients determined in the calibration study, the measured pipe area at the traverse location, and the average value of the differential pressure. This value was compared to the value read by the reference standard to determine the error of the flow measurement.

Disturbed Flow Study Error Analysis

A summary of the error statistics for each pitot tube at three measurement locations is found in Tables 6 and 7.
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The columns labeled individual error present the error when calculating the flow rate based on one of the three traverses conducted at each tap set. For the average error columns, the flow was based on all three traverses at each location. The rotated columns indicate the error when the differential pressure between the static ports of the elliptical and Fechheimer pitot tubes was minimal, indicating the pipe was aligned with the primary flow vector. Negative error values are printed in red; positive errors are printed in black.

Observations from the error analysis of the disturbed flow study are:

- The flow rate reported by the Simplex pitot tube has very high positive errors in the most disturbed flow situations, and the amount of error increases with the severity of the disturbance.
- Both the elliptical and Fechheimer pitot tubes gave more accurate results than the Simplex tube in disturbed flow locations. For both the elliptical and Fechheimer pitot tubes, positive errors predominated in disturbed flow.
- All pitot tubes yielded accurate measurements in locations with undisturbed flow.
- Both the elliptical and Fechheimer pitot tubes gave accurate flow results at tap location 2 (7 diameters downstream of the butterfly) even when the valve was partially closed. This remarkable result should result in a revision of STD 146 guidelines for acceptable location of pitot taps, if the elliptical or Fechheimer pitot tube is adopted as the standard.
- Measurements made with the elliptical and Fechheimer pitot tubes showed significant errors for measurements that were made at tap location 1 (3 diameters downstream of the valve). However, these errors were surprisingly small, given the severity of the disturbance.
- At tap location 1, the error increases with increasing flow velocity.
- Rotating the elliptical and Fechheimer pitot tubes to equalize the pressure between the static ports did not typically increase the accuracy of the results. The time required to complete a traverse when rotating the pitot tubes was approximately double that required when aligning the tube perpendicular to the pipe.
- For tap location 1, the error in the flow rate for individual taps was significantly different between the three taps at this location. For this location, it seems that flow measurement based on three taps significantly improves the accuracy of the result. Flow measurement was not significantly increased through the use of three taps at tap locations 2 and 3.

### Analysis

#### Pitot Tube Selection

Based on the results of this study, it is recommended that the elliptical pitot design be adopted as the new standard measurement device for water flow measurements. The justifications for this recommendation are:

- The flow measurements made with the elliptical pitot tube are much less sensitive to flow disturbances than the Simplex pitot tube. The sensitivity to flow disturbance is similar to that of the Fechheimer pitot tube.
- The tip design of the elliptical pitot tube permits measurements closer to the pipe wall than the Fechheimer pitot tube.
- The pitot coefficient for the elliptical pitot tube showed a very low dependence on Reynolds number. This is a very desirable characteristic because it reduces the number of calibration points required to accurately determine the Reynolds number dependent pitot coefficient.
- The coefficient determined at each Reynolds number had the least deviation from the Reynolds number dependent calibration curve for the elliptical pitot tube as compared to the other pitot tubes.

For the elliptical pitot tube used in this study, each of the static pressure ports was connected to separate tubes. Separate tubes for the static ports are only necessary when the tube is rotated to equalize the pressure between the static ports. Since the disturbed flow study showed no improvement in the accuracy of the measurements when the pitot tube is rotated, it is not recommended that the probe be rotated into the flow when conducting measurements. Separate lines for the static ports are not a necessary part of the design. Tying the static ports together at the tip would greatly simplify the design and fabrication of the elliptical tube, allowing for larger ¼ inch internal plumbing and is, therefore, recommended.

#### Pitot Tube Calibration

The recommended Reynolds number calibration range for the elliptical pitot tube is 10,000 to 50,000. These values correspond to velocities between 4 and 20 ft/sec if the water temperature for calibration is 70°F. The Reynolds number for almost all field based flow measurements will be within this Reynolds number range. Because the coefficient of the elliptical tube is not highly dependent on Reynolds number, the regression line for the pitot coefficient may be extrapolated without substantial error on those rare occasions where this is necessary. Measurements at flow velocities below 4 ft/sec should be avoided because of the measurement errors associated with low differential pressure.

It is recommended that blockage corrected coefficients be used for the elliptical pitot tube. The blockage area of the elliptical pitot tube is much greater than for an unreinforced simplex pitot, and the potential for blockage effects is, therefore, greater. The effect of blockage is seen by the difference in differential pressure between the near and far wall of the pipe when measurements are made in a location where radial symmetry would be expected. The application of a blockage correction largely removes this discrepancy. The blockage correction may be applied by correcting the square root of the differential pressure at each measurement point by the ratio...
\((A_{\text{gross}} - A_{(\text{block},i)})/A_{\text{gross}}\). If this approach is used, the flow is calculated based on the gross area. Alternatively, the average blockage for all measurement points can be calculated and subtracted from the gross area when calculating the flow.

**Disturbed Flow**

In the disturbed flow study, flow measurements conducted with the elliptical pitot tube were found to be substantially erroneous only when measurements were conducted within 3 pipe diameters of a flow disturbance. Elliptical pitot based flow measurements made 7 pipe diameters downstream of a butterfly valve produced acceptable results even when the valve was 40 percent closed. If the elliptical pitot is designed, the guidance offered in STD 146 for the acceptable placement of pitot taps should be altered to reflect the reduced sensitivity to flow disturbances. When flow measurements must be made at locations where the flow is highly disturbed, it is recommended three pitot taps be installed to enable measurements to be made on three diameters.

Measurements conducted in highly disturbed locations had a predominantly positive bias. That is, when measurements were made close to upstream flow disturbances, the measured flow was higher than the actual flow.
Rental Cooling Towers and CTI Certification

Billy Childers and Atul Swamy
Aggreko Cooling Tower Services

Abstract:
Cooling towers are not one size fits all and are therefore designed and built to achieve a specific amount of cooling at a predetermined water flow. However, in the rental industry a single cooling tower will be utilized in various applications, with varying water qualities, temperatures and flow rates without important modifications or thermal capability rating adjustments taken into account to adjust for the varying conditions. The paper will cover case studies including test results from CTI Licensed test agencies that demonstrate how this effects performance and how having CTI Certification for rental cooling towers can help ensure the end user gets the results they are paying for.

Introduction:
Renting cooling towers can be a great alternative to shutdowns or accepting an interruption or limitation in the supply of cooling water. As renting cooling towers becomes increasingly more common there are some things users of these services need to know. Even in the simplest of applications there are numerous variables that determine proper sizing and selection of the rental cooling tower. Many systems/processes are very sensitive to water temperature and water flow variation and it is therefore important to get a cooling tower that will achieve the appropriate thermal performance. Failure to get any of this right can lead to inadequate cooling and/or unreliable operation.

Rental vs Permanent Product Differences:
When a buyer is purchasing a new permanent cooling tower, the cooling tower seller provides a cooling tower that is built specifically to meet the required design parameters specified by the buyer. The cooling tower selection is very custom and includes variables such as cooling tower type, fill media selection, fan motor type, speed, and horsepower, fan type/size, fill type, fill depth, overall dimensions of the tower, water distribution system, nozzle configuration, nozzle orifice size, air inlet height, drift eliminator type, construction materials, etc... All of these are important to matching the cooling tower to the specific application.

When a buyer is renting a cooling tower the seller is providing a cooling tower that is already built with limited ability to customize. A cooling tower built for the rental market is typically designed to operate at a specific set of conditions that were predetermined at the time it was manufactured. The type of tower, the dimensions of the tower, the fan motor size, the fan type, the fill type and depth, the water distribution system, nozzle configuration, nozzle orifice size, air inlet height, drift eliminator type, and construction materials are fixed. The seller is limited to selecting from the existing model(s) of cooling tower(s) within their fleet and choosing the quantity of cooling towers the application will require.

Capacity Ratings for Rental Cooling Towers:
Proper sizing and selection for rental cooling towers is challenging for three primary reasons. (1) Capacity rating systems for cooling towers used in the rental industry are very inconsistent, (2) Formulas or rules of thumb that often get used for sizing any cooling tower are unreliable, and (3), selection tools used for sizing cooling towers are rarely reflective of actual rental cooling tower capacity due to the tower not being configured for varying water flow rates. These three issues make it difficult for an end user to ensure they are getting the capacity they need or properly evaluate bids of various suppliers.

Reason #1 - Cooling Tower Capacity Rating Systems:
The rental industry is inconsistent in ratings used for cooling tower capacity. Most, if not all rental cooling tower suppliers rate the capacity of their cooling towers in either "tons" in the US or "kilowatts" in other parts of the world. However, there is little consistency in the standard rating conditions on which these ratings are based.

Some rental cooling tower suppliers use the traditional ratings of 12,000 BTU's per ton for their ratings, while others use the HVAC industry standard of 15,000 BTU’s per ton. The discrepancy between the two rating methods accounts for a 25% discrepancy between the two sizing standards. See tables below for comparison between ratings for the same cooling tower with one table using 12,000 BTU/h and the other using 15,000 BTU/h.

Chart “A” and Chart “B” below are ratings for the exact same cooling tower. Chart “A” referred to as Figure 1, shows the cooling tower ratings in tons using 12,000 BTU/h while Chart “B” referred to as Figure 2, shows the cooling tower ratings in tons at 15,000 BTU/h.

![Figure 1: Cooling tower Capacity chart based on 12,000 BTU/Hr](image-url)
The highlighted rows and columns below are examples of how a rental cooling tower supplier could choose to rate its towers. The discrepancy in ratings for rental cooling towers grows even more between suppliers due to an inconsistency in conditions at which “tons” are calculated. Because “tons”, “kilowatts”, or any other unit of energy measurement chosen by suppliers to rate their cooling towers does not consider approach temperature it is not possible to know the actual capacity of the cooling tower without knowing the exact conditions used for its ratings.

The chart shown in Figure 3, demonstrates how the choice of conditions a rental cooling tower supplier chooses to use to rate the capacity of their cooling towers can have a large effect on the ratings. The chart below is the ratings of the same cooling tower depicted in the previous two charts, but electing to rate the capacity at a different range and approach. Using Chart “B”, which is for a cooling tower rated at 1000 nominal tons when using 15,000 BTU/h at the conditions of 95° entering hot water, 85° exiting cold water, with an entering wet bulb temperature of 78°. Then it will only work for sizing the rental cooling tower if the rental cooling tower supplier uses 15,000 BTU’s per ton at 95-85-78 for rating their cooling towers.

### Reason #2 – Formulas and Rules of Thumb are Inadequate:

Formulas that do not consider approach to wet bulb are insufficient for sizing a cooling tower. The primary reason formulas for sizing cooling towers do not work is they fail to consider the approach to wet bulb. Any formula that fails to capture this component will not work for sizing a rental cooling tower. Below are some common formulas that are mistakenly used for sizing rental cooling towers.

- 12,000 BTU’s per ton – Using 12,000 BTU’s per ton is fine for establishing heat load but it does not establish the cold water temperature and the approach to wet bulb and therefore cannot be used to size a cooling tower.
- 15,000 BTU’s per ton - 15,000 BTU’s per ton is used to establish cooling tower duty for the HVAC industry where the cooling tower is used in conjunction with a chiller. The chilling capacity is determined by using 12,000 BTU/h, but to size a cooling tower to match the chiller capacity an extra 25% of heat load must be added to allow for additional heat generated by the chillers compressor. Using 15,000 BTU’s per ton will compensate for this additional heat load. However, since rental cooling tower ratings by suppliers are inconsistent this method should not be used for sizing of a rental cooling tower.
- 3 GPM per ton – this is a rule of thumb for sizing a cooling tower used in the HVAC industry. This rule of thumb can be used when applying a cooling tower to a chiller, but for this to work the operating conditions must be 95° entering hot water, 85° leaving cold water, and an entering wet bulb temperature of 78°. Then it will only work for sizing the rental cooling tower if the rental cooling tower supplier uses 15,000 BTU’s per ton at 95-85-78 for rating their cooling towers.

### Reason #3 – Selection Tools are often Inaccurate for Rental Cooling Towers:

Cooling tower efficiency depends on maximizing contact of the incoming air with the hot water. A cooling tower water distribution system is intended to evenly spray the hot water across the entire area of the fill media. This is the most critical step to ensuring maximum use of the fill media and maximizing the thermal capacity of the cooling tower.

Most of the spray nozzles we tested performed well over a fairly large range of water flow (+/-25% of design flow) with minimal impact to the thermal capability of the tower (less than 10% tower capacity loss). However, when water flow rates per nozzle are significantly below their design operating range the spray pattern will be reduced and tower thermal capacity will be reduced. This results in areas of the fill media being underutilized and therefore cause the tower performance to be negatively impacted. Water flow rates per nozzle that are above the design operating range for a specific nozzle orifice size will cause the spray pattern to increase in size. This condition will result in overlapping spray patterns and excessive wall spray. Pattern sprays that are too small or too large will have a significant impact on the cooling towers ability to maximize contact between incoming air and the hot water resulting in underperformance of the cooling tower. Figure 4 shown below depicts the contrast between poor water distribution and proper water distribution.

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**Figure 2:** Cooling tower Capacity chart based on 15,000 BTU/Hr.

**Figure 3:** Cooling tower capacity comparison at different range and approach.
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The water spray pattern on the left is not evenly distributing across the fill media due to low water flow. The spray pattern on the right is receiving adequate water flow and is therefore properly wetting all of the fill media. To correct the pattern on the left the water flow must be increased or the nozzles (or nozzle orifices) must be changed to accommodate the lower flow rate.

In order to achieve optimum water distribution across the fill media, cooling tower manufacturers place a specific quantity of spray nozzles at specific locations, at a specific height above the fill media, with each nozzle having a specific orifice size matched to its intended water flow. The spray nozzles, depending on type will have a variety of orifice sizes that are intended to create a specific spray pattern at a given flow rate. Figure 5 shown below depicting a typical counter flow spray nozzle and the various orifice sizes that are used to create the proper spray pattern for a variety of flow rates. Please note that this specific nozzle has (6) separate orifices that are used to optimize the spray pattern at various flow rates.

Rental cooling towers, just like permanent cooling towers are designed at the time of construction for a specific water flow. However, rental towers are used in a wide range of applications and are often used in flow ranges that are well below or above what it was designed for. In some process applications the design water flow rate for a cooling tower can be less than 1/3 of the design flow rate for a cooling tower used in an HVAC application. As a result rental cooling towers often operate at significant deficiencies that can have a large impact on the thermal performance of the cooling tower.

In applications where a rental cooling tower is operated above or below the water flow it has been designed for sizing tools are not reflective of the actual capacity of the cooling tower. This is due to sizing tools and selection charts are created to reflect the maximum capacity of the cooling tower with optimum water distribution. Sizing tools do not typically account for improper water distribution that occurs when the cooling tower is operated at a water flow rate that is less than or more than the water flow rate for which the tower is configured.

In order to quantify the impact of water distribution on the thermal performance of a cooling tower various types of nozzles were tested. These tests were all conducted in one cell of a two cell cooling tower at the Aggreko test facility located in Chickasha, Oklahoma shown in Figure 6. This cooling tower is counter flow cooling tower which can be utilized for forced draft and induced draft testing. The cooling tower test cell was configured as follows:

- Dimensions - 6 feet wide x 6 feet long, x 11 feet high with an air inlet height of 4 feet.
- Fill media - 19 mm cross fluted fill media, five feet in depth.
- Fan - 57 inch diameter fan that was powered by a single 7.5 HP direct drive motor.
- Nozzle – (4) nozzles were used with each spaced evenly to cover an area of 36 sq/ft.

The thermal performance tests conducted on the Aggreko R&D test cell concluded that the capacity of the cooling tower varied as the water flow changed. Each nozzle configuration was tested at (3) flow rates, 100 GPM (2.78 GPM per square foot), 200 GPM (5.55 GPM per square foot), and 300 GPM (8.33 GPM per square foot). The results of the tests are displayed in the Figure 7 shown below. It should be noted that these tests were all conducted using 19 mm cross corrugated fill media with each of the layers of fill stacked in alternating directions. It can be assumed that the impact would be greater with vertical fluted fill media and could vary with splash type media, however alternate fill media was not tested.
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Figure 7: Cooling tower performance results with various types of spray nozzles.

Please note: Nozzle test #3 is considered a variable flow nozzle that is intended to provide a wider range of flow capability, but in this testing proved to be no better at variable flow than the fixed orifice nozzles.

To compare the lab tests to actual rental cooling towers at various water flow rates multiple field tests were conducted on full size rental cooling towers. Where available, the test results were compared against published ratings of the cooling towers. For tests conducted on cooling towers without published thermal capabilities, computer models were utilized in conjunction with actual testing to establish the base line performance for comparison.

Performance data for (4) separate rental cooling towers that all have a nominal rating of approximately 1000 tons when rated at 3 GPM/ton, 95-85-78 is shown in Figure 8 below. All 4 towers tested were counter flow cooling towers. Of the 4 towers, 3 were force draft towers and 1 was an induced draft design. The 3 forced draft towers were equipped with 5ft of CF-1900 cross corrugated fill media and the induced draft tower was equipped with 2 ft of CF1200 cross fluted fill media. All 4 towers had different water distribution systems. Each tower performed near or above the predicted capacity at flow rates around 3000 GPM. However, all (4) of the towers tested performed significantly below the predicted capacity at lower flow rates. The results of the comparison between the rental cooling towers and the predicted results are displayed in Figure 8 shown below.

Another set of comparison tests were performed on the ID-3000 rental cooling tower. The ID-3000 tower is no longer manufactured, but the units are still widely used by numerous suppliers in the rental industry and serves as a good example of the inconsistency in capacity ratings. The ID-3000 cooling tower is a counter-flow, induced draft cooling. The tower is 50 ft long x 12 ft wide and is comprised of (5) 12 ft x 10 ft cells. Each cell has (4) 15 HP motors driving (1) 36 inch diameter direct drive fan per motor (20 motors total). The tower is equipped with 5 ft of cross corrugated cellular fill media with a 19 mm spacing between the sheets.

The exact conditions at which the tower the cooling tower will provide 3000 tons of cooling are unknown. However, when capacity is determined using the HVAC standard rating for a cooling tower of 3 GPM per ton at the conditions of 95° hot water, 85° cold water, and a 78° entering wet bulb it is only capable of ~1900 tons. The test results on this tower demonstrate the effect of inconsistent rating standards. Figure 9 shown below demonstrates the performance variance in cold water temperature of the ID-3000 when compared on an equal basis. The difference between the implied 3000 ton capacity rating and the actual capacity 1900 tons results in a 6.34° variance in cold water temperature.

In addition to the rating inconsistency demonstrated above, the water distribution system in the ID-3000 cooling tower makes it highly susceptible to underperformance when the minimum flow rate is not maintained. Although the ID-3000 cooling tower is an induced draft counter flow cooling tower with an enclosed low pressure water distribution system, the water distribution system in this cooling tower functions similar to that of a hot water deck water distribution system common to cross flow cooling towers. Maintaining the minimum water flow rate in this type of cooling tower is necessary in order to get water to each spray nozzle. Notice in Figure 10 below there is good distribution from the nozzles on the left and no water at all coming from the nozzles on the right. This illustration represents what happens the tower is operated below the minimum flow rate of 5000 GPM.

Figure 8: Performance comparison of ~1000 ton cooling towers.

The graph above compares thermal performance of the (4) cooling towers against computer generated performance. The results demonstrate the effect of operating a cooling tower at water flow rates other than where it is designed to operate. At a flow rate of approximately 1000 GPM all 4 of the towers evaluated performed near or below 75% of the predicted performance.
When the minimum water flow is achieved all of the spray nozzles receive water, but if the flow is below ~5000 GPM the nozzles further away will not receive any water. See the cooling tower capability results at various water flow rates in Figure 11.0 below.

![Figure 11: ID-3000 Cooling Tower Performance vs water flow](image)

**Summary:**
The study found capacity ratings for rental cooling towers were inconsistent due to methodology and criteria used to determine capacity; the use of rule of thumb formulas and simple calculations are inadequate for sizing cooling towers; and cooling tower sizing tools did not accurately reflect cooling tower capability when operated at flow rates different from the initial design point for the cooling tower.

**Recommendations:**
- Specifiers/End users – Be specific with the conditions required for your rental cooling tower needs. This should include the water flow rate, the hot water temperature, the cold water temperature, and the wet bulb temperature. Avoid requesting capacity in tons, kilowatts, BTU’s, etc… Require the cooling tower to be CTI Certified. Verify the CTI Certified tower(s) being proposed match the performance published in the CTI 49 point table from the CTI website. [http://cti.org/certification.php](http://cti.org/certification.php)
- Suppliers – Know the capacity of the equipment you offer at all potential operating conditions. Develop your own performance data that properly represents de-rates for equipment when operated outside the original design conditions. Train engineers and sales personnel to use proper sizing tools/discontinue the use of simple calculations and rules of thumb. Get your towers CTI certified.
- CTI – consider developing a standard specific for CTI Certified rental towers. The standard should require testing at minimum, maximum and midpoint of flow ranges at the initial time of certification.
Legionella Litigation: How Cases Are Won And Lost At The Microbial Level

Janet E. Stout, Ph.D.
Special Pathogens Laboratory & University Of Pittsburgh

Abstract:
Outbreaks of Legionnaires’ disease are well publicized and cases often make their way into court. Determining the source of exposure is a key factor in determining responsibility and involves many disciplines, including engineering, water treatment, epidemiology and microbiology. The microbiology of Legionella in the suspected environmental source is explored through examination of culture results. Ideally, the Legionella bacteria causing the infection is available from the patient for comparison to the Legionella isolated from the environment (water sources). If the source is identified, the patient and environmental strains match. There are a variety of methods that are used to make this link and these will be reviewed. The role of microbiology in determining the source of infection will be discussed along with examples of cases and their outcomes from hotels and healthcare facilities.

Introduction
Legionnaires’ disease (Legionellosis) is a form of pneumonia most often caused by the bacterium Legionella pneumophila. Symptoms include high fever, dry cough, headache, and diarrhea. Legionella infections account for 2 to 5% of the cases of pneumonia acquired in the community. This translates into approximately 20,000 to 30,000 cases annually in the U.S. Legionella infections often go unrecognized because specialized laboratory tests are required to make the diagnosis. These include culture on special media, urinary antigen testing and antibody testing.

The time between exposure to the onset of symptoms is called the incubation period. The generally accepted incubation for Legionnaires’ disease is 2-10 days, although there have been instances where it has been longer.

Although there are currently more than 60 named Legionella species, Legionella pneumophila is the species that causes the majority of human infections. There are at least 16 serogroups of L. pneumophila, but serogroup 1 accounts for the vast majority of cases.

Water sources that have most notably been associated with cases of Legionnaires’ disease include warm water systems of buildings and private residences, water cooled air-conditioning systems, decorative fountains, and whirlpool spas and hot tubs. Legionella bacteria are transmitted from the environment (usually water) to the lungs of susceptible individuals via inhalation of aerosols, aspiration or direct instillation (hospitalized patients). There is essentially no person-to-person disease transmission. One case was reportedly due to person-to-person transmission.

Legionnaires’ disease is an environmental disease where the disease risk can be mitigated at the environmental source. Failure to recognize or control this risk has resulted in disease and subsequent litigation. One of the key questions in determining liability in such cases is determining whether the disease resulted from exposure to Legionella from the suspected/alleged source. Cases can be won or lost based upon the microbiology.

Litigation
Legionnaires’ disease garners a lot of media attention. It is not unusual therefore, that Legionnaires’ disease cases attract the attention of attorneys that wish to represent those afflicted by the disease (plaintiffs). The owner/operators of the suspected source or device must then provide a defense against the allegations of negligence. The damages sought and sometimes awarded can be substantial. Reported settlements and jury awards range from $255,000 to $5.2 million.

Causation Is Difficult To Prove
A combination of epidemiology and microbiology data is needed to ascertain with some certainty the source of exposure for cases of Legionnaires’ disease. There are several key elements where microbiology can have a significant impact on whether a case can be made for a causal link between the suspected source and the disease:

1. Diagnosis
   • Was the diagnosis made by the urine antigen test? This test tells you that Legionella pneumophila, serogroup 1 was responsible for the infection, but the bacteria is not available for further analysis.
   • Was the diagnosis made by culture of Legionella from the patient? If Legionella was cultured from a respiratory specimen, is the Legionella bacteria (isolate) available for further analysis? If the answer is yes, the microbiologist can then compare the patient isolate with any Legionella recovered from suspected environmental sources and determine if they are identical (indistinguishable).

2. Epidemiology
   • Have public health officials performed an epidemiologic investigation? This means has there been a study by qualified individuals to find causes of the disease in the affected individuals and of the factors surrounding the presence or absence of the disease and the pathogen.
   • Is there one case or more than one (an outbreak)? If multiple cases, are they related in time and space (common location or area)?
   • Were the cases exposed to the same potential source of exposure within the 2-10 day incubation period for Legionnaires’ disease?
   • In the epidemiologic investigation, did the epidemiologist or public health official use statistical methods such as case control studies to identify conditions or activities that are significantly associated with disease acquisition?

3. Sources of Exposure to Legionella
   • An epidemiologic investigation seeks to identify all likely and potential sources of exposure and test a representative number of locations.
   • Were each of these sources tested for the presence of Legionella by the standard culture method such that the Legionella bacteria are available for further analysis?
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4. Making the Microbiological Link

- Subtyping of *L. pneumophila* with molecular methods has proven invaluable in elucidating environmental sources. The subtype of *Legionella* isolates taken from patients has been shown to be identical to the isolates recovered from putative environmental reservoirs. Both physical and genetic methods have been used to demonstrate identity among strains of *Legionella pneumophila* in epidemiologic investigations. The most commonly applied methods include serotyping, monoclonal antibody subtyping, pulsed field gel electrophoresis (PFGE), and DNA fingerprinting using polymerase chain reaction (PCR). Maximum discrimination among isolates is achieved by combining multiple methods such as monoclonal antibody subtyping and PFGE or sequence-based typing (SBT) and whole-genome sequencing (WGS).

The microbiologist recovers the *Legionella* bacteria from the patients and the environment and then performs the bacteriological analysis that can either strengthen or weaken the associations identified by the epidemiological data. In effect, the epidemiologist shines the light of suspicion on a certain potential source of exposure. If the microbiologist finds the disease-causing strain of *Legionella* in the suspected water source and this organism is identical to the *Legionella* isolated from a person with Legionnaires’ disease, the association is strengthened. If the organism is not found in the suspected source or does not match (by subtyping) the disease-causing organism, then the epidemiologic conclusion for causation is weakened.

Case Investigations Where Microbiology Mattered

Example 1: NYC Outbreak in July 2015

The New York City Department of Health and Mental Hygiene detected an increase in cases of Legionnaires’ disease in the South Bronx on July 17, 2015.

**Diagnosis:** 138 cases (16 deaths) were identified and 26 were culture-confirmed with *Legionella pneumophila*, serogroup 1 isolated.

**Epidemiology:** Early focus on the South Bronx resulted from standard case detection and an epidemiological tool called spatiotemporal cluster detection analysis that identified 8 reports of Legionnaires’ disease centered in the South Bronx with a radius of 1.6 miles. Of the 8 reports, 2 were from one of 7 South Bronx zip codes or census tracts (outbreak zone). Two cases of travel-associated Legionnaires’ disease were reported to the CDC and were guests at a South Bronx Hotel (Building A). The number of cases per neighborhood exceeded the historical mean by 7.6-24.5 standard deviations – indicating a very rare event and an outbreak was in progress.

**Sources of exposure:** Cooling towers in the area were tested for *Legionella* and *Legionella pneumophila*, serogroup 1 was recovered from 52/183 cooling towers. The location of 3 towers showed higher case clustering and this included the tower on the South Bronx Hotel (Building A).

**Making the microbiological link:** Typing of *L. pneumophila*, serogroup 1 isolates by PFGE showed that those from the South Bronx Hotel and a homeless shelter (Building B) were identical to 26 clinical isolates (pattern O-1).

Genetic analysis (SBT) analysis showed that these isolates also had the same sequence type (i.e., 731). Whole-genome sequencing (WGS) showed that only the 5 *L. pneumophila* serogroup 1 isolates recovered from the South Bronx Hotel (building A) cooling tower were identical to 41 clinical *L. pneumophila* serogroup 1 isolates from 26 patients linked to this outbreak. No patient isolates matched to the strain from building B by WGS.

WGS was the only method to discriminate between South Bronx Hotel and all the other environmental isolates and confirmed the South Bronx Hotel cooling tower as the source of this outbreak.

**Example 2: Flint Michigan 2014 -2015**

**Diagnosis:** 88 cases (10 deaths) were identified [45 cases 2014 and 43 cases 2015] and the causative agent was confirmed as *Legionella pneumophila*, serogroup 1 by urine antigen and by culture isolation.

**Epidemiology:** Extensive epidemiologic investigation as early as the fall of 2014 showed an unusual increase in cases in Genesee County compared to historical averages and surrounding counties. The pattern of an abrupt increase in cases of Legionellosis in Genesee County in 2014-15 that occurred after a shift to the Flint River strongly implicated the water source and treatment of the water as a potential cause of higher Legionellosis case incidence.

**Sources of exposure:** Numerous potential sources of exposure including community sources and healthcare facilities. Thirty percent (26/88) had no healthcare exposure. Michigan Department of Health and Human Services released data showing 70% of people who contracted Legionellosis in the Flint outbreak were exposed to Flint water 2 weeks before their symptoms began.

**Making the microbiological link:** Typing of *L. pneumophila*, serogroup 1 isolates by PFGE showed that the majority of patient isolates did not match each other suggesting there was no single point source but rather diverse and varied sources of exposure.

Conclusions

Microbiology plays a key role in the investigation of outbreaks of Legionnaires’ disease. The microbiologic analysis of *Legionella* bacteria recovered from patients and suspected environmental sources has the potential to confirm the source of the outbreak and can contribute to a robust defense of the owner operator when defending against negligence claims.

Sampling the suspected environmental source before remediation can provide a *Legionella* bacterial isolate that may be a critical piece of evidence in outbreak investigations. Consideration should be given to the fact that failure to obtain isolates or performing remediation prior to sampling may constitute evidence tampering.

References

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Fundamentals Of Compression Testing Cooling Tower Fill

Joe Evans and Bob Petterson
SPX Cooling Technologies

Introduction

With the introduction of PVC crossflow film fill in 1970 and later counterflow film fill in 1979, methodologies to determine the design requirements for fill media were needed. Bottom-supported counterflow fill has had industry-wide acceptance for many decades. Fill manufacturers developed compression testing (a.k.a. crush testing) of packs to provide meaningful structural data on film fills. This statistically repeatable approach has been a cornerstone of reliable design, and therefore aided in the success of PVC film fills in the cooling tower industry.

Compression testing of fill has been used across industry with relative success, however there has been little time spent on developing a standardized methodology by which all fill manufacturers’ products can be judged. The absence of a standardized test has led to ambiguity and difficulty verifying claims of pack capability. A standardized test method would help customers to consistently compare the strength of various fill pack products.

This paper will discuss in detail the test equipment, procedure, results and the effects of different parameters. This paper is intended to be a foundation for the development of a test standard for compression testing of cooling tower film fill packs.

Background

Many methods of determining the quality of a fill pack have been used over the years. One such method that has been specified by end users is the testing of individual bond points. In theory this appears to be reasonable, but in reality individual bond testing is of limited value in evaluating quality and pack capability. See figure 1:

Figure 1 illustrates both a peel/tear and a shear mechanism for evaluation. When the connection point has eccentricity (e.g. an out-of-plane connection point) it can rotate and deform eventually failing by peel/tear, left above, the worst case for any connection point. The true-shear mode, right above, is very difficult to test, especially with thin-sheet products. That being said, neither peel/tear nor shear results provide an accurate representation of a fill pack’s overall capability. This type of testing is generally unreliable and can show large variability. See Chart 1 for a representation of several tests, with standard deviation bars.

Most of the loading imposed on film fill packs in a cooling tower acts vertically on multiple sheets. Failure mode is primarily by buckling of the sheet edges or buckling within the pack. The pack’s load resistance for any particular condition is affected by material properties, sheet thickness, fill geometry, and assembly method.

Another type of testing that has been used with limited success is flexural testing of fill. Flexural testing of fill media attempts to evaluate the bending strength of the fill using a uniformly distributed load, simply supported on two end supports. This uniformly distributed load is increased at a constant rate until failure occurs. For this to truly be a flexural test the failure mode must be in bending. Otherwise, the test becomes a crush or shear test, depending on the failure mode. SPX has found that the span-to-depth (L/D) ratio must be at least 6 or more for flexural failures to occur in cross-corrugated fill packs having 16 sheets per foot with a before-forming thickness of 15 mils. This means a 1’ tall fill pack would require a test span of 6’, or 12’ span for a 2’ tall pack. This is not a realistic test based on application of film fill packs in cooling towers. Other drawbacks for this type of testing include the large size of the test machine required and the difficulty of maintaining uniformity of the applied load while the top surface bends during test. Development of a repeatable methodology for this type of testing will become very complicated. Furthermore, designing a fill system to fail in flexural mode could result in the fill falling out of the tower due to overload. Designing a fill system to force the overload failure mode to a localized crushing at the supports results in minimal impact to the fill media and cooling tower.

Chart 1

Compression (Crush) Testing

Compression, or crush, testing of fill media accomplishes what both joint connection testing and flexural testing aim to do. Crush testing is an accurate method for determining the quality and strength of
the fill media as it relates to actual cooling tower service. Compression testing reduces the errors that are prevalent in individual joint testing because a large volume of the pack is tested in a manner similar to the loading in tower operation. Therefore, any effect of connection variability will be reflected in the result of a compression test, which provides an accurate representation of the fill packs capability. It also avoids the difficulties presented by flexural testing as described above.

The following describes recommended equipment, instrumentation, and procedure for compression testing of fill packs:

Crush testing is accomplished by using a machine that applies a uniform load across the top surface of fill media. The machine should be capable of a constant rate of deflection or crosshead motion, either by mechanical or hydraulic means. Crosshead speed should be standardized due to time effects on the viscoelastic materials used for fill. A reasonable range for crosshead speed is between 0.05 and 0.10 inches per minute. A test machine should consist of two platens, one which is stationary and one which moves. One platen should also be self-leveling or pivot to reduce test error due to localized uneven loading of a test specimen. The machine should employ both a load-indicating device for measuring force, and a deflection-measuring device for measuring displacement. The load-indicating device should not have an error that exceeds ±1% of the maximum load and should be verified in accordance to ASTM E4\textsuperscript{2}. The deflection measuring device should be accurate to within ±0.005 in. Calibrations should be performed on a periodic basis. The stiffness of the test frame should be such that the total elastic deformation is not greater than 1% of the total deflection of the test specimen(s). Test machines should be large enough to accurately represent the fill media within a cooling tower. The larger the machine, the more representative the result. A test-platen plan area of 16 square feet (4' by 4') is preferable to anything smaller. See figure 2 for an elevation view of an example test machine.

A ramp-load test uses a constant rate of crosshead travel to apply the uniform load to fill media until failure occurs. Both load and deflection are captured during the entire test period. The frequency of capture should be fast enough to produce a smooth load-vs.-deformation curve. Upon completion of a ramp-load test, a curve like one of those shown in Chart 2 should be generated. This chart shows many examples of differing shapes of curves that can be generated during a fill crush test.

Figure 2

Chart 2

The crush test can be used as a quality screening test with minimal parameters being tested for comparison of fill types. Testing can also incorporate various support methods beyond the platen-to-platen compression test, which is typically used to determine the maximum load or capability of the fill pack. While different fill types could yield unexpected results when tested on supports, trends can be established for the purposes of design. Just as support arrangements in cooling towers vary, test supports can be adapted. Variables such as bearing width, number of supports, edge distance, and support location can be incorporated. Test arrangements should be set up to simulate the support used in the cooling tower. For example, if the fill media is being supported on 6” FRP channels every three feet, the test should be designed to reflect this bearing arrangement.

A foot test can also be employed to determine how well fill media can support foot traffic. This test utilizes a 17.6 square inch loading head, shaped as part of a human shoe, to mimic foot traffic on the top fill surface. A ramp-load test is used to increase the load until failure occurs. This test should be done in three fixture orientations: parallel, perpendicular and 45° to the sheets.

Interpretation of Results

There are five important regions of the load-vs.-deformation curve in a short-term crush test: toe compensation, linear elastic region, yield point, failure and end of test. Chart 3 will be used as an example. The first region at the beginning of the curve in the lower left portion of the chart is the toe compensation region (A). This initial region of the chart is where the x-fixture of the machine and specimen are settling and aligning as the load increases. Any calculation based on deflection, or any long-term (creep) test, discussed further below, compensates for this area of the curve by using methods described in ASTM D695\textsuperscript{3}.
The second region is the linear elastic region shown by the dark dashed line (B). This region is where stiffness or modulus of elasticity (MoE) can be calculated. Stress and strain are directly related to MoE in this linear region. The MoE is calculated by using the slope of the stress-strain curve in this area. Deflections in the linear range of the curve are generally recoverable for rigid plastics.

The third region is where yielding occurs (C). This is beyond the top of the linear portion of the curve (proportional limit) and is basically the transition between elastic and plastic deformation.

The fourth region on the curve (D) is the point at which the load ceases to increase with additional deformation. This is the first peak or horizontal section in the curve beyond the yield point and is useful as the basis in the design of fill media. Beyond this region, the load begins to decrease, but can fluctuate and even increase beyond the initial peak load. This is considered as the failure point.

The final region is where yielding continues and the test is complete (E). A test completion point can be considered after a 10% decrease in load beyond the peak has occurred. Continuing the test to this point is not necessary, but will ensure a full representation of the fill behavior.

There are various approaches to interpreting load-vs-deformation data in order to determine a component design basis. One method is to identify the load at an arbitrary deflection. Chart 2 shows a dotted red line at a specific deflection point. The various curves are at several different stages at this deflection. Some are still increasing in load, while others are approaching a yield point. The corresponding load means very little for the cases where load is still increasing. For these cases, the associated fill would be underutilized from a design perspective. In some cases, up to half of the load capacity could be ignored. This interpretation methodology does not provide an optimized design for all fill types.

A more representative approach for interpreting crush data is to identify a point at which failure occurs. A reasonable point to utilize is the first peak (or horizontal section) as indicated in area D on Chart 3. This approach is more objective and results in a consistent and fair basis for fill-pack design. This load level can then be used as a basis for design calculations, with appropriate factors applied.

**Adjustment Factors**

A typical ramp-load test can capture multiple parameters controlling fill design. It can be used to measure the effects of temperature, support bearing width, and fill-sheet thickness. Design must also account for load duration, or time-dependent behavior. These parameters are discussed below.

**Temperature**

The effect of temperature can be evaluated empirically by testing at various temperatures. Factors can then be generated from the data. The graphical form of temperature factors is generally shaped as seen in Chart 4. Extrapolation to higher temperatures for amorphous polymers such as PVC must be done carefully due to their behavior as the temperature approaches their glass transition temperature (approximated by the heat deflection temperature or deflection temperature under load per ASTM D648). For an amorphous material such as PVC, maximum service temperatures should be well below the glass transition temperature. It is reasonable to apply the same temperature factor for various fill geometries, provided the material is the same.

**Support Bearing Width**

The effect of support bearing width must also be taken into account. Testing should be done using a support arrangement as representative of the application as possible. Test results can be converted to other support widths using data such as that portrayed in Chart 5. This chart represents data from dozens of tests with various support widths and fills. As the chart shows, the relationship between bearing surface width and load capacity is not linear, and therefore cannot be characterized by straight ratios. Large increases in bearing surface width yield relatively small increases in the load capacity of a pack. The diminishing returns of increases in bearing surface must be weighed against the increased air blockage affecting the cooling tower performance. Also, the effect of end distance must be considered. Most film fills have diminished load capacity if supported at the extreme edge of the pack.
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Sheet Thickness

Obviously thicker material will provide higher strength for the fill packs with the same geometry. From many compression tests of PVC film fills, the thickness factor has been found to correlate fairly closely to the square of the sheet thickness, within the range of typical sheet thicknesses. This is evident for various film-fill geometries, such as vertical flute, cross-corrugated, vertical offset, etc. The square relationship is logical considering that, in a pack compression test, individual sheets fail largely due to buckling. Buckling failures are governed by the stiffness of a "column". Stiffness of a column (or vertical fill sheet section in this case) is related to moment of inertia, I, which is proportional to the cube of the "h" dimension, or sheet thickness in this case.

See Chart 6 for a representation of the relationship of pack strength to sheet thickness.

Load Duration (Creep)

Viscoelastic materials, such as PVC and polypropylene, are subject to deformation under load over time. Creep will manifest itself either by movement under constant stress, or by relaxation (stress reduction) under constant strain. At low stress levels, the deformation is recoverable, but at higher stress, permanent deformations are created. Higher stress or longer time period will also increase the chance of eventual failure by creep rupture.

To account for load duration, creep-test data can be used to establish reduction factors to be applied in design of plastic components. Using the methods explained in ASTM D2990 with published creep data, factors have been calculated for both PVC and polypropylene.

These factors are shown in Chart 7, in a semi-logarithmic graph, as they relate to the duration of load.

Safety Factor

5 Conclusions & Recommendations:

- Compression testing of cooling tower fill packs provides a consistent method of comparison and a good basis for long-term design.
- Industry testing experience exists and should be used to establish a standardized test procedure for compression testing of counterflow film fill packs.
- Short-term ramp-load compression tests can be performed using a simulation of the actual support arrangement of interest.
- The initial peak load, where the load ceases to increase with increasing deformation, is the best basis point for comparing fills and designing for service.
- Adjustment factors for variables not accounted for in the test procedure, such as higher temperature, other support arrangements, or different sheet thicknesses, can be derived from other tests of packs with like material.
- To account for time-dependent movement under load, or creep, load-duration adjustment factors should be applied. These can be calculated from published data using the methods of ASTM D2990.
- The above factors, along with an appropriate safety factor, can be applied to compression test data to arrive at a safe operating design load for given conditions.

References

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Strategies for Reducing Uncertainty in Legionella Analysis

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Abstract
The accuracy and efficacy of Legionella testing is affected by a variety of factors that increase measurement uncertainty. Such factors include interference from non-Legionella organisms, subjective interpretation of test results, and differential performance of agar media, among others. Examples of these effects are discussed in relation to strategies for minimizing uncertainty. A culture method based on a most probable number (MPN) technique for quantification can provide an alternate approach to reducing measurement uncertainty. A comparison of an MPN method with conventional agar plate methods is presented with a specific focus on the challenges associated with testing nonpotable water from cooling towers and related sources.

Introduction
Legionnaire’s disease (LD) is an escalating worldwide public health problem [1, 2]. The disease is caused by bacteria from the genus Legionella, and can result in a severe bacterial pneumonia that may be fatal [3]. Certain segments of the population are more susceptible to LD, including the elderly, individuals with certain medical conditions, and those with a history of smoking. Although there are many species of Legionella, the disease is most frequently caused by L. pneumophila serogroup 1 [1, 2, 4].

LD is acquired by inhalation or aspiration of aerosolized water containing Legionella bacteria [3]. Legionella are ubiquitous at low levels in the environment, but upon introduction into a building water system they can proliferate to high levels that increase the probability of infection and disease [3, 5]. Water systems in which Legionella can multiply include both potable and nonpotable sources such as plumbing networks, medical equipment, decorative fountains, cooling towers and evaporative condensers [3, 6]. Cooling towers and related systems are particularly important due to their potential for amplification and aerosol transmission of Legionella [7]. Risk factors for Legionella proliferation in such systems include water temperature, plumbing network design, and inadequate procedures for disinfection and cleaning. Effective management of Legionella contamination requires an appropriate program that includes control measures and routine monitoring for Legionella [8–10].

Testing for Legionella may be performed using a variety of methods and technologies, however, microbiological culture remains the gold standard. Examples of culture methods for Legionella testing include those published by the U.S. Centers for Disease Control and Prevention (CDC), the International Organization for Standardization (ISO), and Standard Methods for the Examination of Water and Wastewater [11–13]. Such methods are complicated by use of multiple parallel testing approaches, optional treatment steps, and a requirement for significant analyst expertise and judgement. Furthermore, the accuracy of these methods may be affected by a variety of factors that increase measurement uncertainty such as interference from non-Legionella organisms, subjective interpretation of test results, and differential performance of media and reagents.

In this study, we discuss the impact of these factors on measurement uncertainty with a specific focus on testing of nonpotable waters from cooling towers. Our results show uncertainty to be a significant concern that should be considered when selecting and implementing a test method, and strategies for reducing uncertainty are suggested. We also discuss a most probable number (MPN) method for quantification that provides an alternate approach to reducing measurement uncertainty. Comparisons are presented between conventional colony-count methods and a new MPN-based method for detection of L. pneumophila.

Results & Discussion
Differential performance of agar media from different manufacturers
A variety of medium formulations are used for Legionella cultivation. Most formulations share a common recipe for base components including buffer, charcoal, and yeast extract, known as BCYE. This base medium may be supplemented with additional selective agents, primarily antibiotics, to prevent growth of non-Legionella organisms (NLO) that may otherwise interfere with the test. For example, selective formulations used in standard culture methods include PCV, GVPC, and CCVC agar [11–13]. These different agar media may be prepared in the lab from individual components or premade mixtures that simplify the process. Fully prepared media that is ready for use is also available and may be obtained direct from manufacturers or third-party suppliers.

During routine testing in our laboratory, it was observed that aliquots from the same Legionella-positive sample consistently showed different numbers of colonies, or colonies of different sizes, when plated on agar media from different manufacturers (Fig. 1). To explore this difference, we inspected the base BCYE formulation and preparation procedure for several different commercial products. We observed that different concentrations of yeast extract (10 to 11.5 g/L), ACES buffer (6 to 10 g/L), charcoal (1.5 to 2 g/L), and agar (13 to 17 g/L) were used among the different products. We found that the method of supplying materials varied by manufacturer, and either employed a single mixture of all chemical components, or two separate mixtures with separate storage. We also observed differences in the selective GVPC formulation affecting the antibiotics vancomycin (1 to 5 mg/L), polymyxin B (80,000 to 100,000 Units/L), and glycine (2 to 3 g/L).

Collectively, these differences suggested that the different products may vary in their ability to culture Legionella quantitatively. To examine this possibility, GVPC media was prepared with BCYE base reagents obtained from three different manufacturers, herein designated A, B, and C, each according to the respective product instructions. The GVPC selective component was either prepared following the manufacturer’s instructions, or if unspecified, according to the recipe published by CDC [12]. Each medium was then tested for its ability to support Legionella growth by plating equal aliquots of natural nonpotable samples in parallel on each medium. Samples were obtained from commercial laboratories and represent those that are routinely tested for Legionella. Testing was performed over multiple days using multiple independent batches of each medium.
Results from 170 nonpotable samples showed that differences in *Legionella* counts were obtained between the different media types (Fig. 2). Analysis of the data by one-way ANOVA indicated these differences were significant ($p = 0.006$). Post hoc comparison of the means using Student’s t-test showed that A and C were both significantly different from B ($p = 0.036$ and $p = 0.002$, respectively), while A and C were not significantly different from each other ($p = 0.297$). The mean of C (27.7) was 2.4-fold higher than the mean of B (11.5), and the mean of A (22.4) was 1.9-fold higher than the mean of B (11.5).

These results showed that the choice of medium had a significant impact on the *Legionella* test result. The observed differences may result from one or more of the factors discussed above, or other potentially important factors such as the method of production and the age of the materials. For example, medium A was prepared using a manufacturer supplied GVPC formulation, while media B and C were prepared using the CDC recipe. The observed difference between B and C shows that performance of the base BCYE ingredients or formulation can vary. Collectively, these findings suggest that measurement uncertainty could be reduced by ensuring that the agar medium is obtained consistently from a single source and that the method of preparation is uniform.

**Effect of bacterial concentration on measurement uncertainty**

With microbiological colony counting methods, an accurate count requires the number of colony-forming units (CFU) on a petri plate to be within a specified range. For a typical 90 mm plate, it is generally accepted that the appropriate range for quantification is between a lower limit of 20 to 30 and an upper limit of 200 to 300 CFU per plate [14–17]. However, it has also been reported that the appropriate range may vary depending on the organism and culture system under study [14, 17]. The lower limit is due to the decreasing accuracy of small counts as the result approaches the method limit of detection. The upper limit is created by constraints on the growth of bacteria at higher concentrations; as the number of cells inoculated on an agar plate approaches the upper counting limit, the number of colonies that result will not concomitantly match, and the inoculum will be underestimated.

Many factors affect the ability of a cell to form a discrete colony on a plate that can be observed and counted. First, when multiple inoculated cells are deposited close together, the colonies that form may merge into a single colony that is not clearly different from a colony originating from a single cell. This occurs more often at high bacterial concentrations, and may be exacerbated by regional plating effects, such as an uneven distribution of cells on the surface, and the size and shape of colonies formed by organisms that may be large or spread over the plate. Second, at higher levels of growth the nutrient supply of the medium may become depleted, or the accumulation of metabolic waste products and secondary metabolites may become inhibitory. Third, in cases where mixed populations are growing together, cells that form colonies sooner may inhibit detection of others that grow more slowly. This may occur among different cells of the same species, or when two or more bacterial species having different growth rates are co-cultured. Representative plates displaying the effect of increasing inoculum on the size and separation of colonies formed by *Legionella* are shown in Figure 3. The plates show both generalized and localized effects that increase the uncertainty of the colony count.

To examine the quantitative counting range of *Legionella* on agar media, an experiment was performed in which increasing concentrations of *L. pneumophila* were plated on GVPC (Fig. 4). Three different sources of the bacteria were tested, including an artificial suspension of a pure *L. pneumophila* lab strain in water and two natural nonpotable samples known to be contaminated with *L. pneumophila*. To control for chemical effects in the varying inoculum levels, each sample was diluted with a portion of the same sample that had been sterile filtered through a 0.22 um membrane. This removed microorganisms and larger particulate matter, but is expected to have little to no impact on the chemical composition of the diluent.

In all three cases, at lower *L. pneumophila* concentrations the number of CFU obtained showed a linear response proportional to the volume of sample inoculated on the plate. In contrast, at higher concentrations the number of observed colonies was less than expected based on the volume plated. Although consistent with results from other bacteria as discussed above, the effect we observed with *L. pneumophila* was more pronounced and showed that the accuracy of colony counts may be affected at levels significantly lower than the typical upper quantification limit of 200 to 300 CFU per plate.

Results with a pure strain suspension in distilled water showed that reduced colony counts occurred when only *L. pneumophila* was present, indicating that this organism is sensitive to its own colony density (Fig. 4A). For the two natural samples, the situation was more complex, as the natural water matrix also contained chemical and biological components that may have affected growth. The first sample produced only colonies of *Legionella* on GVPC, indicating that the GVPC selective agar suppressed growth of any other viable microorganisms that may have been present in the sample. Results in this case were consistent with the pure strain, with both appearing to depart from a linear response at approximately 50 to 75 CFU per plate (Fig. 4B). The second sample showed a mixture of *L. pneumophila* and several different types of NLO growing on the plates. In this case, the observed counts showed a loss in linearity at a lower *L. pneumophila* count of approximately 30 CFU per plate (Fig. 4C). In this case, self-inhibition by *L. pneumophila* may have been compounded by an additional inhibitory effect caused by the NLO present on the plates.

Collectively, these results show that the generally accepted practice to quantify *Legionella* on plates containing up to 200 or 300 CFU may lead to underestimation of the true *Legionella* concentration. The results are directly relevant to the processes used in standard culture methods; the data points shown at the right side of each plot correspond to plating 0.1 mL of sample directly onto GVPC medium as would typically be performed in a standard culture method. The reduced *L. pneumophila* counts obtained from these conditions show that the accuracy of standard method procedures will be highest in a relatively narrow range of colony counts. Improved accuracy would likely be obtained by preparing appropriate dilutions to provide counts equal to or fewer than 100 CFU per plate. However, dilution factors must be selected carefully to also avoid producing counts that are too low and which fall below the lower quantification limit of the method.

**Non-Legionella interference**

NLO are frequently observed during analysis of nonpotable water, where they can have a dramatic effect on the accuracy of *Legionella* detection and quantification. Nonpotable waters originate from many different natural and manmade systems and have the potential for contamination with different organisms at varying concentrations. Example results from plating 0.1 mL of a nonpotable water sample containing problematic NLO on GVPC are shown in Figure 5. Despite the use of a selective medium, a variety of interfering organisms are observed. Some form small colonies that may have limited impact. Others form spreading colonies that could prevent detection of *Legionella* over a large area of the plate. Although some NLO may interfere by obstructing or out-competing *Legionella* colonies due to their more rapid or expansive growth on the plate, other organisms, such as Pseudomonas, can inhibit *Legionella* through the more subtle effects of secreted secondary metabolites [18, 19]. The accuracy of a *Legionella* plate count may therefore be affected...
even when the frequency or extent of NLO interference appears low. Chance events can also have a large effect, for example, when replicate plates yield significantly different Legionella counts due to co-inoculation of a problematic NLO in one instance. Notwithstanding such outcomes, Legionella colonies are routinely identified from among NLO based on their characteristic colony morphology. However, some NLO form colonies that appear similar to Legionella and a definitive result is only obtained after presumptive positive colonies are confirmed in a secondary test. Collectively, the accuracy of the result obtained in the presence of NLO will depend on the nature and level of interference, as well as the experience and subjective judgement of the analyst.

To mitigate the effects of NLO interference, nonpotable samples are typically tested using a selective medium in combination with acid or heat treatment. We conducted an experiment in which a collection of 30 nonpotable samples, including many from cooling towers, were plated on different selective and nonselective media, both with and without acid pretreatment. A summary of the frequency and extent of NLO interference that was observed is shown in Table 1. As expected, the results showed that nonselective media such as BCYE performed poorly with nonpotable samples and few usable plates were obtained due to the presence of NLO in the water. The addition of acid treatment provided only a small increase in usability with BCYE. In contrast, the various selective formulations showed improved utility, with GVPC medium combined with acid pretreatment giving the lowest extent of NLO growth. Although Legionella is generally more resistant than NLO to acid and the selective agents in GVPC or other media, their use can reduce the number of Legionella colonies that are detected [20, 21]. It is therefore preferable to use selective media and pretreatments only when necessary, for example, by conducting tests in parallel with less selective or nonselective conditions, as described in the standard Legionella culture methods [11–13].

**Benefits of a MPN-based approach**

A culture method based on a MPN quantification technique can reduce or eliminate the limitations of agar-plate methods discussed above. In a MPN test, the water sample is divided into an array of independent aliquots of the same volume at one or more dilution levels. After incubation, each aliquot is individually scored as positive or negative, and the concentration of the target organism in the original sample is determined, typically using a pre-calculated lookup table, based on the statistical probability of obtaining the observed ratio of positive and negative aliquots [22, 23]. Positive aliquots are identified based on a characteristic result that may include development of turbidity due to visible cell growth, or a colorimetric or fluorescent change resulting from reaction with a chemical indicator substrate. The results of a MPN test are expressed as a “most probable number”, which is equivalent to the colony forming units (CFU) obtained in an agar plate test. Legiolert is an example of a MPN-based culture test that has been developed for the specific detection of L. pneumophila. In this test, sample aliquots are compartmentalized into two arrays of independent chambers, each with a different volume. This design provides two ‘dilution’ levels for the MPN calculation resulting in a broad counting range from 1-2273 MPN. After incubation, a positive result for L. pneumophila is indicated by a brown color change (Fig. 6).

The first aspect of the MPN approach that contributes to reduced uncertainty is compartmentalization of the sample into independent chambers. The physical barrier created between aliquots confines inhibitory effects and prevents them from spreading to affect other parts of the test. To demonstrate this effect on quantification of L. pneumophila, the linearity of MPN-based quantification with Legiolert was tested using the same experimental strategy and biological samples discussed above (Fig. 7). The MPN approach displayed a linear response across all dilutions tested, and in one case, reached an upper limit of approximately 400 MPN. This contrasted with the GVPC results where nonlinear counts were observed at much lower levels. This improved result using the MPN approach was likely due to the elimination of inhibitory effects through compartmentalization of the sample, including self-inhibition of L. pneumophila growth and the negative impacts of NLO. As shown in Figure 4C, one of the nonpotable samples showed a negative effect likely due to NLO interference; however, no impact on Legiolert was observed with this sample (Fig 7C).

A second benefit of a MPN approach is more objective result interpretation. As discussed above, because the colonies formed by different Legionella species on agar plates can vary in appearance, and because some NLO form colonies that resemble Legionella, the correct identification of true positives depends on the subjective judgement of the analyst for each colony morphology that arises. In contrast, the MPN approach can provide a more uniform positive signal that requires less interpretation. Assessment of a positive MPN result is more objective because it relies more on the fundamental performance characteristics of the test and less on analyst judgement.

To achieve a more objective result, a MPN test must be robust to interference from non-target organisms. Unlike an agar-plate test where individual cells are separated on the plate to allow isolated colonies to form, in a MPN test, each aliquot may contain a mixture of different organisms. To prevent false-positive results, such a test must produce a positive reaction signal that is highly specific for the target organism. This may be accomplished through formulation of a selective growth medium, use of a specific indicator substrate, and use of specific incubation conditions, for example. Although it can be challenging to develop a MPN test with the required specificity, when successful, this approach can greatly simplify test interpretation. An additional benefit is that a ‘confirmed’ result may be produced without requiring the added time, cost and complexity of secondary confirmation testing. Furthermore, a specific test simplifies analysis of samples lacking the target organism by consistently providing completely negative results that can be interpreted unambiguously.

The Legiolert test, for example, was developed to be specific for L. pneumophila and provides all the advantages described above for a MPN-based test. The specificity of this test is due to its selective growth and indicator formulation and the efficacy of its Pretreatment reagent that was specifically developed for use with nonpotable samples. A recent study with North American nonpotable water samples showed that Legiolert provided very high selectivity for L. pneumophila [24]. In the rare event that a NLO does proliferate and cause a reaction in the test, the independent nature of each well prevents interference with other wells in the tray. This contrasts with the agar plate, where a single spreading organism could potentially compromise the result from an entire plate (Fig 5).

**Conclusion**

This study showed that factors affecting measurement uncertainty can lead to statistically significant differences in the number of Legionella reported when nonpotable samples are analyzed. If the true Legionella level is underestimated, critical remedial actions may not be implemented to maintain Legionella concentrations below acceptable levels and increased public health risk may result. Conversely, overestimation of the Legionella level may lead to unnecessary consequences and costs for system decontamination. This study suggest that underestimation of the true Legionella concentration is more likely to occur due to the specific limitations affecting quantification with agar-plate based methods.

Uncertainty may result from multiple factors, including the source of agar media, the number of CFU counted on an agar plate, the
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subjectivity of test interpretation, and the presence of non-Legionella organisms, among others. Where possible, it is advisable to take actions to reduce the impact of these factors, including for example, preparation and use of consistent agar media, reporting results from within the linear range of the measurement system, and minimizing the impact of NLO interference. However, these factors are challenging to control fully in practice. For example, the availability of media from a specific source cannot be guaranteed and it may be necessary to obtain materials from alternate sources. Furthermore, the frequency and extent of NLO interference is variable and cannot always be reduced without collateral effects on Legionella quantification. Such challenges are particularly important for analysis of nonpotable samples, such as those from cooling towers, that may contain high levels of Legionella or extensive NLO contamination. A MPN-based test can provide an alternate approach to reducing uncertainty that is not subject to the same limitations as agar plate methods, and provides several advantages that can improve the accuracy of testing for L. pneumophila.

Materials & Methods

Legionella testing with agar media. Legionella testing was performed as described by the CDC [12]. Briefly, 0.5 mL of sample was transferred to a sterile 1.5 mL centrifuge tube containing 0.5 mL of KCl-HCl acid (18 parts 0.2M KCl mixed with 1 part 0.2M HCl), mixed, and incubated for 15 minutes at room temperature. A 0.1 mL aliquot of acid-treated sample was then inoculated onto GVPC agar plates. For comparison of media from different manufacturers, GVPC medium was prepared using BCYE base materials from each manufacturer following each product instructions. Selective GVPC components were prepared and used following the manufacturer's instructions, or if unspecified, following the CDC protocol. For comparison of plates containing different selective agents, BCYE, GVPC, PCV were prepared according to the CDC protocol [12], and CCVC was prepared according to Standard Methods 9260J [11]. All agar plates were incubated at 35 ± 2°C with humidity for 7 days. Cultures were examined after 7 days to identify bacterial colonies resembling Legionella. Two suspect colonies were confirmed from each sample by streaking on BCYE and blood agar plates (tryptic soy agar with 5% sheep’s blood). After incubation at 35 ± 2°C with humidity for 2 days, colonies that grew on BCYE but not on blood agar were considered confirmed Legionella.

Legionella pneumophila testing with Legiolert. Testing with Legiolert was performed following the product insert using the protocol for nonpotable samples. Briefly, 0.2 mL of sample was combined with 0.2 mL of Legiolert pretreatment in a 1.5 mL microtube and incubated for 60 ± 5 seconds. A 0.2 mL aliquot of the acid treated sample (containing 0.1 mL of original sample) was then transferred into a 100 mL vessel containing Legiolert dissolved in deionized water. The vessel was mixed and the contents were poured into a Legiolert Quant-1-Tray. Quanti-Trays were sealed in a Quanti-Tray Sealer PLUS, and incubated at 37 ± 0.5°C with humidity for 7 days. Positive results were identified by the appearance of turbidity or brown color.

Linearity of quantitative response. Two nonpotable water samples known to contain high concentrations of Legionella pneumophila were selected for evaluation. To create a cell-free diluent, a portion of each nonpotable water sample was sterile filtered using a 0.22 um polycarbonate membrane. Each sample was then diluted with its respective sterile filtrate to create different dilutions containing from 0.25% to 100% of the original sample. Each dilution series was then tested in parallel using both (1) acid-treatment and plating on GVPC according to ISO 11731:1998 [25], and (2) the Legiolert nonpotable protocol as described above. Briefly, for the 11731 protocol, 0.45 mL of sample was mixed with 0.045 mL of 10x concentrated KCl-HCl acid solution (3.9 mL of 2M HCl solution mixed with 25 mL of 2M KCl) and incubated for 5 minutes at room temperature. Four 0.11 mL aliquots of acid-treated sample were then plated on replicate GVPC plates. Plates were incubated at 36 ± 2°C with humidity for 7 days. Two of each colony type were confirmed by subculture onto BCYE and blood agar plates as above. Legiolert was performed as described above, except that four replicate aliquots of each pretreated sample were inoculated into separate Quanti-trays. For the pure strain analysis, Legionella pneumophila ATCC 33152 (Serogroup 1, Philadelphia 1) was selected for evaluation. A suspension of this strain having an optical density of 0.1 at 600 nm was prepared in sterile one-quarter strength Ringer’s solution (2.25 g/L sodium chloride, 0.105 g/L potassium chloride, 0.12 g/L calcium chloride, 0.05 g/L sodium carbonate). Serial dilutions of this suspension were prepared in the same diluent to provide an inoculum ranging from approximately 1 to 200 CFU. Each dilution was inoculated directly onto GVPC or into Legiolert (without acid treatment or pretreatment), and the respective tests were incubated and analyzed as above.

References


Figure 3. Effect of increasing inoculum concentration on colonies formed by *L. pneumophila*. Dilutions of a *L. pneumophila* strain suspension were prepared in water and plated on GVPC medium to inoculate increasing numbers of cells on each plate.

Figure 4. Quantitative response of varying *L. pneumophila* inoculum on GVPC agar medium. Known dilutions of a pure bacterial suspension (A) and two natural nonpotable samples (B, C) were plated on GVPC medium. The corresponding colony count obtained for each inoculation volume is shown. Each point indicates the average obtained from 4 or 5 replicate plates. For each plot, the data was examined for a linear response near the origin. A linear regression (dotted line) was fit to the portion of the data judged to be linear, corresponding to the first 11 to 13 data points in each case. The dotted line was extrapolated to show the expected response across all volumes tested. A second-degree polynomial regression was fit to all data (solid line) to show the non-linear response observed experimentally at higher volumes.

Figure 5. Example results showing interference from various non-*Legionella* organisms (NLO) observed during plating of nonpotable cooling tower samples on GVPC.

Figure 6. Example positive result showing *L. pneumophila* detection in a MPN-based method, Legiolert. The four trays are replicates of the same test, and show very consistent positive large (L) and small (S) well counts of 6L-16S, 6L-16S, 6L-15S, and 6L-14S. The MPN for *L. pneumophila* obtained from each test was 98.9, 98.9, 92.1, and 85.4, respectively.
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Figure 7. Quantitative response of varying *L. pneumophila* inoculum with a MPN-based method, Legiolert. The same dilutions of a pure bacterial suspension (A) and two natural nonpotable samples (B, C) shown in Figure 4, were inoculated into Legiolert. The corresponding MPN obtained for each inoculation volume is shown. Each point indicates the average obtained from 4 or 5 replicate plates. For each plot, a regression line (dotted line) was fit to the first 13 data points, and extrapolated to show the expected response across all volumes tested. A second linear regression line (solid line) was fit to all data.

Table 1. Frequency of non-*Legionella* organisms (NLO) observed on agar plates.

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<td>Non-quantifiable *</td>
<td>100%</td>
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<tr>
<td>Countable NLO †</td>
<td>0%</td>
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<td>None ‡</td>
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* *Legionella* organisms (NLO) observed on agar plates.
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<td><a href="mailto:meinolf.gringel@dmt-group.com">meinolf.gringel@dmt-group.com</a></td>
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<tr>
<td>45307 Essen, Germany</td>
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<tr>
<td>McHale Performance</td>
<td>Jacob Faulkner</td>
<td>865.588.2654</td>
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<tr>
<td>4700 Coster Rd</td>
<td><a href="http://www.mchaleperformance.com">www.mchaleperformance.com</a></td>
<td>865.934.4779 F</td>
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<tr>
<td>Knoxville, TN 37912</td>
<td><a href="mailto:ctitesting@mchaleperformance.com">ctitesting@mchaleperformance.com</a></td>
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Key Features of CTI Toolkit Version 3.2:

- **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.

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Now works with Microsoft Windows 10 and all earlier Windows Operating Systems back to Windows 95

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

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"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

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Cooling Towers Certified by CTI Under STD-201

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

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

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

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

The CTI STD-201 Thermal Performance Certification Program has grown rapidly since its' inception in 1983 (see graphs that follow). A total of 64 cooling tower manufacturers are currently active in the program. In addition, 11 of the manufacturers also market products as private brands through other companies.

While in competition with each other, these manufacturers benefit from knowing that they each achieve their published performance capability and distinguish themselves by providing the Owner/Operator's required thermal performance. The participating manufacturers currently have 143 certified product lines plus 17 product lines marketed as private brands which result in approximately 38,000 CTI Certified cooling tower models to select from.

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

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

Those Manufacturers who have not yet chosen to certify their product lines are invited to do so at the earliest opportunity. Contact the CTI Administrator at vmanser@cti.org for more details.
Thermal Performance Certification Program Participation Through June 15, 2018

NUMBER OF CTI CERTIFIED PRODUCT LINES

Through 6/15/2018

NUMBER OF PARTICIPATING MANUFACTURERS

Through 6/15/2018
Current Program Participants (as of June 15, 2018)

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

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

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

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

---

**A**

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

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

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

**American Cooling Tower, Inc.**
ACF Series Validation No. C36D-18R00
ACX Series Validation No. C30C-16R00

**AONE E&C Corporation, Ltd.**
ACT-C Line Validation No. C28B-09R01
ACT-R/ACT-RU Line Validation No. C28A-05R05

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

**Axima (China) Energy Technology Co., Ltd.**
EWK Line Validation No. C72C-17R00
EWX Line Validation No. C72A-15R02

---

**Baltimore Aircoil Company, Inc.**
FXT Line Validation No. C11A-92R02
FXV Line Validation No. C11J-96R10
NXF Line Validation No. C11Q-18R00
PF Series Validation No. C11P-12R02
PT2 & PTE Series Validation No. C11L-07R05
Series V Closed VF1 & VFL Validation No. C11K-09R02

**Baltimore Aircoil Company, Inc., continued**
Series V Open VT0, VT1, VTL & VTL-E Validation No. C11B-92R06
Series 1500 Validation No. C11H-94R09
Series 3000 A, C, D, E, Compass & Smart Validation No. C11F-92R18

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

**C**

**Cenk Endüstri Tesisleri İmalat Ve Taahüt A.Ş.**
LEON Line Validation No. C89A-17R00
LISA Line Validation No. C89B-17R00

**Composite Cooling Solutions, Inc.**
PLC Line Validation No. C79A-17R00

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

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**D**

**Decsa**
RCC Series Validation No. C42C-14R00
TMA-EU Validation No. C42C-17R00

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

**Delta (India) Cooling Tower Pvt, Ltd**
DFC-60UX Line Validation No. C85A-18R00

**Dongguan Ryoden Cooling Equipment Co., Ltd**
RT-L&U Series Validation No. C71A-15R02
RTM-L Series Validation No. C71B-15R00
Elendoo Technology (Beijing) Co., Ltd.
EL Line Validation No. C59C-15R02
ELOP Line Validation No. C50B-14R02

Ebara Refrigeration Equipment & Systems Co.
CDW Line Validation No. C53A-13R03
CXW Line Validation No. C53B-14R01

Evapco, Inc.
AT Series Validation No. C13A-99R19
ATWB Series Validation No. C13F-09R09
AXS Line Validation No. C13K-15R03
ESWA & ESWB Series Validation No. C13E-06R09
L Series Closed Validation No. C13G-09R04
L Series Open Validation No. C13C-05R03

Flow Tech Air Pvt Ltd
FTA Series Validation No. C69A-16R01

Genius Cooling Tower Sdn Bhd
MK Series Validation No. C67C-16R00
MT Series Validation No. C67A-16R00
MX Series Validation No. C67B-16R00

Guangdong Feiyang Industry Group Co., Ltd
LK Line Validation No.C77A-17R00

Guangdong Zhoarin Industrial Co., Ltd
SRN Series Validation No.C95A-17R00

Guangzhou Goaland Energy Conservation Tech Co., Ltd.
GLH Series Validation No. C96A-17R00
GLN Series Validation No. C96B-17R00

Guangzhou Laxun Technology Exploit Company, Ltd.
LC Line Validation No. C45F-16R00
LMB Line Validation No. 12-45-02
PC Line Validation No. C45G-17R00
PL Line Validation No. C45E-16R01

Guntner U.S. LLC
ECOSS Line Validation No.C84A-17R00

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

HVAC/R International, Inc.
Therflow Series TFC Validation No. C28B-09R01
Therflow Series TFW Validation No. C28A-05R05

Industrial Mexicana, S.A. de C.V.
Series 1000 Validation No. C60A-15R00
Series 2000 Validation No. C60B-16R00
Series 6000 Validation No. C60C-15R00

Jacir
DTC ecoTec Validation No. C46E-18R00
KS Line Validation No. 12-46-01
KSF Line Validation No. C46B-15R00
S Series Validation No. C46D-18R00
VAP Line Validation No. C46C-16R01

Jiangsu Dayang Cooling Tower Co., Ltd.
HLT Line Validation No. C94A-14R02

Jiangsu Greenland Heat Transfer Technology Co.
GBH-TS Line Validation No. C87A-18R00

Jiangsu i-Tower Cooling Technology Co., Ltd.
REH Series Validation No. C75B-16R00
TMH Series Validation No. C75A-16R00

Jiangxi Ark Fluid Science Technology Co., Ltd.
FKH Line Validation No. C93A-17R00

Ji’Nan Chin-Tech Thermal Technology Co., Ltd.
CTHX Line Validation No. C91E-16R00
CTNX Line Validation No. C91D-16R00

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

KIMCO (Kyung In Machinery Company, Ltd.)
CKL Line Validation No. C18B-05R03
Endura Cool Line Validation No. C18A-93R08

King Sun Industry Company, Ltd.
HKB Line Validation No. C35A-09R04
HKD Line Validation No. C35B-09R04
KC Line Validation No. C35-11R01
KFT Line Validation No. C3SD-16R00
Liang Chi Industry Company, Ltd.
LCTD Line Validation No. C20J-18R00
LCTR Line Validation No. C20H-17R00
Series C-LC Validation No. C20B-09R02
Series D-LC Validation No. C20F-14R02
Series R-LC Validation No. C11E-11R03
Series U-LC Validation No. C20D-10R04
Series V-LC Validation No. C20C-10R01
TLC Line Validation No. C20G-16R00

Marley (SPX Cooling Technologies)
Aquatorower Series Validation No. 01-14-05
AV Series Validation No. C14D-98R03
DTW Series Validation No. C14N-16R01
LW Series Validation No. C14P-16R01
MCW Series Validation No. 06-14-08
MD and CP Series Validation No. C14L-08R07
MHF Series Validation No. C14G-04R08
NC Series Validation No. C14A-92R20
NX Series Validation No. C14M-15R01
Quadraflow Line Validation No. 92-14-02

Mesan Cooling Tower, Ltd.
MCC Series Validation No. C26G-12R03
MFD Series Validation No. C26J-16R01
MXC Series Validation No. C26H-12R01
MXR-KM, MXL, MXH Series Validation No. C26C-08R08

MITA S.r.l.
PM Series Validation No. C56B-16R00

NIBA Su Sogutma Kulerleri San, ve Tic, A.S.
HMP-NB Line Validation No. C55A-14R01

Nihon Spindle Manufacturing Company, Ltd.
KG Line Validation No. C33B-12R05

OTT Company, Ltd.
OTTX Line Validation No. 12-44-02
OTTX-C Line Validation No. C44C-14R00

Ocean Cooling Tower Sdn Bhd
YC Series Validation No. C86A-17R00

Paharpur Cooling Tower, Ltd.
CF3 Line Validation No. C51A-13R02
OXF-30K Line Validation No. C51B-14R00

Protec Cooling Towers, Inc.
FRS Series Validation No. 05-27-03
FWS Series Validation No. C27A-04R06

Reymsa Cooling Towers, Inc.
(Fabrica Mexicana de Torres, SA de CV)
HFC Line Validation No. C22F-10R4
RT & RTM Series Validation No. C22G-13R05

Rosemex, Inc.
RC (RSC/D) Series Validation No. C54A-13R03
RO (ROS/D) Series Validation No. C94A-14R02

RSD Cooling Towers
RSS Series Validation No. 08-32-01

Ryowo (Holding) Company, Ltd.
FRS Series Validation No. 05-27-03
FVS Series Validation No. 12-27-06
FWS and FCS Series Validation No. C27A-04R06

Shangdong Grad Group Co., Ltd.
GAT Series Validation No. C89A-17R00

Shanghai ACE Cooling Refrigeration Technology Co., Ltd.
AC Line Validation No. C80A-17R00

Shanghai Baofeng Machinery Manufacturing Co., Ltd.
BTC Line Validation No. C49A-12R01

Shanghai Liang Chi Cooling Equipment Co., Ltd.
LCM Line Validation No. C62A-14R00
LNCM Line Validation No. C62B-16R00
LRS Line Validation No. C82C-16R00

Shanghai Wanxiang Cooling Equipment Co., Ltd.
FBH/HL Line Validation No. C54A-13R03
FKH/FKHL Series Validation No. C94A-14R02

Sinro Air-Conditioning (Fogang) Company, Ltd.
CEF-A Line Validation No. C37B-11R02
SC-B Series Validation No. C37C-11R02
SC-H Series Validation No. C37A-10R02
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