JOURNAL

A PUBLICATION FOR THE COOLING TECHNOLOGY INDUSTRY

WINTER VOLUME 43, NO 1. 2022


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FUTURE MEETING DATES

See upcoming meeting dates and venues so no matter when you open your CTI Journal, you can plan and prepare to attend.

CERTIFICATION AND TESTING

From Thermal Certification to our Licensed Testing Agencies, we've got the information that you need to maintain your tower.

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VIEW FROM THE TOWER

CHRIS LAZENBY
CTI PRESIDENT
SOUTHERN COMPANY

A few centuries ago, Mary Shelley noted in her famous novel Frankenstein that, “Nothing is so painful to the human mind as a great and sudden change.” If she was alive today, I wonder what she might have said about the last two years. It seems like almost every aspect of life has undergone significant change: from the way we live to how we shop, how we travel, how we work…it all looks different than it did at the beginning of 2020. Some of these changes had already been in motion and were merely accelerated by the pandemic, and others were direct results of it. Whatever the case, more changes appear on the horizon, and the cooling industry is no different than any other in this regard. Changes in the way we produce goods and services continue to affect us.

For example, in my own “day job”, the way that we generate and transmit electricity is changing and will continue to change as carbon fuels are replaced with emerging and newly developed technologies. For someone who began his career in an era where large coal and nuclear plants had long been the mainstay of power generation, transitioning to renewable energy, carbon capture, alternate fuels, energy storage, new nuclear designs, and other developing processes and systems sometimes causes the anxiety that Mary Shelley astutely described.

Balancing it out, though, is a sense of anticipation and even excitement almost as strong. I was in a meeting a few weeks ago where various R&D efforts and the general future of the electrical generating mix were being discussed, and the comment was made that, “No matter what happens, cooling systems and water chemistry are going to be important. No matter what shape things take, along the way, everything we’re looking at will still involve getting rid of heat and managing water resources.” And that is correct. The overall processes and components will look different, and long-held operating modes will change. The fundamentals that underly them, though, will not. There will always be a need for products and services to remove heat from industrial and commercial processes, and those products and processes will always need attention and expertise to design, maintain and operate them well.

This, of course, is why CTI is such a valuable organization. Certainly, the technical development of products and services by our member companies will help guide the future of industry around the globe. But as an organization, the information and ideas shared at our meetings, the guidelines and standards we develop to ensure quality products and operation, and the growing input and influence we are gaining with other technical organizations and regulatory agencies will be critical in helping shape the future. It may not always be comfortable when the status quo is shaken up, but I think we’re poised to enter an exciting time. I look forward to sharing the journey.

THE CTI JOURNAL

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MISSION STATEMENT

As a broad based industry association, our mission is to advocate and promote, for the benefit of the public, the use of all environmentally responsible, commercial cooling technologies, such as wet cooling towers, air-cooled condensers, dry coolers, indirect cooling, and hybrid systems, by encouraging:

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

LETTERS/MANUSCRIPTS

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

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A BRAND NEW LOOK FOR A

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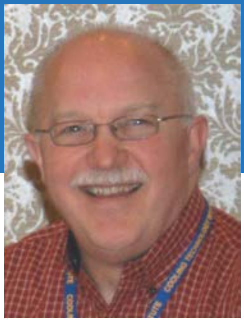
COMING SUMMER 2022

COOLING TECHNOLOGY INSTITUTE

EDITOR'S CORNER



Paul Lindahl - Editor in Chief
SPX Cooling Technologies

The impacts of Covid-19 are still with us in January of 2022. CTI will have a mostly in-person meeting in Houston in early February. ASHRAE is planning on a hybrid face-to-face and virtual meeting and show in Las Vegas (aka Lost Wages) in January, 2022. Over 68,000 people attended in LV in 2017. The preliminary indications are 30-40% in-person for a number of the committee meetings. I haven't heard the numbers for the presentations part of the meeting and the show, which is going to happen also. Interesting times, indeed.

CTI continues to be active in working to influence governmental and other organization standards impacting our members:

California Title 24 – We believe that they will push for increased energy efficiency for evaporative heat rejection equipment in future revisions, but not in the current one.

California Title 20 – It appears that they will hold to the exemption for heat rejection equipment fan efficiency requirements. We have still not yet seen language to confirm that.
US DOE Fan Rule – A notice has been posted asking for feedback on an AMCA test method for fans using a Fan Energy Index (FEI). Multiple organizations have commented on this, and have supported CTI's request for exemption of embedded fans per the ASRAC agreement within the DOE process some years ago. DOE is becoming more active in energy related issues with the new administration. No response from DOE yet.

ASME Boiler & Pressure Vessel Code – The scope task force is still pushing to remove the exemptions for less than 6" vessels and for those with non-boiling water. CTI has successfully joined other organizations in written opposition to this since other standards have evolved to cover such equipment. A small joint working group of AHRI and ASME members (including Frank Morrison as one of the ASME members) has been appointed to try to work out the differences. CTI and AHRI's positions were in sync as they applied to CTI equipment.

Legionnaires' – CTI has published GDL-159 - 2021 for evaporative heat rejection equipment (cooling towers, open and closed loop, and evaporative condensers) to include some editorial changes. The Guideline 159 committee is meeting in Houston in January to consider possible improvements to the existing Legionnaires' document for. cooling towers, open and closed, and evaporative condensers. ASHRAE Guideline 12-2020 has been released and is now in continuous maintenance. ASHRAE Standard 188 will be republished with multiple addenda included in 2021 and is also in continuous maintenance. ASHRAE Standard 514P is in development to cover other building water system hazards, and CTI has official organization representatives, Helen Cerra and Frank Morrison. An advisory public review was successful in gaining a number of comments, which were considered in 2021, in preparation for the first full public review in early 2022
CTI R&D is continuing to be active in exploring and developing R&D projects. They should be proposed through the standing committees and other committees.

Our goal is to introduce a new CTI regulatory update newsletter this year on the CTI website for CTI members only. Watch for notice of availability as CTI members by email.

Best wishes for the New Year, and hoping the Covid blues get behind us sooner than later...

COOLING TECHNOLOGY INSTITUTE

2023 Call for Papers

2023 CTI Annual Conference
February 5-9, 2023
The Peabody Memphis
Memphis, TN

Approved papers will be presented at the 2023 CTI Annual Conference. Authors will be notified by the CTI Program Chair. For a complete list of deadlines and instructions, visit us online.

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Cooling Technology Institute
Licensed Testing Agencies

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

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

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

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

Cooling Tower Technologies Pte Ltd
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Cooling Tower Test Associates, Inc.
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913.681.0027 / (F) 913.681.0039
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Sound Testing

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

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Cooling Technology Institute Certification Program
STD-201 for Thermal Performance

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

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

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

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FUTURE MEETING DATES

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Join us in beautiful Steaboatm Springs, Colorado for our annual CTI Committee Workshop, July 10-13, 2022.

July 10-13, 2022
The Steamboat Grand
Steamboat Springs, CO

2023 Conference and Expo

The historic Peabody hotel in Memphis, TN is the site of the 2023 Annual Conference and Expo. Join us February 5-9, 2023 for a conference of firsts in all the best ways!

February 5-9, 2023
The Peabody Memphis
Memphis, TN

2023 Committee Workshop

July 9-13, 2023 the CTI Committee Workshop is heading to Lake Buena Vista, FL at a gorgeous Hilton Lake Buena Vista. Hard work and a vacation destination rolled into one!

July 9-13, 2023
Hilton Lake Buena Vista
Lake Buena Vista, FL

What's happening?

Houston, TX - December 1, 2021

The Cooling **Technology Institute announces** its annual invitation for interested t**hermal 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 no later than July 1, 2022 to the CTI office.

COOLING TOWER PLUME

JAN CIZEK
CZECH TECHNICAL UNIVERSITY IN PRAGUE

Evaporative cooling systems are today, and have also historically been, the most widely applied methods of waste heat removal to the environment, not only in energy applications. In the past, particularly in the period 1920-1980, huge attention was therefore devoted to them and several basic theories thus emerged which form the basis for design and operation of these facilities for modern society to date (see, for instance, [1] or [2]). The stated period is characteristic in the search facilities for modern society to date (see, for instance, [1] or [2]). The stated period is characteristic in the search for analytical approaches to the basic physical principles for this specific area of technical knowledge. After 1980, there was a clear deviation from the search for analytical procedures in professional literature and, mainly, thanks to the possibilities provided by the rapidly developing field of computer technology, transition to procedures based on numerical solutions for the individual specific applications.

In the period 1960 - 1980, a certain share of the attention of the professional public was also focused on the issue of creation and spread of the steam plume. The major motivation for this activity was however not utilisation of the knowledge existing at the time for its reduction, but only to describe its behaviour. The necessary knowledge was relatively fresh at the time and society at the time was substantially more tolerant to the limitations, which was brought by the application of technical resources in the living space. The advent of computer technology at the end of this period, then gave rise to several more or less accurate models of the emergence and spread of the steam plume that sufficed for the next several decades, especially in the area of design of the location of large energy and industrial complexes in areas, which guaranteed minimal impact on urban agglomerations with undesirable accompanying phenomena whose typical representative may certainly be the steam plume.

The period after year 2000 may be considered as a relative breaking point in the given branch. On one hand this is caused by the higher development of vaporisation cooling systems excluding energy applications (typically as a component of the air-conditioning systems of the large residential and office buildings, extensive data centres, etc.), and on the other hand by greater pressure from the general public on minimisation of the impacts of human activity on the environment. At the same time, this period is however characterised by a decline in the interest of the professional public in the given issue and subsequent shift of scientific-research activities in this area in the field of the individual manufacturers of entire vaporisation cooling systems, or their individual parts.

The result of the above-state facts is the current situation in the given scientific branch with practically non-existent non-commercial scientific research teams investigating this issue on one hand, and at the same time, not even the adequate theoretical background of the commercial scientific research teams on the other. Practically the only more significant publication focused on training of new experts in the field of vaporisation cooling can be considered as the two-part monograph by the recently deceased prof. D. G. Kröger [3] , who was historically a member of the university in the city of Stellenbosh in South Africa, which although it is capable of introducing the basic computational procedures in a very good way to the parties interested in the given branch (including suitably chosen examples), but whose outreach for the application of state-of-the-art procedures is limited for comprehensible reasons.

Common Theory of Plume Formation

Plume formation is from the theoretical viewpoint linked to the problem of moist air, which is one of the basic chapters of classic thermodynamics. The detailed description of the individual physical characteristics of humid air can thus be found in many university textbooks and other texts (e.g. [4]). The individual states of the humid air are on standard basis displayed either in a psychrometric diagram (in Anglo-Saxon countries), or in the, so-called, Mollier h1+x-x diagram (in European literature). The transition between both descriptions of the state is given in Fig. 1.; here, all the derivations shall be given in the Mollier diagram.

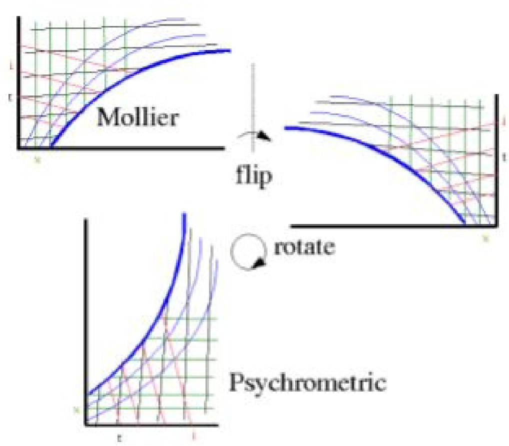

Fig. 1.: Transition between the psychrometric and Mollier diagram

The steam plume is a term established long-term in the field of vaporisation cooling. Its substantiated can be found in the fact that there is a space above the cooling tower, where two flows of humid air mix. The resultant mixture we can consider to be a dry air and steam that is unsaturated in this case. It is thus only a different view of the same problem (supersaturated wet air is on standard basis considered as a mixture of dry air, water vapour in a saturated state and water). In the Mollier h1+x-x diagram, the formation of the plume is conditional to the existence of areas in which the humid air is in supersaturated state, i.e. the points lying below the saturation curve. Due to the fact that from the physical viewpoint, the mixing of two air flows with different humidities occurs, the stated contention is equivalent to the fact that at least some points on the line showing the condition of the air leaving the cooling tower and the ambient air lie within the Mollier diagram below the curve as shown in Fig. 2.

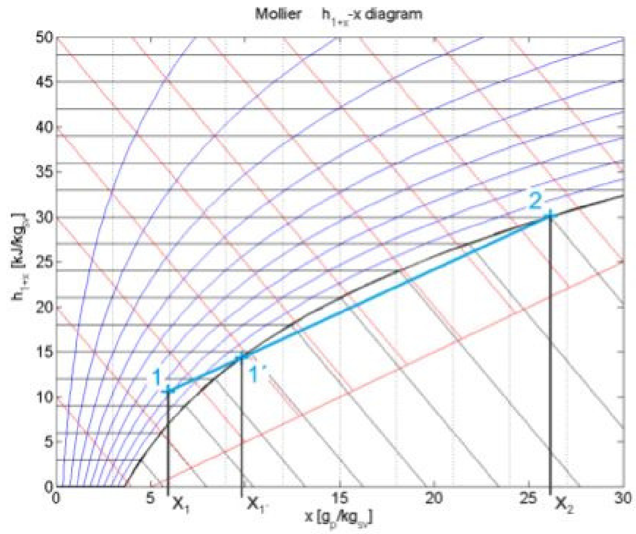

Fig. 2.: Condition for formation of the plume in the Mollier diagram

The steam plume as such can be defined as an area, where condensation of water droplets from supersaturation of the moist air "visibly" takes place. The droplets, at the same time, must have an adequate diameter and their number must be adequate in a unit volume.

In principle, two approaches can be applied. The first is based on the existence of the so-called Wilson Line, which is derived from the transition from overheated steam to wet steam. According to [5] it is possible after the basic calculations to implement it in the h1+x-x diagram, where it appears as a line corresponding to approximately 106% relative air humidity. In professional literature, it is then possible to find additional values. At the same time, it is defined here that it does not concern explicit determination of this line, but rather its upper limit estimate, which shows where the water vapour can be present in a supercooled state. In this case, it is not explicitly necessary to express the number of droplets in a unit volume and we can only assume that the steam plume shall be visible in areas, where the relative air humidity is higher than 106%.

The second possibility is to consider the minimum mean diameter of the droplets and their minimal number in the unit volume (if one of the conditions shall be unattained, the plume shall not be visible). In this case, it is possible to base this only on publications focused on meteorology [6], respectively, specific observation of various types of clouds. Specific data are stated in Table 1; however, it is possible to find many other sources [7]. The small r here represents the real radius of the droplets, r´apparent radius, N is their number in the unit volume and L total volume of the water phase in the unit volume.

Table: 1.: Size and number of droplets in standard cloud types

environment	cloud type	r [µm]	r' [µm]	N [1/cm³]	L [g/m³]
above land	stratus	4.7	7.3	250	0.28
	cumulus (pure)	4.8	5.8	400	0.26
	cumulus (contaminated)	3.5	4.0	1300	0.3
	cumulonimbus (growing)	6-8	7-10	500	1-3
	cumulonimbus (disintegrating)	7-8	9-10	300	1.0-1.5
	mist	8.1	10.7	15	0.06
above the sea	stratus	6.7	11.3	80	0.30
	(strato)cumulus	10.4	12.7	65	0.44
above land and sea	cirrus (-25°C)	-	92	0.11	0.03
	cirrus (-50°C)	-	57	0.02	0.002

Comparison of two approaches (i.e. the Wilson Line and use of the values stated in Table 1) is given in the h1+x-x diagram in Fig. 3 (the expression is based on the water content determined from the values stated above on the diameter and concentration of the droplets).

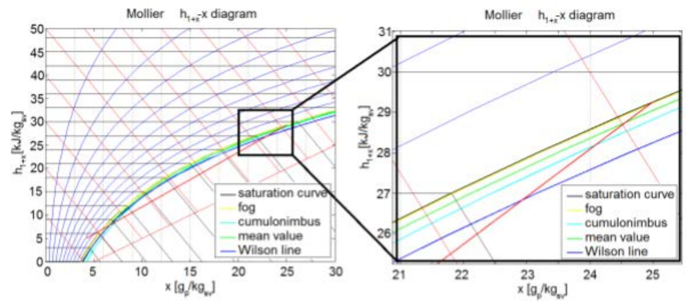

Fig. 3.: Conditions for formation of the plume in the Mollier diagram

It is clear that selection of the method for assessment of the visibility of the plume will have relatively substantial influence on its resultant size values. Because it is not possible to exactly specify this influence in view of the above-stated, it shall be included in the following text in the form of uncertainty, which is associated with the computational model of the visibility of the plume.

In professional literature, it is possible to find procedures, which just like the given procedure, express the bulkiness of the steam plume in relation to the parameters of the ambient and discharged supersaturated air, respectively, their images in the h1+x-x (or psychrometric) diagram. But, in most of the cases, the authors limit themselves only to statements without any further derivation. A typical example may be the publication [3], where it is stated on pages 314-319 that the plume mass can be derived from:

- the distance between the points of the intersections of the limit curve with the connecting line of both initial moist air states,
- the size of the angle between the limit horizontal lines in the h1+x-x diagram and the connecting line of both initial states,

- the size of the space closed on one side by the saturation line and on the other by the connecting line between points 1 and 2 (see Fig. 4.).

Schematically the individual approaches are shown in the h1+x-x diagram in Fig. 4.

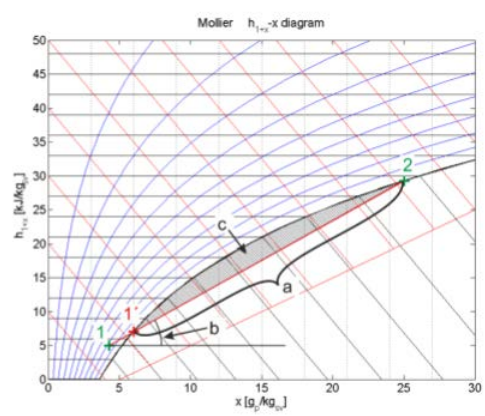

Fig. 4.: Individual approaches to assessment of the plume mass

In the case of the first two approaches, it is stated that the results obtained could be misleading. For evaluation of the absorptive capacity of the plume, the third approach is recommended with reference to literature. The major drawback of all these approaches is their little relationship to the essence of the given physical problem together with the impossibility of correct numerical

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expression of the total volume of the plume. The following text will show the reason why it is not possible to use any of the stated approaches for correct assessment of the plume mass. But, firstly, it will be necessary to state at least the basic mathematical framework according to which it is possible to do the elementary calculation of the size of the area taken up by the plume above the cooling tower.

Mathematical Model

It is possible to use all sorts of steam plume modeling (see, for instance, [8], [9] and [10]). For the purposes of this paper, a maximally simplified procedure was designed, which makes it possible to get a basic idea of the mechanism of plume formation and its spread. The procedure is based on the defined velocity, temperature and concentration field derived in [11].

The derivation of the velocity field stated in [11] is based on the idea of maintaining the overall momentum flux carried by the effluent air-flow from the cooling tower. In principle, the case can be simplified to a non-isothermal flood flow, whose basic geometrical characteristics are given in Fig. 5

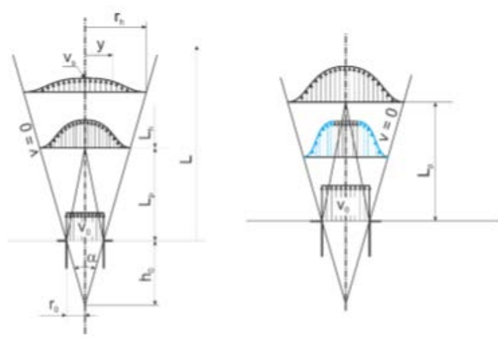

Fig. 5.: Implementation of the geometrical characteristics of the flood flow

If the influence of the different densities of the effluent air flow and ambient air are neglected for the first approximation, it is possible to [11] write:

$$L_p = \frac{0{,}67\cdot r_0}{a},$$

$$h_0 = \frac{0{,}29\cdot r_0}{a},$$

$$r_h = 3,3\cdot r_0 \cdot \frac{v_0}{v_s},$$

$$v_s = \frac{0{,}96\cdot v_0}{\frac{a\cdot L}{r_0}+0{,}29},$$

$$v = v_s \cdot \left[1-\left(\frac{y}{r_h}\right)^{\frac{3}{2}}\right]^2.$$

The advantage of the solution in [11] is mainly that it is possible to expand it further with the velocity of the ambient air in a case where the spreading of the steam plume is influenced by side wind. In this situation, it is therein recommended for calculation of the centre line of the derived velocity profile to use the equation (6) in the shape.

$$\frac{a\cdot y}{2\cdot r_0} = 195\cdot\left(\frac{\rho_{amb}\cdot v_{amb}^2}{\rho_0\cdot v_0^2}\right)^{1,3}\cdot\left(\frac{a\cdot x}{2\cdot r_0}\right)^3 + \frac{a\cdot x}{2\cdot r_0}\cdot cotg\alpha.$$

The given equation was approximated from the experimental data and its area of validity is therefore very limited, specifically up to an ambient air velocity of about 0.3-fold the velocity of the main flow. For the conclusions derived here, however, this condition is sufficient. The shape of the acquired relative velocity field for realistically chosen parameters is shown in Fig. 6.

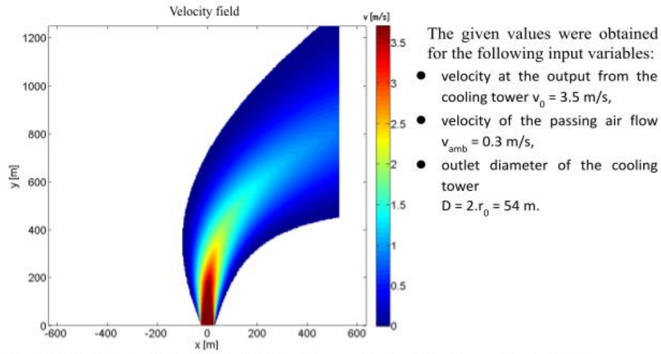

*Fig. 6: Calculated velocity field with the influence of lateral wind according to REF _Ref429501675 \r \h * MERGEFORMAT* **Chyba! Nenalezen zdroj odkazů.**

In the preceding chapter, it was stated that the steam plume is formed by local condensation caused by change of the concentration of two interacting media, i.e. supersaturated moist air leaving the cooling tower and the ambient air, which is in a general condition (from the essence of the problem, it is always at a lower temperature). For the first approximation, we can thus numerically solve the formation of the steam plume as a calculation of the concentration field of the two above-mentioned elements.

For the concentration field of two gases of same density and known velocity field shown in the preceding chapter, [11] recommends use of the relationships on the analogy between the dimensionless velocity and concentration field in the form:

$$\sqrt{\frac{v-v_{amb}}{v_s-v_{amb}}} = \frac{c_i-c_{i,amb}}{c_{i,s}-c_{i,amb}} = 1-\xi^{\frac{3}{2}},$$

where the dimensionless coordinate ξ is defined as

$$\xi = \frac{y}{r_h}.$$

The concentration profile in the flow axis was then for reason of continuity at point L = Lp left the same as for the velocity. The denoted profile of concentration then could be written analogously to equation 4 in the form:

$$c_{i,s} = \frac{0{,}96}{\frac{a\cdot L}{r_0}+0{,}26}.$$

If the velocity of the ambient air shall be zero and the individual specific humidities of the concerned media shall be equal to x1 for the ambient air, respectively, x2 for the effluent air from the cooling tower, we can, due to the fact that equations (7) and (9) are written for molar concentration, we can directly derive the equation for the specific air humidity in the area influenced by the flood flow that is defined by the equations (1) to (7). The resultant specific humidity shall be given by the equation

$$x = x_1 + (x_s - x_1)\cdot\sqrt{\frac{v}{v_s}},$$

where x_s is determined using the equation

$$x_s = \frac{0{,}96\cdot(x_2-x_1)}{\frac{a\cdot L}{r_0}+0{,}26} + x_1.$$

The specific humidity fields calculate on the basis of the velocity field and equations (10) and (11) is for the case without and with side wind stated in the graphs in Fig. 7.

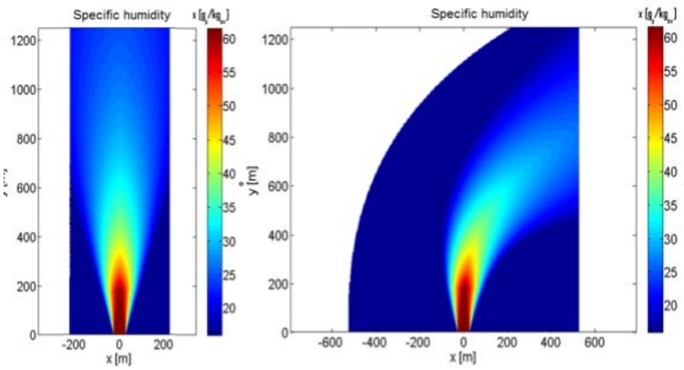

Fig. 7.: Specific humidity fields for the case without and with side wind

In order to allow for the visualisation of the individual local states in the Mollier h1+x-x diagram, it is necessary, apart from the specific humidity, to also know the enthalpy. Thanks to the applicability of the lever rule, this can be calculated according to equations similar to the equations for the specific humidity.

Specifically in this case, they change to the shape:

$$h = h_1 + (h_s - h_1) \bullet \sqrt{\frac{v}{v_s}} \ ,$$

where

$$h_s = \frac{0{,}96 \cdot (h_2 - h_1)}{\frac{x}{r_0} + 0{,}26} + h_1 \ .$$

If it is now possible on the basis of equations (10) to (13) in the monitored space for all its points to determine the image in the Mollier h1+x-x diagram, it is possible to finally calculation the local temperature value, but simultaneously also the specific humidity corresponding to the limit curve (or also to another curve in h1+x-x defined on the basis of various levels of supersaturation). In this context, it thus concerns points with the same specific enthalpy and different specific humidity. In areas where the difference of the two stated humidity values is positive, it is thus possible to assume the presence of the steam plume.

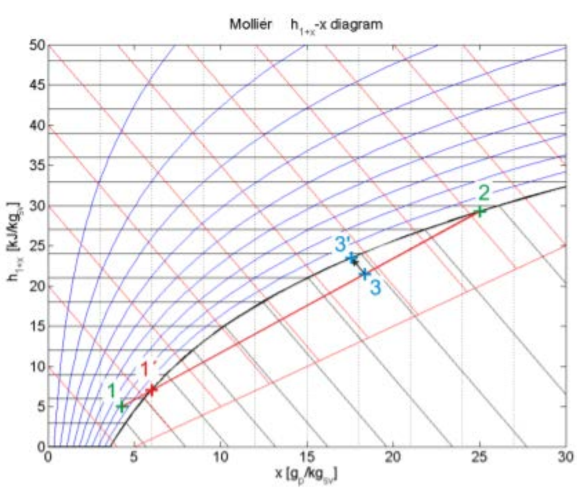

Fig. 8: The position of point 3´ corresponds to the position of point 3 on the limit curve.

The result of the given model is then dependent on the input parameters and many other conditions (see, for instance, the selected plume visibility model) of the area in the space taken up by the steam plume. The resultant image in the form of the specific content of condensed water is shown in the axial section for some specific selected parameters shown in the graph in Fig. 9.

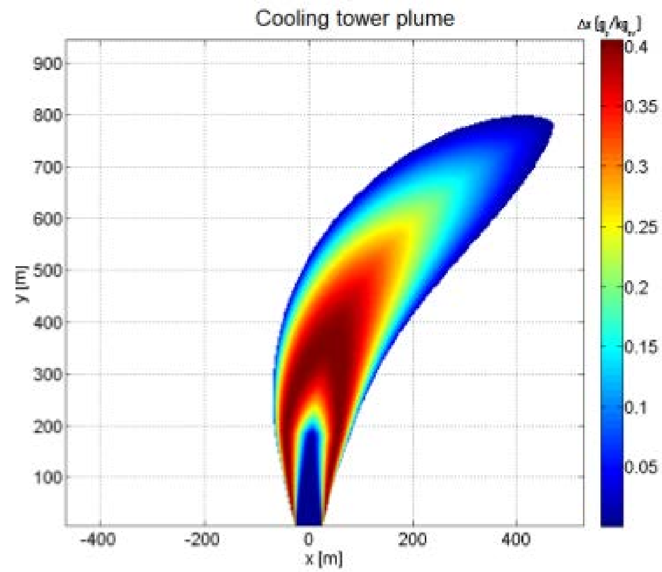

Fig. 9.: Results of the above-stated plume model

Results of the Mathematical Model

Using the model above, it is possible to eliminate most of these deficiencies. By analysis of this model, it is possible to show that the absorptive capacity of the steam plume is not affected by:

- the degree of supersaturation of the moist air at the output from the cooling tower,
- the average size of the droplets at the output from the cooling tower,
- the velocity at the output from the cooling tower.

and on the contrary, the following have a very significant effect:

- cooling tower output radius
- temperature and humidity of the air output from the cooling tower
- temperature and humidity of the ambient air
- wind velocity*

* velocity of the wind is a parameter which influence is being investigated nowadays, the biggest problem is with the calculation of the total volume since the whole problem is not symmetrical anymore.

Results of dependence of the total volume of the plume on the output diameter of the tower are given in Fig. 10 and it is clear that this dependence very precisely copies the correlation of the third power of the diameter.

The fact that the total volume of the plume corresponds very well with the third power of the cooling tower diameter highly corresponds with the assumed o-shape of the velocity, respectively, concentration field. Due to the above-stated, it is possible from the results in the graph in Fig. 10 to also make a more general conclusion, that is, if it is possible to:

- ignore all the accompanying influences and consider the entire problem as the isobaric mixing of two different gases, Moore® FANS

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- to convert the velocity field in the area above the cooling tower into a similarity shape (all velocity fields for various geometrical parameters and velocities at the cooling tower output are similar),
- an analogy applies between the heat and mass transfer (for that matter for the practical arbitrary Lewis factor; this condition simultaneously in combination with the rest of the factors states that the concentration fields are independent on the cooling tower output velocity and are mutually geometrically identical for various geometries of the assigned task),

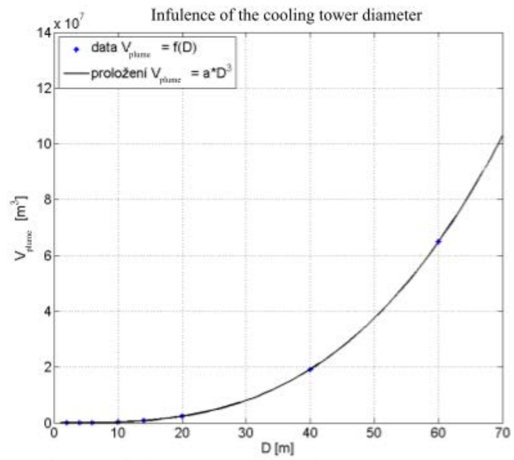


Fig. 10.: influence of the outlet diameter of the cooling tower on the size of the steam plume

then the size of the plume is proportionate to the third power of the cooling tower diameter and the characteristics of both considered air masses. In mathematical terms, the above-stated can be expressed as:

$$V_{plume} = K \cdot D^3, \quad \text{where } K = f\left(t_{in}, t_{OK}, \varphi_{in}, \varphi_{OK}\right)$$

The last question that remains is what this dependence of coefficient K in the above equation (12) on the parameters of the ambient air and cooling tower output air really is. It can be demonstrated that the size of coefficient K can best be defined using the ratio of the distance of the intersection of the connecting line of the initial states of both air masses with the state at the cooling tower output to the distance of that same intersection with the state of the ambient air.

Mathematically, the above-state can be expressed as:

$$K = f\left(\frac{x_2 - x_{1'}}{x_{1'} - x_1}\right)$$

where the individual variables for clarity are shown in the Mollier h1+x-x diagram in Fig. 2.

If we use the definition of K according to the question (13), it is possible to demonstrate that the best is the definition of the parameter of the K function

$$K = C_1 \cdot \left(\frac{x_2 - x_{1'}}{x_{1'} - x_1}\right)^{C_2}$$

where the coefficient C2 can be considered as value C2=3, as shown in Fig. 11.

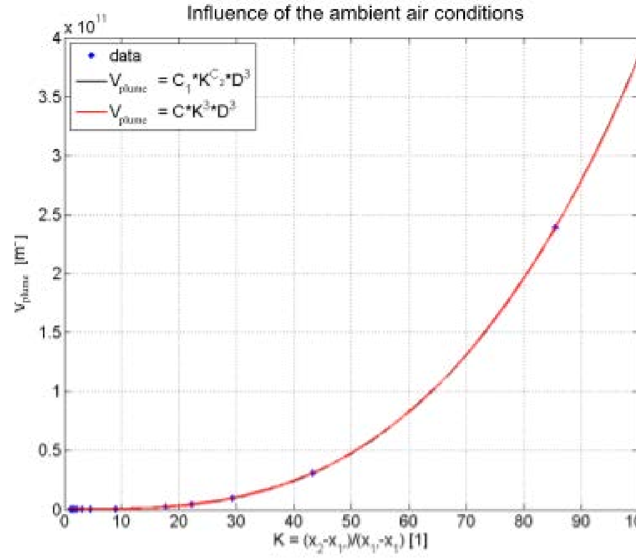


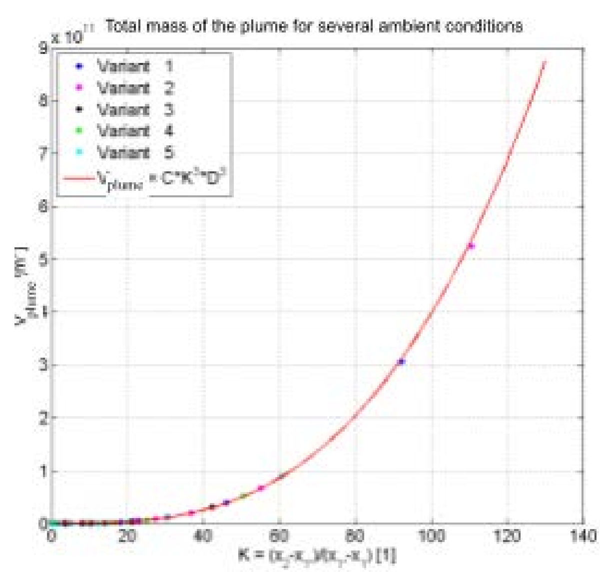
Fig. 11.: Size of coefficients C_1 and C_2 for equation (14)

Given the above-stated, the absorptive capacity of the plume can thus be calculated as follows:

$$V_{plume} = C_1 \cdot \left(\frac{x_2 - x_{1'}}{x_{1'} - x_1}\right)^3 \cdot D^3$$

The independence of this model on the position of the individual points in the Mollier h1+x-x diagram is shown in Fig. 12, for the test, various combinations of states 1 and 2, which are defined in Table 2 were used. The ambient air humidity was always selected in the range of 50% to 99%; cooling tower output air humidity was always left at 100%. Table 1 also shows the calculated values of coefficient C1.

No.	t_{in} [°C]	t_{amb} [°C]	C [1]
1	40	20	2.50
2	30	10	2.47
3	40	25	2.58
4	30	15	2.55
5	20	5	2.55



Conclusion

From the given model, it is possible to deduce a number of very interesting conclusions regarding the behaviour of the plume, for instance, the fact that its size does not depend on the output velocity, but only on the dimensions of the cooling tower and enthalpies and specific humidity of both air masses. At the same time, it is subsequently possible to use the model for basic assessment of the efficiency of the individual systems for condensation of water vapour from supersaturated moist air still in the cooling tower.

The main conclusion of this paper is thus tied to the equation (15) and graphs in Fig. 11 and Fig. 12 from which it is clear that the influence on the plume mass can best be assessed on the basis of the ratio of distances x2-x1 ´and x1 ´-x1. When using this approach, it is subsequently possible to quantify the plume mass using its overall volume and rigorously decide its size on the basis of the values of the individual variables. This fact is subsequently very substantial in the design and operation of hybrid cooling systems (in that cases where the cooling towers allows to regulate dry and wet part of the tower during the operation continuously) as well as, for instance, moisture recovery systems. The equation (15) is moreover relatively trivial and thus easy to implement in any computational model, or SW application. Inclusion of other influences can thus be done only by change of constant C1, whose value may be validated experimentally for the primary cases of the individual types of cooling towers.

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ONLINE ROBOTICS: CLEANING AND INSPECTING TANKS AND BASINS WHILE REMAINING OPERATIONAL

JOSEPH LEIST, RANDI LEIST, & STEVEN RYDAROWSKI
SCANTRON ROBOTICS USA, INC.

Across the board, equipment maintenance is essential to operate at peak efficiency and safety. However, some equipment is extremely costly—in the price on the related invoices and the time and means—on which to perform maintenance. The price of the maintenance, equipment, and shutdowns of any stage of operations adds up to a significant value more often than not, making it difficult to fit maintenance for certain equipment into a budget.

Water tanks, towers, and basins of all kinds see maintenance, such as cleaning and inspections, regularly delayed due to this, with some plants failing to clean tanks for decades, often opting to build new structures than maintain the standing ones. Meanwhile, sediment build up is damaging the production process. Process water tanks perform less capably and add contaminants when not properly cleaned. Cooling towers cannot function with too much buildup. Firewater tanks can run dangerously low if too much sediment is allowed to collect in them. Quite simply, an uncleaned water unit is an inefficient—or ineffective—unit.

Cleaning water tanks, towers, and basins can be costly and create lengthy delays. Traditional methods require turnarounds and tank entries, which create additional production costs and safety liabilities. A new method, however, is mitigating—and often eliminating—these additional costs. Online robotics have changed the way tanks are cleaned and inspected, increasing efficiency while decreasing the associated costs and dangers associated with traditional methods.

TRADITIONAL METHODS

The traditional methods of cleaning and inspecting industrial water towers, tanks, and basins—permanent structures within industrial facilities designed to contain non-flammable liquids, classified by OSHA as permit-required confined spaces—involve tank entry of some kind, with or without being drained. There are three traditional cleaning models: vac trucks, offline robots, and divers.

Vac truck teams clean tanks by draining them, entering, performing abrasive blasting, vacuuming out the contents, and refilling the containment. It is the most common method used and comes with many drawbacks.

The first failing is the drainage of the water. Stored water, regardless of purpose, has to be treated in order to maintain a minimal quality for its usage. The water in the basin is basically poured down the drain, along with these chemicals, which is both wasteful and an environmental concern. The water has to also be replaced after cleaning and retreated, which can be extremely costly and often is left off of invoices from service providers.

Secondly, there are serious safety liabilities involved with this process. Workers must enter the tanks, which are classified as confined spaces, in order to perform services. This is risky in and of itself. Confined space entry comes with serious risks and requires a great deal of training and oversight. This risk, though, is coupled with abrasive blasting. In dark, enclosed areas, pressurized material, often water or silica, is sprayed against built up materials by teams of vac truck workers to break up sediment that can be as hard as concrete. Limbs can be lost in this process when out in the open; exposure to material can cause myriad health problems outside of confined spaces; so, performing these in enclosures where emergency recognition can be difficult and rescue all the more troublesome creates great safety risk.

Finally, because tanks must be drained, they must be taken offline, which means a shutdown of all related processes. This makes scheduling, coordinating, and performing these services difficult and extremely costly. Multiple services in the affected area are often performed together at the same time, which creates problems with other site functions and accesses. A great deal of money is lost at once because production halts and the job is rushed. There is also the risk of unseen delays, which cost even more production time.

Robotic cleaning services have existed for some time. Large, heavy machines are placed in drained tanks. They run across the floor, breaking up material, making it more easily removed. It is a similar method to vac trucks, except with robots replacing the abrasive blasting. While they do remove some of the material themselves, they are often followed by vac truck teams, who suction out the remaining material. This truly is a more advanced version of vac trucks and carries many of the same costs and risks.

The robots cannot be used in water, meaning the tanks must still be drained, creating a stoppage and creating environmental concerns. These services must be done when coordinated with other down time activities, which makes it more difficult due to the bulk of the materials used.

Because these robots are unable to completely pull the material out and collect everything on their own, vac truck technicians are still required to enter the tank to clean what the robots have left, meaning confined space entries are still a requirement of the process. The abrasive blasting, which is a significant danger in and of itself, has been removed, but much of the process has the same dangers as vac trucks.

Finally, these robots are large. Weighing up to 500 lbs., basin linings and structures can be damaged by the movements of these machines. Increases to risks against the tank being serviced while not fully mitigating the safety, environmental, and cost concerns makes this method a minor improvement upon the vac truck method.

Divers clean tanks by having trained and licensed employees enter filled tanks, swimming throughout the materials, and performing cleaning services inside the filled towers. It combines some aspects of the vac truck methods, such as utilizing suction to remove materials, while eliminating the potential environmental costs of draining the basins. Some companies claim to be able to perform cleanings without shutdowns; however, it is a requirement that pumps be shut down, which can essentially pull some tanks offline. There are still extra risks and costs associated with this method.

First, confined space is always a concern, but when coupled with the dangers of diving, the risks highly outweigh the advantages. Oxygen depletion, drowning hazards, and pressure issues are just the tip of the iceberg. More safety watches, permits, and trainings are required, and time limits are given for working in order to reduce risks, which increases costs and service times.

Secondly, exposure is a constant risk in this method. While these tanks are primarily for water, there other chemicals are present, and prolonged exposure to these can create a major safety risk. Extreme mishaps, such as chemical burns and inhalation, are always possible. Because of these safety risks, support and medical crews must be on-hand at all timed during diving procedures. These risks also limit the circumstances in which diving cleaning can be done. If the pH of the liquid is off, it can be too dangerous for divers to even enter the water.

Divers run across one other issue which the others do not: turbidity. The motion of the divers as they move, arms swinging and legs kicking and feet flipping, forces the water to move in ways it does not during normal operation. Combining this with the breakup and collection of sediment creates turbidity within the unit. While often dismissed as harmless, cloudy water by some, this can create many problems later on, such as coagulations in pipes or blooms in bacteria and other biological material in the water. This has potential to create the need for future servicing, which decreases the efficiency of and increases the costs related to this method.

THE NEW METHOD: ONLINE ROBOTICS

A new method has been developed to clean tanks while remaining online. The technology, based upon the methods used for cleaning swimming pools, enables all matters of water-based tanks, towers, and basins, to remain online and operational while cleaning services are performed. Since entering the potable water industry in 2010, these robots have proven their effectiveness at utilizing micro-dredging methods in order to pull material and water from basins while they function and without requiring them to be drained or entered. These machines have evolved to fit different styles and methods for containment and tackle various jobs over the last decade.

The key to online robotics is the use of the water within the tank being serviced to do the cleaning, which means this method works better when the tank is online than when it is not. Robots are deployed into the water; drive along the bottom; break up sediment as they move; suction out water with onboard pumps, which pulls the material with it; and pushes the water to filtering boxes, where material is removed before the clean water is sent back to the tank. Therefore, water is not wasted and shutdowns are not required. The suction's placement also eliminates risks of turbidity as well, essentially using the locally created turbidity to take the material out of the tank by pulling the water behind it and preventing mixing within the stored water.

Safety is significantly increased in this method over all of the others for several reasons. First, confined space entry is rarely required. The process itself does not involve people entering the containment and robots do not face the same risks as people when going into these systems. Second, exposure is fairly limited. Dewatering is done in weir tanks and boxes, which are taken away after becoming full. Finally, no abrasive blasting is required at all. Therefore, the safety liabilities are significantly reduced in this method.

Unlike other methods used, the material created in the online robotics method is fully dewatered and classified as dry material because the water has been removed and sent back to the tank. This saves on disposal fees, which can be up to 7 times higher for wet material, and creates a much more environmentally safe collection to send to waste sites. Because filtering is targeted as suspended material, chemicals for water treatment to prevent fouling or corrosion are not removed from the water, meaning it does not need to be retreated upon its return to containment, saving money and preventing extraneous chemical exposure during the disposal process.

Process

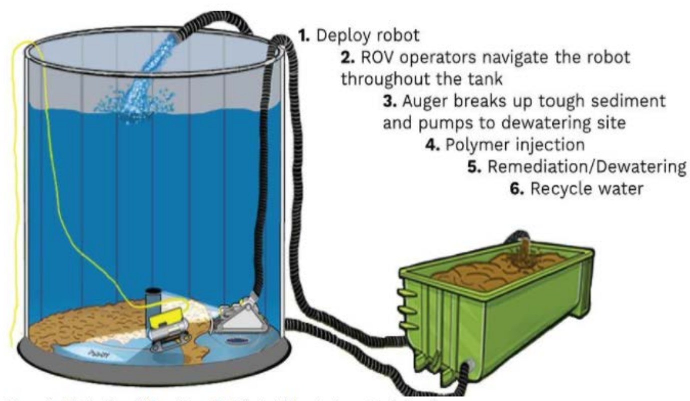


Figure 1 - Illustration of the online robotic industrial water tower basin cleaning process

Step 1: Deploy Robot

Utilizing an operator-owned, custom-made crane, the robot is lowered into the water and safely placed on the bottom of the water, resting on top of the sediment at the bottom. As soon as it enters the water, the onboard electric pumps are activated, eliminating any turbidity resulting from the robot landing on embedded sediment on the floor of the basin.

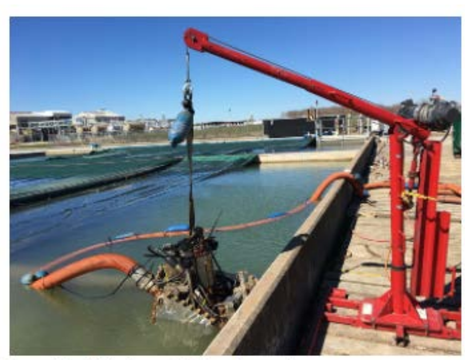


Figure 2 - Robot being deployed into a basin using custom crane

Step 2: ROV Operators Navigate the Robot Throughout the Tank

Remote operating vehicle (ROV) operators control the robot using a controller connected to an electrical control box. They control the robot's movement, the auger speed, and the onboard pumps from the safety of an operations trailer. Live-feed cameras, mounted with lights on the robot, project on televisions in the trailer, allowing the operator to view the robot's path and progress as it drives along the bottom of the tank, and blueprints enable technicians to anticipate any obstacles they might encounter. In extra murky water where vision in the water may be difficult, radio relays between the technician in the trailer and technicians with visual access to the access point may also be used in order to aid in navigation.

Figure 3 - Online robotic tank cleaning operator

Step 3: The Auger Breaks up Tough Sediment as it is Pumped to a Dewatering Site

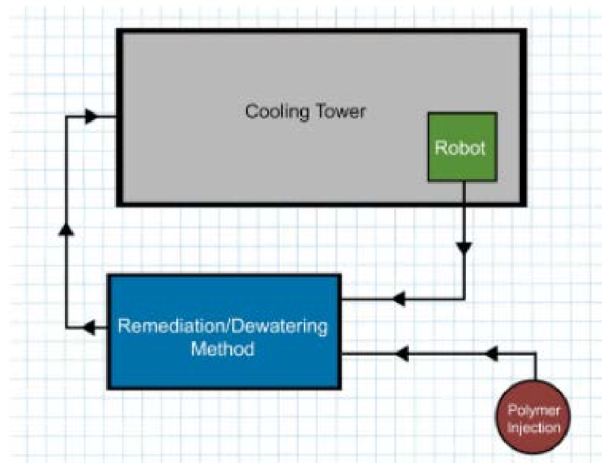
Stainless steel augers, mounted to the front of the robot and utilizing motors independent of the track drives, rotate as the robot moves along the bottom of the tank, breaking up and pulling in compacted sediment. Several factors, including tank construction materials and sediment make-up, determine the type of auger used. Stainless steel augers are the most common, but other options are available. Brush augers, for instance, are used to protect rubber tank liners.

A constant suction by a pump from behind the auger pulls water from the tank through the face of the auger, creating a vacuum point and forcing the material out with the water itself. These pumps create a 2-foot suction footprint, covering every direction from the base, preventing and eliminating any turbidity created by the auger. The mixture of sludge and water is sent through large hoses to a dewatering site outside of the water's containment.

Figure 4 – Auger at front of robot

Step 4: Polymer Injection

Polymer injection is often used in order to accelerate the dewatering process. When requested or approved by the client, polymers are injected as the water leaves the hoses and enters the dewatering boxes. The polymers bond with the material, forcing the water out of the suspended material, significantly reducing the amount of time required for dewatering.



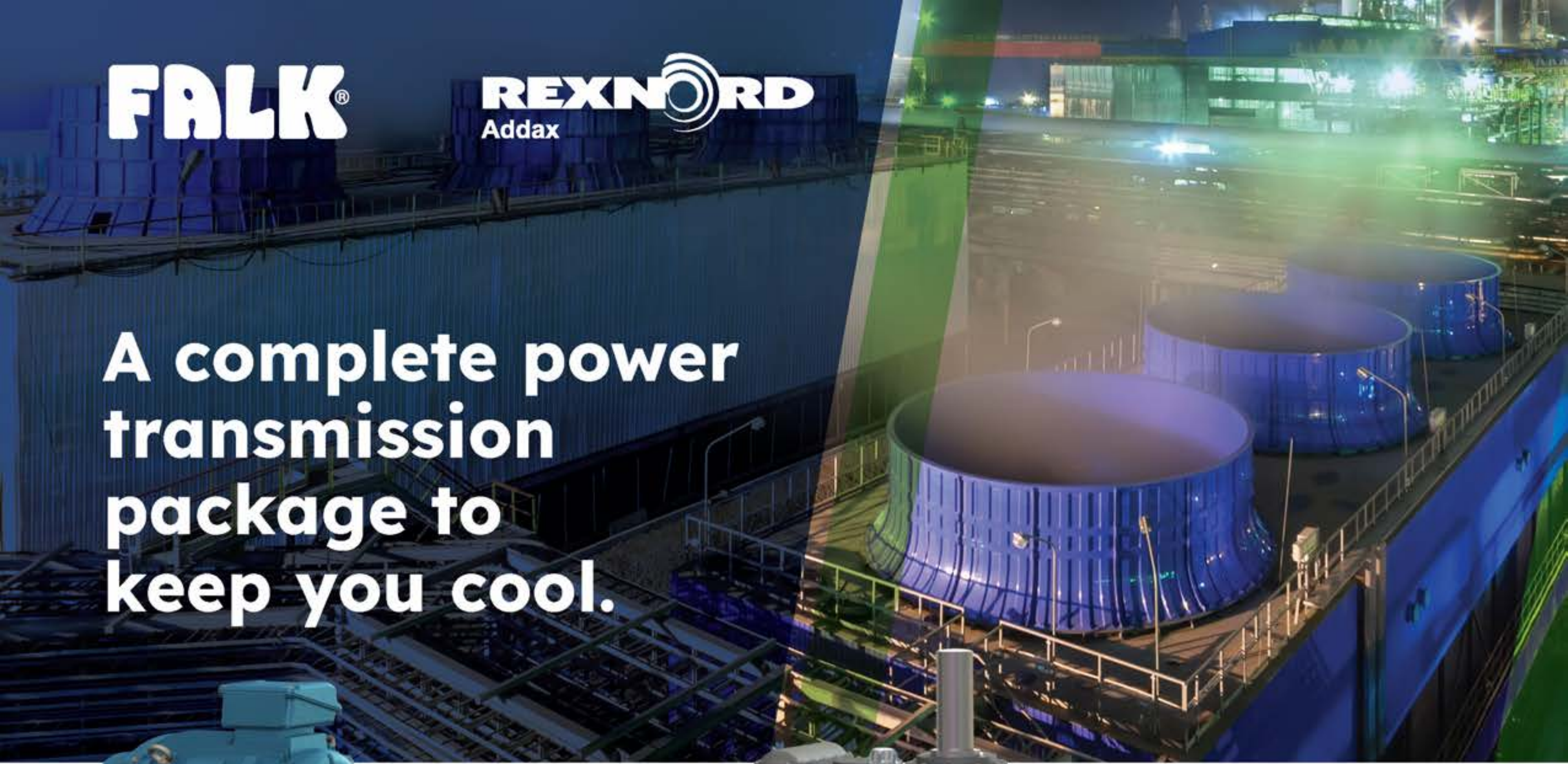
Step 5: Remediation and Dewatering

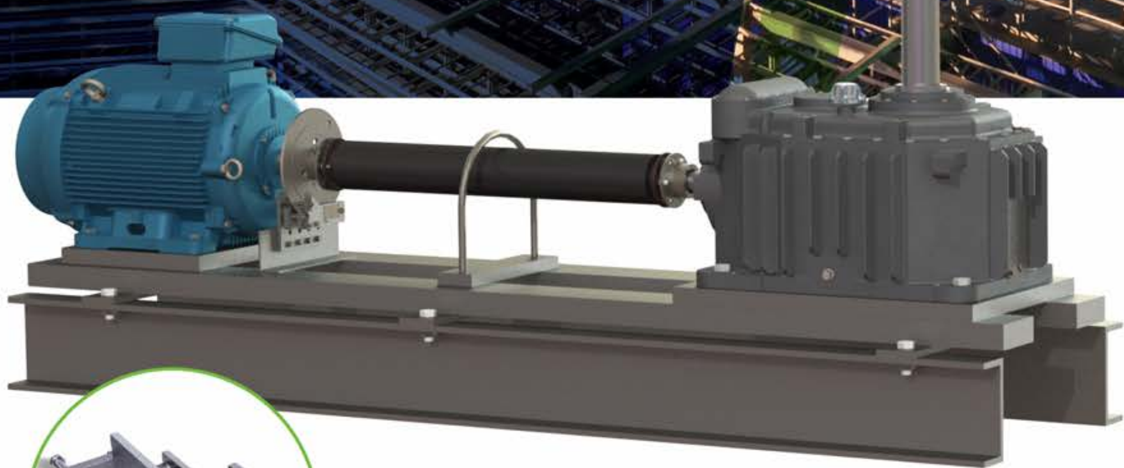
Dewatering boxes, weir tanks, geo bags, centrifuges, plate/filter presses, or a combination of these are used to separate the water from the sediment pulled from the tank. These methods capture the material and pass cleaned water out of the dewatering containment.

Figure 6 - Common dewatering methods used in online robotic tank cleaning

Step 6: Clean Water is Returned to the Water Tower Basin

Water taken from the dewatering site, having been cleaned, is constantly pumped directly back to the original containment, often drastically improving the water quality in the tank.





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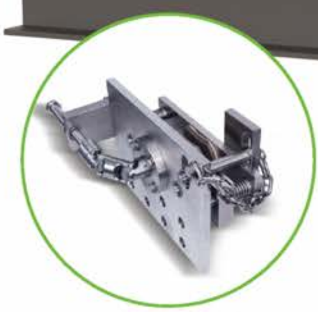

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Figure 7 - Clean water pumped into the basin after remediation process

MATERIAL ESTIMATION

Several traditional methods have been used to estimate the amount of material built up within containment systems.

The Stick Test

In the stick test, an estimator pushes a pole down into the water, stopping once resistance is felt on the bottom. It is then removed, marked where at the top water line, and measured for how deep it went into the water. This is then compared to the blueprints in order to estimate who much material has built up along the bottom of the tank.

The Brick Test

While similar to the stick test, the brick test uses a rope tethered to a brick or stone, which is lowered into the water. Once slack appears in the rope, the brick is pulled out, the rope measured, and estimations are derived from the comparison of the depth of the water to the blueprints.

These two tests have major flaws and create wildly inaccurate data from which a true estimate of the sediment buildup on the floor of a basin.

The data is relatively incomplete. Access is often limited, preventing multiple test locations within the basin. Sediment is rarely uniformly collected across the floor of a tank, so measuring in only a few locations creates a false picture of the material.

The measurements are not always accurate. The items used in lowering could lower at an angle or could easily catch on something unexpected within the tank, such as debris or protrusions from the sides of the unit. Water may also influence and change lowered items. Material density can also create issues with these readings because lighter material must compact beneath the tool in order to resist and be measured. This means there could be a great deal more buildup on the bottom than was measured.

Inaccuracies within these methods can prove extremely costly. Service estimates use them to determine the amount of time and, therefore, the cost of cleaning a water storage unit. If data presented proves to be off by even a few inches, an estimate may be off by a few days and several required storage units for material removal. If predictions are too high, charges will be added for days not worked and required items not used. If predictions are too low, jobs will take longer, cost more than anticipated, and extra removal equipment will be warranted. If done during an outage, this could also prolong the length of the outage, significantly costing the company production time.

Sediment Mapping

A new method, known as sediment mapping, creates far more accurate estimates of sediment buildup within tanks. The process is performed utilizing another form of online robotics in which an ROV is lowered into the water multiple measurements are made throughout the basin. These measurements are then used to make a clear picture of the sediment throughout in the form of heat and topographic maps.

The ROVs, operated much like drones within the water, utilize sonar imaging as it moves throughout the water, taking in measurements as it moves. The scans create upward of 500 data points, which can be analyzed to calculate the sedimentation.

The measurements are the depth at each point throughout the tank, letting the technicians see the depth at multiple points. Because water levels at the surface, differences in depths must occur along the bottom. This means differences in the data must be caused by one of two things: variation in the tank shape or unwanted material. Blueprints are used for comparisons in order to differentiate between tank design and sedimentation, which is done using the following calculation:

Hsediment = Hdrawing – (Hmeasured + Hsonar)

Hsediment = sediment height
Hdrawing = distance between water surface and the basin floor, as measured from water level and basin diagram
Hmeasured = Distance between sonar and sediment, as measured from sonar
Hsonar = Height of sonar from water surface

With these measurements, many possibilities arise. Sedimentation calculations can be used to create more accurate estimates for cleaning, saving time and money while enabling plants to more accurately predict service times. Sedimentation buildup tendencies can also be seen, and with multiple readings over several periods of time, trends can be found in how the material presents within a tank. These trends can also lead to predictions of how often cleaning should be performed for optimal servicing. Waterflow tendencies within the basin can also be identified, which can aid in identifying the need for other servicing.

The data is then compiled and charted in order to create a sediment heat map. These create visual representations of the unwanted material on the bottom of the basin, which are much more accurate than the other methods.

Heatmaps give a quick grid overhead view of the sedimentation within a tank. The numbers in each cell describe the depth in a specified distance on the basin floor. These numbers are then color-coded in order to have the areas with the most material stand out from the rest of the data. This presents a graphic understanding of the buildup and can be used to create a schedule of attack for cleaning the unit.

5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.46	4.39	4.40	4.43
5.10	4.84	4.85	4.82	4.80	4.80	4.71	4.71	4.70	4.66	4.42	4.61	4.42
4.66	4.15	4.17	4.10	4.07	4.07	3.89	3.88	3.87	3.86	4.45	4.81	4.40
4.48	4.37	4.44	4.14	3.91	2.88	2.81	2.83	2.84	3.16	3.74	3.95	3.50
4.30	4.59	4.70	4.17	3.75	1.68	1.73	1.78	1.81	2.46	3.02	3.09	2.59
3.62	3.71	3.84	3.45	3.22	1.92	2.18	1.78	2.04	2.67	3.16	3.31	3.06
2.94	2.83	2.98	2.72	2.69	2.16	2.63	1.78	2.27	2.88	3.30	3.52	3.53
2.25	1.94	2.12	1.99	2.15	2.39	3.07	1.78	2.49	3.08	3.44	3.73	3.99
2.54	2.47	2.56	2.36	2.41	2.60	2.77	1.98	2.48	2.92	3.22	3.31	3.47
2.83	2.99	3.00	2.73	2.66	2.81	2.46	2.18	2.47	2.75	3.00	2.89	2.94
3.12	3.51	3.44	3.09	2.91	3.02	2.15	2.38	2.46	2.58	2.78	2.46	2.41
3.25	3.51	3.38	3.12	3.00	3.07	2.45	2.74	2.65	2.54	2.75	2.61	2.58
3.37	3.50	3.32	3.15	3.09	3.11	2.74	3.10	2.84	2.50	2.72	2.76	2.75
3.49	3.49	3.25	3.17	3.17	3.15	3.03	3.46	3.03	2.46	2.69	2.91	2.91
6.45	6.76	6.83	6.77	6.70	6.61	6.32	6.91	6.85	6.29	6.15	6.44	5.64
5.91	6.53	6.91	6.86	6.72	6.57	6.10	6.86	7.17	6.62	6.10	6.46	4.86
6.06	6.64	6.54	6.73	6.54	6.46	6.64	7.02	7.37	6.15	6.40	6.00	4.98
6.20	6.75	6.17	6.59	6.36	6.35	7.17	7.17	7.57	5.68	6.70	5.53	5.10
6.15	6.77	6.48	6.40	6.23	6.09	6.27	6.29	6.45	5.50	6.01	5.24	4.64
6.10	6.78	6.78	6.20	6.10	5.83	5.36	5.41	5.33	5.32	5.31	4.95	4.18
5.91	6.22	6.21	5.99	5.76	5.78	5.59	5.38	5.55	5.61	5.68	5.36	4.77
2.22	2.16	2.14	2.28	1.92	2.23	2.32	1.85	2.27	2.40	2.55	2.27	1.86
2.02	1.60	1.57	2.07	1.57	2.18	2.54	1.81	2.49	2.68	2.91	2.68	2.44
1.96	1.99	1.78	2.09	1.88	2.35	2.67	2.24	2.71	2.80	2.90	2.69	2.74
1.90	2.37	1.99	2.11	2.19	2.52	2.79	2.67	2.93	2.92	2.89	2.70	3.04
1.83	2.75	2.20	2.12	2.49	2.68	2.91	3.09	3.15	3.04	2.88	2.70	3.33
1.89	2.49	2.05	2.28	2.44	2.66	2.90	3.21	3.24	3.77	3.91	4.12	4.43
1.94	2.23	1.89	2.44	2.39	2.63	2.89	3.33	3.33	4.49	4.93	5.53	5.53

Figure 8 – Sediment Heat Map

Heatmaps can be helpful, but they do not offer a complete picture and often fail to provide the clearest view of sedimentation. Therefore, the data is used and compiled into three-dimensional topographic maps. These show the measured depths and sediment depths in order to more clearly demonstrate how material distributes throughout the tank. Peaks and valleys become evident, and problem collection areas can more easily be identified using these maps.

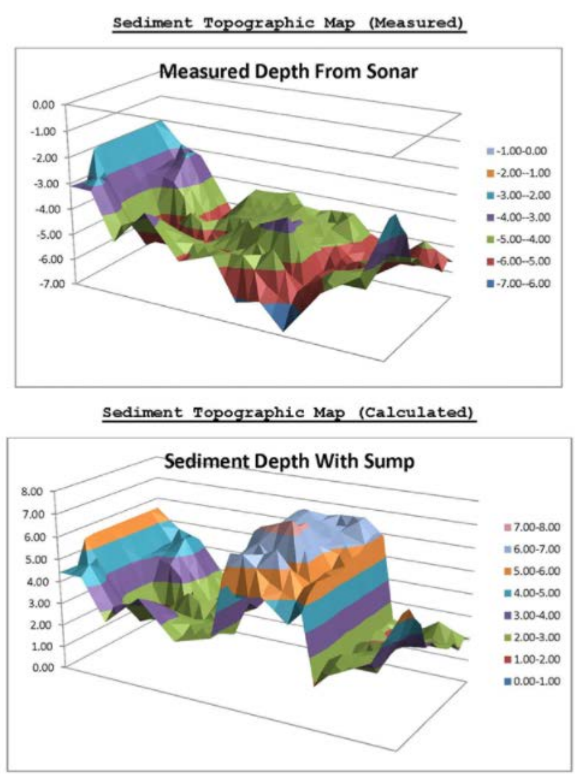

Figure 9 – 3D Topographic Sediment Map

INSPECTIONS

Inspections of water tanks is necessary in order to perform necessary maintenance to keep them both operational and safe to be in service. More standard methods require divers to enter the tanks or for the tanks to be drained and entered, which always carries major risks. Online robotics, however, has a new method for these services, as well, which also eliminate confined space entries.

Again utilizing ROVs, tanks are explored and inspected without the need for people to enter. Lights and underwater cameras are affixed to these robots, which move throughout the water in the basin with ease. The pictures and scans are stabilized by the small turbines that move the ROV, giving it steady control and creating clear views. The HD cameras take pictures and videos of the process and are used at the same time to navigate the unit. Ultrasonic thickness (UT) can be done in order to test the stability of the infrastructure and its integrity. These can combine to give an accurate view of the tank's stability, any corrosion, and any other issues that might arise from operation over time. API-653 certified inspections can be performed through this process, without having to take a unit offline.

SAFETY IMPROVEMENTS

One of the most dangerous aspects of industrial tank cleaning is confined space entries. In the past, employees have been sent into enclosures in order to gain the access required to perform cleanings. This meant personnel were exposed to chemicals, which required various PPE—including monitors, masks, gloves, and possibly suits—in order for safety to be maintained. Permits had to be made for each entry, with proper supervision and authorization. Even with these safety practices, confined space entries still carry great hazards and risks. When issues do arise, retrieval of personnel from inside of a tank can often be difficult and slow, which lengthens exposure and reduces the ability of emergency workers to provide aid in a timely manner. In fact, statistics from the Department of Labor show approximately 96 people die each year in confined space entry accidents, 61% of which occur during construction, repair, or cleaning processes. People are injured and do die each year using the traditional method.

The Online Robotics method, on the other hand, strives to avoid and eliminate confined space entries whenever possible. Since robots are sent in through an opening in the tower and retrieved using a winch system, people do not enter the tanks. When issues or damages do occur, they occur with the robot, not a human being. Robots can easily be pulled from the tank and repaired or replaced—people tend not to be so lucky.

Time spent in safety planning and preparation is also significantly reduced. General industrial safety standards are met and adhered to, but there is not need for additional procedures on most sites. Since confined space entries are not required, time is not spent identifying who must go in and addressing the permitting needs. Specific site needs can be focused on without as much worry as to who goes where when. This shift also saves money by reducing costs in planning time and liabilities.

Exposure to extreme climate is also reduced and limited. Prolonged exposure to extreme heat and cold, as well as rain or sleet, can be common dangers for those who clean tanks. Online Robotics, however, allow employees to limit exposure when the need arises. Drivers control robots from inside an air-conditioned trailer. Positions within a team can be easily rotated, and monitoring of dewatering and pump lines can be done from under cover. The only weather condition which precludes the use of


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Online Robotics is prolonged extreme cold. The reason is simply that if the water is frozen, it will not flow through the robot. In such cases, draining a tank is not really an option, either, as frozen water will not flow through an exit line. Below is a picture of a robot after being utilized for an extended period of time in sub-zero temperatures.

Figure 10 –Robot Exposed to Extreme Cold during use

CONCLUSION—A NEW STANDARD FOR INDUSTRIAL TANK CLEANING

The savings, especially those in continuing to utilize tanks while services are performed, completely outweigh the competition. Any time spent offline for cleaning is time spent in losses of production. There should be no need to drain for simple cleanings any more. Refilling and treating new water take time and costs money, which usually goes unnoticed. Wet waste disposal also has significantly higher fees than the dry waste Online Robotics creates.

Environmental savings also abound in Online Robotics. Draining basins needlessly dumps thousands of gallons of treated water out, affecting the other systems into which it flows. Taking out more clean water to fill the tanks also requires unnecessary burdens placed on water and ecosystems. Wet waste has a much higher environmental impact than the dry waste created using Online Robotics.

The safety increases provided by Online Robotics keep employees healthier, saving both lives and money. Reduced liabilities by reducing confined space entries helps keep employees out of harm's way. Keeping people from danger limits risks and liabilities, which prevents injury and saves money. Also, the reduction of permitting required for confined space entries saves both time and money.

Online Robotics, therefore, is the next wave in industrial tank cleaning. It is cost-effective, environmentally friendly, and safer than any previous option. Soon, it will be the standard of the industry.

PLANNING TO FAIL - COMPREHENSIVE WATER TREATMENT SPECIFICATIONS ARE A MUST!

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INTRODUCTION

In recent years, there have been a large number of catastrophic corrosion-based failures of system water piping associated with HVAC systems in mid-rise and high-rise buildings. Systems designed to provide long term service life are failing due to leaks and obstruction incident to severe pitting attack, corrosion and massive tuberculation in both galvanized and un-galvanized carbon steel and copper piping. It is not uncommon to encounter systems where complete penetration has occurred within a few years after initial commissioning. There are a number of reasons for the increased incidence of failures.

Prior to the late 1980's and early 1990's (EPA-2000, a ban on the use of chromate in cooling water systems) the use of chromate for corrosion control in all sorts of aqueous environments was commonplace. A few hundred parts per million of hexavalent chromium could maintain a corrosion-free, well passivated system even in stagnant water within mild steel pipe and mixed metal systems. It is little wonder that the phenomenon of exacerbated piping corrosion that we see today was relatively rare prior to the late 1900's. Today, treaters are restricted to the use of inhibitors composed of phosphate, carbon, sulfur and nitrogen containing material - all relatively non-toxic, biodegradable compositions. While the benefits of less dangerous chemistry are obvious, so too are the higher product costs and the system damages that are occurring at an alarming frequency.

It is becoming a far too commonplace occurrence for aggressive early onset corrosion to develop in HVAC piping and equipment installed in new commercial buildings. In severe instances, this corrosion presents in the form of water leakage into finished interior spaces within a few years after the building is first occupied. Frequently, this results in occupants being constructively evicted, with the attendant inconvenience, damage to personal property and business assets, and loss of domicile and/or business for the occupants. When significant amounts of corrosion products accumulate in the piping, an ideal environment is created for the proliferation of various anaerobic bacteria. The attendant biomass attracts opportunistic pathogens such as Legionella sp., and other undesirable organisms. Once this process has progressed, it becomes very difficult for chemical treatment and/or cleaning products to penetrate these accumulated deposits and reach the metal surface without the use of strong acids and mechanical intervention. The damaged parties expect to be compensated for resultant damage including human disease, loss of assets, loss of revenue, and inconvenience.

COMPLEX "HIGH STAKES" LITIGATION

Regardless of whether the building is used primarily as residential space, office space, for manufacturing, research, data storage, retail, education or healthcare, the costs begin to soar, patience runs short, and legal counsel is ultimately engaged to recover damages and to compensate for inconvenience.

Anyone involved in the design, construction, installation, commissioning, start-up and maintenance of these systems may find themselves in the crosshairs of a lawsuit. The building owner and/or the building management company are often targeted by the occupants and the insurance carriers are quickly drawn into the fray. The building architect, the design engineering firm, the specifying engineer, the general contractor, the mechanical sub-contractor, and all other sub-contractors who installed the piping and equipment, or who are assumed to have rendered services to prevent this scenario, are likewise usually implicated. This typically involves the water treatment supplier, the party that conducts the required hydrotesting, the party that provides post construction piping cleaning and passivation services, and frequently the suppliers of HVAC equipment, piping, and treatment and control equipment. All of these parties can be recipients of multi-million dollar demands.

Attempts to determine responsibility and to seek compensation for these failures, result in considerable legal expense, as well as business disruption that may last for years. Moreover, the scope of a defendant's potential liability may far exceed the amount they were paid for their services, as it may include not only the damages incident to the repair and replacement of the water system and its attendant equipment, but also to any surrounding structures and improvements, the expenses incident to constructive eviction of the building tenants who are displaced while such repairs or replacements are performed and, in some cases, the prevailing party's attorneys' fees and costs.

The lawyers for both the plaintiffs and various defendants will hire experts and investigators with a range of experience and skills to help them determine the root cause of the issues. Months of expensive work ensues as the parties, their lawyers, and their experts develop their positions and prepare for extensive document-based written discovery, site inspections, party and non-party depositions, hearings, court-ordered mediations and ultimately, trial.

These scenarios can be especially severe, inconvenient, and costly when a high-rise structure is involved, with multiple large diameter

steel riser pipes that extend from the basement to the rooftop. These risers usually supply a larger number of small diameter horizontal piping which services the various entities and spaces on the many floors of the building. Over the past decade, the authors of this publication have been involved in high-cost litigation of these matters on a national scale. Experience dictates that the damages in these disputes ranges from $10,000,000 to $30,000,000 and the corresponding litigation invariably takes years to resolve.

In some of these matters, sub-standard piping quality was a significant factor that was identified, while in others design issues contributed to the corrosion. In all of these instances it was found that vague and/or non-existent specifications resulted in failure to detect sub-standard materials, inadequate flow due to design issues, failure to provide adequate cleaning of piping and equipment, failure to treat the system water adequately to minimize the corrosion, and in failure to manage the progression of the process of moving from initiating construction through hydrotesting, post hydrotest cleaning and passivation, and in continuously maintaining the corrosion control process from hydrotest through cleaning and passivation to HVAC system startup, occupancy, and turn-over of the property to the owner/operators.

Strict adherence to well-prepared specifications may help reverse this trend. In this document we offer recommendations for use in formulating comprehensive engineering specifications to help minimize these instances.

COORDINATE NOW OR LITIGATE LATER

The process of taking a complex structure from the architect's design to a finished facility, ready to turn over to the owner/operator is inherently complex. This process is interdisciplinary and involves coordination with a wide array of various trades. Despite this fact, research and experience reveal no true comprehensive domestic industry standards to outline the process of ensuring that the HVAC piping and equipment is preserved and protected from corrosion during and after the construction process.

Without some generally accepted domestic standard that deals with the necessary procedures and practices required to ensure the owner that the property has been properly constructed, inspected, treated and tested, we are completely dependent on the engineering specifications and the experience and integrity of the various disciplines involved. Comprehensive engineering specifications are vital to ensure that the new facility can be started up and occupied without suffering severe corrosion damage along the way.

Without an industry standard to ensure that correct practices are required by all parties and are understood by those responsible for executing them, the entire process can easily spiral into an unregulated bidding war with final cost as the only consideration. The corrosion control and inspection process necessary to protect the HVAC piping and equipment involves a relatively small expense for products and equipment, but potentially a large amount of labor. Unless there is some means of insuring that only highly motivated and well-trained personnel are supervised by someone with appropriate experience and qualifications, "cutting corners" may result in a very attractive quoted bid price, followed by very disappointing results down the road.

Those who may be ultimately liable are the very people with the training and experience for the architects and engineers to enlist to ensure that all bases are covered. Corrosion consultants, corrosion engineers, plumbing experts, chemical cleaning experts and water treatment experts should be enlisted by the specifying engineer early in the conception and design of the facility and remain involved with the various contractors until the facility is built, turned over and occupied.

HVAC CONSTRUCTION MILESTONES

As it relates to corrosion prevention, there are several milestone moments in the life of an HVAC system from commissioning to start-up. They include but are not limited to: (1) Specification Preparation; (2) Bidding; (3) Materials Procurement, Shipment and Inventory; (4) Piping Construction; (5) HVAC Equipment Installation; (6) Hydrostatic Pressure Testing; (7) Piping & Equipment Passivation; (8) Piping & Equipment Cleaning; (9) Piping & Equipment Passivation; (10) On-Going Corrosion Protection of Completed Construction; (11) HVAC Equipment Start-Up and Operation Pre-Turnover; and 12) Commissioning and Turnover of the Property.

As reflected in the list, there is a series of related activities conducted in a sequential fashion, often by different sub-contractors, involving many different trades. To ensure that the project is completed in a manner that results in one or more well-built HVAC systems being turned over to the owner/operator with only minimal and appropriate time-related general corrosion of metallic components evident, it is necessary to consider this entire multi-stage process as an on-going continuous process from the corrosion control view point.

A single subcontractor could ideally be hired to manage the completion of corrosion protection during each construction step, as well as during any intervening time delays between steps. This subcontractor must coordinate closely with the general contractor and the mechanical subcontractor, who will need to ensure that the activities of the corrosion control sub and those of other subs and trades are coordinated to insure a desirable outcome. The mechanical subcontractor must ensure that all needed utilities and appropriate utility services are available for the duration of the appropriate step. The corrosion subcontractor may either supply all needed chemicals, equipment, and services required to accomplish the corrosion control steps needed, or he may work with the appropriate party designated by the mechanical subcontractor to provide any needed equipment, chemicals, and services.

The corrosion control subcontractor could be found from a variety of sources, including a corrosion consultant or a qualified representative of a water treatment company. The corrosion control subcontractor may ensure that inspection of piping and equipment is conducted and documented before each step, as well as at its completion. This subcontractor may provide detailed written instructions for the completion of each step, and either supply all needed equipment, chemicals, and services, or work with a designated supplier to insure smooth completion of each step in the process.

The equipment required may include recirculating pumps, inspection equipment, testing stations and equipment, safety equipment, and chemical feed and control equipment. This equipment may be purchased for the project or rented/leased for use on this project. Any needed chemicals must be supplied by the corrosion control subcontractor, or by his designee, along with any needed labor to apply it, complete instructions for its safe use and disposal, and with any needed equipment and products in the event of an unintentional spill.

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During each construction step different environments may be present, requiring different chemistries and equipment to permit successful corrosion control during the step at issue, as well as during any transition period between steps. An examination of the corrosion subcontractor's involvement at the respective steps is listed below.

Specification Preparation: A corrosion consultant may work closely with the specifying engineer for the project to provide the specification author with detailed information on what is required in terms of services, functions, experience and resources, and to provide specific specification language and requirements for the ensuing steps. It is important that provision for proper utilities be incorporated into the specifications and the attendant construction process. For instance, in order to properly hydrotest, clean, and passivate the piping, a safe and reliable power supply and lighting must be installed at each location where pumps and mixers will be employed. The water supply must be readily available in sufficient volumes and pressures to accomplish these tasks. Advance provision may need to be made with appropriate municipal utilities for the safe disposal of spent hydrotest, cleaning, and passivation solutions as appropriate. Recirculation pumps of sufficient capacity and pressure should be available to accomplish these tasks.

Bidding: A corrosion consultant may be employed to work with the specifying engineer, the construction manager, with the appropriate contractor, and his bid coordinator, to review the bids and ensure that the specification is being met before a contract is awarded.

Materials Procurement, Shipment & Inventory: It is well known that substandard piping and materials find their way into many projects. A corrosion consultant may work with purchasing to review the bids and conduct appropriate inspections to ensure that the piping, equipment, and materials to be provided will meet the specifications. The corrosion consultant may review the proposed shipping methods to make sure that the supplied items will be adequately protected from in-transit corrosion damage. The corrosion consultant may review proposed piping and equipment, as well as any on-site inventory facilities and methods in order to make sure that they are appropriate to prevent damage and deterioration during on-site storage.

A quality control procedure may be established to require a corrosion consultant and/or metallurgist to examine representative piping from each shipment received on site just before the material is used in the project. Specifically, the consultant/metallurgist may look for the correct material identification, weld integrity, and any evidence of inappropriate corrosion, especially pitting and tuberculation.

Piping Construction: The corrosion consultant and/or the corrosion sub-contractor may coordinate with the mechanical sub-contractor before the project starts to make sure that the proposed construction methods and sequences will incorporate adequate corrosion control provisions to ensure that the piping and equipment is not deteriorated during construction due to corrosion. Corrosion coupons fabricated with system metals may be installed in multiple locations, along with removable pipe spools fabricated with the same grade of piping, so that the corrosion rates and piping surface conditions can be followed during the idle period prior to start-up. In addition to pipe spools fabricated from new piping, the use of polished nipples may be considered if periodic pit depth measurements during the construction period are desired. The locations of such devices should be carefully specified by the specifying engineer in consultation with the corrosion consultant.

An example of how such damage might occur is instructive. In some cases, the piping construction may be conducted "stepwise", with the piping risers constructed one or more floors at a time, with hydrotesting scheduled to be completed as each set of floors is completed. If this practice is used, the piping must be protected during the hydrotest with appropriate corrosion inhibitors and microbicides added to the hydrotest water. At the conclusion of the hydrotest, the piping must then be cleaned and passivated to remove construction dirt and debris along with cutting oils, welding slag, corrosion products, etc. Depending on the chemistry and metallurgy involved, hydrotesting and cleaning may be done consecutively, or this may require draining and re-filling the piping before cleaning. Following the cleaning process the piping must be immediately inspected to ensure complete removal of foreign materials and corrosion products, and to ensure freedom from unexpected corrosion damage.

The piping must then be chemically passivated to resist corrosion for the balance of the construction phase. Passivation may involve treating and protecting the piping with the piping full of water containing the corrosion inhibitor, or the piping may be drained, air dried, and treated with a vapor phase inhibitor. If the subsequent stepwise construction likewise involves hydrotesting of the successive series of floors, then the sections that have been previously hydrotested, cleaned, and passivated must be isolated before proceeding. Unless this newly constructed, cleaned, and passivated segment is isolated from the preceding segments, each successive hydrotest will contaminate the previously cleaned and passivated segments. This makes construction stepwise with intervening hydrotesting a very questionable practice unless each segment is isolated from the preceding segments with isolation valves, blinds, caps, or some other temporary mechanisms to ensure that cross contamination does not occur.

HVAC Equipment Installation: Specific components, such as cooling towers, evaporative condensers or fluid coolers, chillers, heat exchangers, water cooled process equipment, pumps, filters, compressors, generators, and others frequently require separate hydrotesting, cleaning, passivation, and inspection after the involved piping has been installed. Conditions such as special metallurgy, special coatings, and difficult geometry, with very narrow fluid passages may impose special manufacturer-imposed cleaning and passivation requirements, and failure to observe these may result in voiding any warranties. Such conditions may also require that the equipment be isolated from the main piping system prior to conducting these procedures. The corrosion consultant or corrosion subcontractor would be well served to review manufacturer's installation, operation, and maintenance manuals, and if need be, consult separately with equipment suppliers in order to make sure that all pertinent conditions are met.

Hydrotesting: The purpose of hydrotesting is to ensure that the piping is free of leaks and weak joints prior to finishing equipment addition and prior to installing walls and finishing out the interior space. The process of hydrotesting involves filling the constructed skeleton piping or piping section with water, excluding air pockets, and then pressurizing the filled piping segment to a specified pressure greater than ambient, and holding that pressure for a specified period while leak checking is conducted. The newly constructed pipe segment may be inspected by the corrosion subcontractor or his designee, and the condition of the piping may be verified with an inspection report accompanied by photographs, videos, and recorded data such as eddy current tests, pit depth readings, or reading of general corrosion or deposition, as applicable. Any deposits should be sampled, analyzed, and removed. This information may be entered into the construction records.

The water used for hydrotesting should be clean water, free of dirt, debris, corrosion products, and other contaminants. The chemistry of the water used for hydrotesting should be specified, tested, and recorded in the construction records. This can become problematic, as frequently the source of the hydrotest water is temporary piping, or from fire hoses. In some instances, the water must be hauled in by tank truck. If there is any question about the integrity, chemistry, or cleanliness of the hydrotest water, then it should be tested and if necessary, externally treated to remove contaminants.

To minimize corrosion of the new piping due to the presence of water, a corrosion inhibitor that has been approved by the corrosion consultant or corrosion subcontractor should be added to the hydrotest water at the specified concentration. The treated hydrotest water should be recirculated until the composition is uniform and the water should be sampled and tested to verify proper chemistry and proper inhibitor concentration. At the end of the hydrotest, the water may again be tested to again verify proper inhibitor concentration and freedom from excess suspended and dissolved corrosion products. If this water is dirty, discolored, or contains obvious contaminants, the system should be drained and flushed prior to chemical cleaning. This information, along with all test data, should also be entered in the construction documentation.

Depending on the inhibitor selected for the hydrotest, it may or may not be appropriate to add cleaning chemicals directly to the inhibited hydrotest water for subsequent cleaning of the piping without intermediate draining and flushing. This should be cleared by the corrosion consultant or corrosion subcontractor. It is important to not allow the hydrotest water to stand stagnant in the piping at the completion of the hydrotest. The selection of the hydrotest corrosion inhibitor composition and dosage is dependent on the construction materials involved, as well as on the chemistry of the water selected. This may all be specified by the corrosion consultant. Typically, the hydrotest corrosion inhibitor may incorporate some or all of the following list of ingredients: phosphates, nitrites, nitrates, borates, molybdate, phosphonates, filming amines, azoles, zinc, surfactants, antifoams, microbial control agents, and dispersants.

Following the hydrotest period, depending on the need for subsequent draining between hydrotest and cleaning, provisions should be made for the appropriate storage, treatment, and safe disposal of the hydrotest water. This may be specified in advance by the corrosion consultant in accordance with local disposal regulations and requirements. It is important that there be no delays between the completion of the hydrotest and the cleaning and passivation steps.

The hydrotest treatment chemicals should be pumped into the hydrotest water as it is being added to the piping at the recommended dosage, and then the solution should be recirculated to ensure good mixing and a uniform solution. The corrosion subcontractor may provide appropriate tanks, pumps, and dissolving equipment and specify needed injection fittings, sampling nozzles, test equipment, and locations. The hydrotest water may be sampled and analyzed prior to removing it and the final analysis should be compared with the initial analysis, and both tests may be entered into the construction record.

P**iping & Equipment Cleaning**: It is common to find some corrosion products firmly attached to the piping interior surfaces by the time that the pipe is incorporated into the building risers and laterals. In addition, depending on shipment and storage methods, the pipe frequently contains dust, dirt, mud, and other types of loose deposits. Inspection prior to construction may detect these conditions. If present, they must be addressed in the cleaning process. In addition, it is common to find materials such as cutting oils, welding slag, and construction debris in the newly constructed piping.

This piping segment will contain mild steel piping. It may also contain galvanized steel, copper, copper alloys, stainless steel, and possibly aluminum alloys. The materials present will dictate the cleaning chemistry and procedures. This may be specified by the corrosion consultant coordinating with the specifying engineer and the mechanical subcontractor.

If any HVAC or process equipment is incorporated into the piping prior to cleaning, it may impact the cleaning chemistry and procedures to be specified. The corrosion subcontractor would be well served to familiarize himself with the materials present, as well as with manufacturer's requirements regarding cleaning chemicals and procedures. The cleaning chemistry may be acceptable to add directly to the hydrotest water after hydrotesting is complete, or it may require draining and refilling the piping. This again may be specified by the corrosion consultant and/or the corrosion subcontractor.

The corrosion subcontractor may provide all required equipment to apply the cleaning chemistry, including tanks, pumps, mixers, safety equipment, sampling and testing equipment, and inspection equipment. The piping segment should be inspected and photographed prior to cleaning. This inspection will dictate specifics of the cleaning process, including ingredients, dosage, recirculation velocities, cleaning times, and cleaning chemistry. The results of this inspection (report and photos) may be recorded in the construction documentation.

The cleaning chemicals may be added by chemical injection pump through specified fittings while the system water is being added and/or recirculated. The cleaning solution may be sampled and tested before and after recirculation. The chemical concentration, solution chemistry, and recirculation time may be specified by the corrosion subcontractor depending on the inspection results. Corrosion coupons and/or pipe spools may be incorporated into the piping before the cleaning process. After cleaning is complete, the piping may be inspected and photographed again. Depending on the starting conditions, one or more cleaning cycles may be required. This process may be repeated until it can be verified by inspection that the piping and equipment to be cleaned is actually clean.

Following the cleaning and inspection period, depending on the need for subsequent draining and/or chemical additions between cleaning and passivation, provisions must be made for the appropriate storage, treatment, and safe disposal of the spent cleaning water. This must be specified in advance by the corrosion consultant or corrosion sub-contractor in accordance with local disposal regulations and requirements. The spent cleaning solution may be sampled and analyzed, the cleaned equipment inspected, and these records may be entered into the construction documents.

Piping & Equipment Passivation: Depending on what has been hydrotested and cleaned, and depending on equipment manufacturers instructions, the cleaning solution may be appropriately drained, the piping flushed, and a passivating corrosion inhibitor added to fresh clean water immediately upon completion of the cleaning. The composition and dosage of the passivating inhibitor is again site specific and depends on metallurgy and equipment manufacturer instructions.

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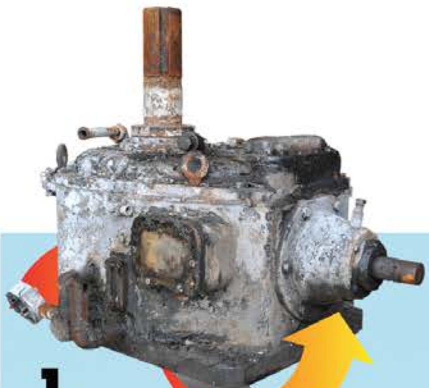

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Typically, the passivating treatment chemical may contain nitrite, nitrate, borate, azole, silicate, molybdate, surfactants, antifoams, phosphates, phosphonates, zinc, filming amines, microbicides, and dispersants. Depending on site conditions, metallurgy, water chemistry, piping design, and manufacturer's requirements, the passivating formulation, required dosage, and required application time and method may be determined by the corrosion consultant and/or the corrosion subcontractor. Again, the passivating chemical should be added by injection pump as the system is being filled with water. The corrosion subcontractor may provide all required equipment, chemicals, testing materials, and labor necessary to get the job done properly. In recent years, new non-fouling amine chemistry has been developed that may be applicable either when used in a flooded piping system, or when applied as a vaporized or steam distilled material to clean dry piping.

Ongoing Corrosion Protection of Completed Construction: The period of time between passivation of the piping and equipment and HVAC system start-up can be highly variable due to a variety of factors. It is not uncommon for the completed and passivated piping and equipment to sit idle for a period of months. Without proper on-going corrosion monitoring and control, the best efforts of the earlier steps can be quickly defeated if piping and equipment is allowed to stand idle without treatment and attention.

Historically, the completed piping and equipment is maintained completely full of clean water with corrosion inhibitors and microbicides added. Depending on the site conditions it may be appropriate to cap the passivated piping and equipment with a low-pressure dry nitrogen cap to exclude oxygen from the passivated system. In recent years, the treatment chemistry of choice has been a high-level nitrite formulation. Typically, such products contain nitrite, nitrate, borate, and often silicate and/or azole. In some cases, a mixture of nitrite and molybdate has been successfully used. In addition, these formulations are frequently supplemented with a non-oxidizing microbicide such as Glutaraldehyde or Isothiazolin.

If such chemistry is to be successfully employed, it is important to maintain the equipment fully flooded with high quality water, and it is important to exclude air. In addition, it is vitally important to provide for recirculation of this treated water periodically while the system is maintained in idle condition. If the water is allowed to stand stagnant for extended time periods, the inhibitor may become locally depleted, leading to aggravated pitting attack at these sites. The nitrite level should generally be maintained at approximately 500 mg/l, as NO2 if the water is continuously recirculated at ambient temperature and a linear water velocity of at least 3 ft/sec. If only periodic recirculation is possible, or if recirculation will result in much lower flow velocities, then higher dosages should be considered. The system should be recirculated weekly for a time period sufficient to accomplish several system volume turnovers, and sufficient to maintain uniform nitrite levels throughout the system.

If periodic recirculation is employed, the nitrite level should be maintained at a higher level, preferably between 1,000 and 3,000 ppm as NO2, depending on recirculation frequency and velocity. The details of dosage and recirculation rate and time should be specified by the specifying engineer in conjunction with the corrosion consultant.
The new filming amine formulations have been successfully used as an alternative to traditional nitrite-based programs. If amines are to be used, their use parameters must be specified by a corrosion consultant with specific experience with these materials in these applications. Notably, the U.S. military has had very good success using amine chemistry lay-up of military equipment that is stored idle for extended time periods.

Regardless of the method and dosage employed, the idle period corrosion protection should be verified using regular testing of the system water supplemented with the previously discussed corrosion coupons, pipe spools, and possible with electronic corrosion probes. Testing of idle solution chemistry should be preceded by recirculation of the water and should involve traditional parameters, including pH, conductivity, hardness, alkalinity, chloride, sulfate, silica, and system metals concentrations, as well as microbial testing for microbial proliferation due to aerobic and anaerobic bacteria, algae, fungi, and mold. The inhibitor chemistry must be specifically tested. While this publication does not address water borne pathogens, specific testing for infectious organisms such as Legionella is advisable. All such information should be maintained in the form of testing reports and corrosion monitoring reports with photos in the construction documents. If the idle period extends beyond two months, it is advisable to supplement this information with periodic fiber optic piping inspections with photos.

The corrosion subcontractor may participate in the commissioning and start-up of the HVAC system to ensure that adequate provision is made for chemical treatment and control to protect the system from startup until the owner/operator takes responsibility for the system operation. This period frequently involves only periodic operation of the system and can require special treatment provisions and periodic recirculation to prevent standby damage and deterioration during any periods of low flow or stagnant conditions.

Depending on the specific site location and the intended purpose of the building, federal, state, & local regulations may require complete system sterilization at specific timing prior to occupancy.

Commissioning & Turnover: It is advised that the mechanical subcontractor and the corrosion control subcontractor meet with owner representatives well in advance of turnover to ensure continuous maintenance of the treatment, control, and monitoring of the HVAC treatment program during the transition. This transition may or may not involve the use of different water treatment contractors.

CONCLUSION

There are a large number of industry prepared guidelines and standards governing the manufacture of piping for various purposes. There is also a wealth of individual equipment manufacturer information that is somewhat relevant with respect to installing, protecting, and maintaining their mechanical equipment, such as cooling towers, evaporative coolers, chillers, compressors, generators, and pumps used in an HVAC system. There is likewise a fair amount of industry information produced by ASHRAE, ASME, NACE, CTI, AWT, and others, regarding proper water treatment practices relating to routinely operating HVAC and industrial cooling water and heating systems. In addition, some of the large domestic and international property management firms have developed water treatment specifications for internal use, and some of the water treatment firms and consulting companies have likewise produced literature, including specifications for use by their customers in the treatment of normally operating systems.

In contrast, research has revealed no North American guidelines or standards pertaining to the practices of surrounding the preservation of HVAC piping system asset value during the complex, multi-step, and frequently delayed construction, commissioning, and turn-over process. Investigation has revealed a document published by the British Iron & Steel Research Association (BISRA) entitled, “A BISRA Guide, Pre-commission Cleaning of Pipework Systems” (2nd edition) by Chris Parsloe. Perhaps this British publication can serve as a starting point to allow one of the appropriate industry trade associations or technical societies to develop an industry standard that can serve as the basis for establishing accepted minimum requirements for those who prepare the mechanical specifications as well as those who implement these specifications during the construction process, extending until occupancy by the owner.

In the absence of specific guidelines and standards pertaining to these construction issues it is vitally important for the project specifying engineer to provide comprehensive specifications governing the conduct of the functions described earlier in this paper.

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PH PHENOMENA IN COOLING WATER

ROBERT J. FERGUSON
FRENCH CREEK SOFTWARE

INTRODUCTION

One of the first lessons learned by new water treatment sales, service and research chemists is that calcite is inversely soluble with temperature. As temperature increases, solubility decreases. A corollary to this rule is erroneously assumed:

“As temperature increases calcite solubility decreases, causing scale potential, the degree of super-saturation, and indices, to increase in response."

This is accurate, if only the solubility of product for calcite is considered. Temperature changes affect more than just the solubility product. When doing an evaluation that includes temperature changes, it is prudent to evaluate the impact of temperature on other parameters. Table 1 summarizes various parameters directly affected by temperature that affect the scale potential.

Table 1 Parameter Impact Upon Scale Potential

PARAMETER	DIRECT IMPACT	IMPACT UPON SCALE POTENTIAL
Solubility Product	Decreases with temperature	Increases Saturation Ratio and Indices
pH	Decreases with temperature	Decreases Saturation ratio by shifting CO_3 equilibrium towards HCO_3
Dissociation	Increases with temperature	Increases Saturation ratio by increasing dissociation of HCO_3 to CO_3
Activity	Increases with temperature in range of interest	Increases Saturation Ratio
Pressure (pCO_2)	As pressure increases, dissolved CO_2 increases. Decreasing pH	Decreases Saturation Ratio and Indices by decreasing pH
Impact(s) are not linear with temperature and may work with or against each other.		

Langelier pointed out and quantified the largest impact in a paper describing the impact of temperature on pH 1 This was a follow up to the paper that outlined the derivation and introduced the Langelier Saturation Index.2 Overlooking the impact of temperature on pH can lead to major discrepancies in the prediction of severity of scale potential. He recommended that the pH at the temperature evaluated be used. Other researchers have further defined the temperature – pH relationship and impact upon saturation calculations. 3,4

At this point, it is useful to define two types of temperature corrections to pH:

- the correction for instrument and probe variation due to temperature; and
- the correction for solvent effects due to change in Kw and other chemical parameters.

The first correction for the instrument and probe is the correction made by the temperature compensation in the pH meter.

The solution chemistry correction is typically made by a speciation engine in a water chemistry evaluation program. The speciation engine accounts for the pH reduction as temperature increases, activity coefficient changes, increase in dissociation such as that for bicarbonate to carbonate. Where applicable, a speciation engine will also account for increases in pressure and pCO2.5,6

Figures 1, 2 and 3 profile what you would expect to see for calcite scale potential as temperature increases. These profiles use the pH from the analysis “as is” and are not corrected for temperature impact. They reflect the “rule of thumb” expectation that scale potential will increase with temperature, because the solubility product decreases. Other factors are ignored.

Figure 4, 5 and 6 profile realistic trends after correcting pH for temperature.

Figure 1 Langelier Saturation Index versus Temperature (Using pH uncorrected for temperature)

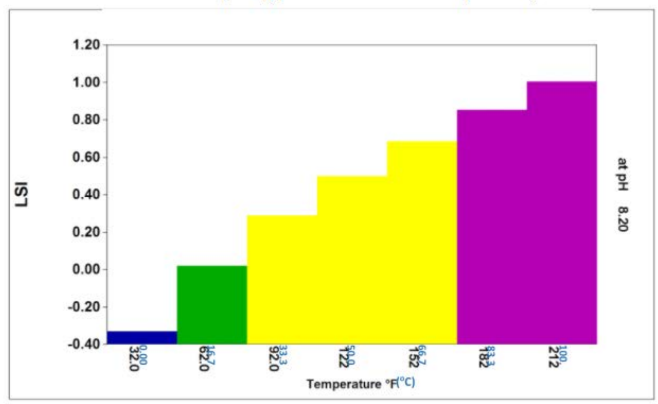
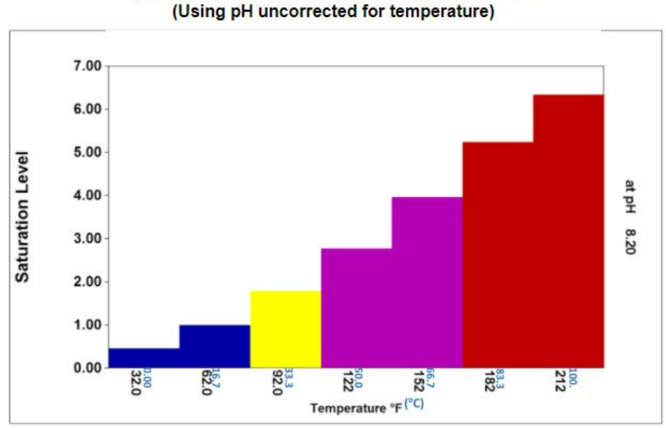


Figure 2 Calcite Saturation Ratio versus Temperature (Using pH uncorrected for temperature)



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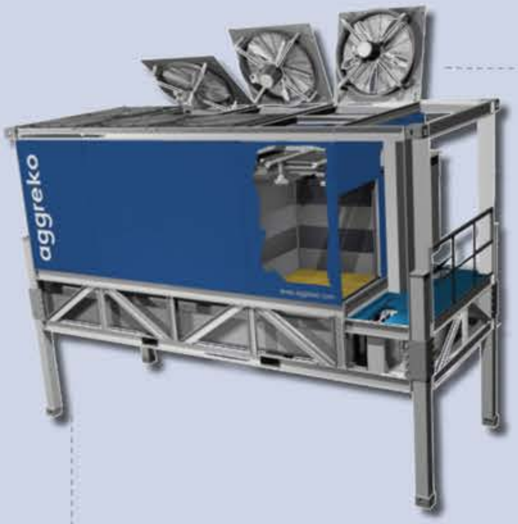

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Figure 3 pH versus Temperature
(Using Measured pH uncorrected for temperature)

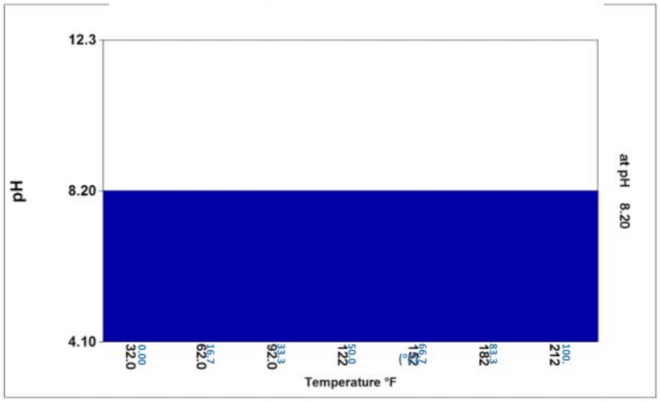


Figure 4 Langelier Saturation Index versus Temperature
(Using pH corrected for temperature)

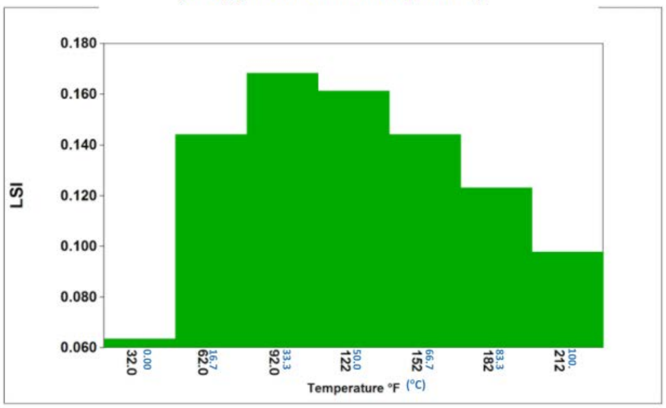


Figure 5 Calcite Saturation Ratio versus Temperature
(Using pH corrected for temperature)

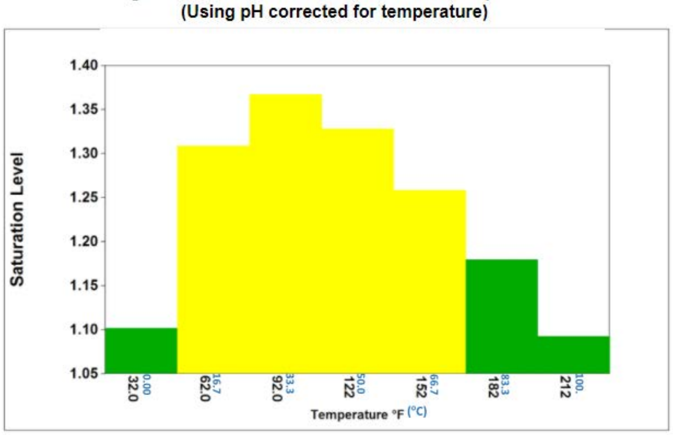
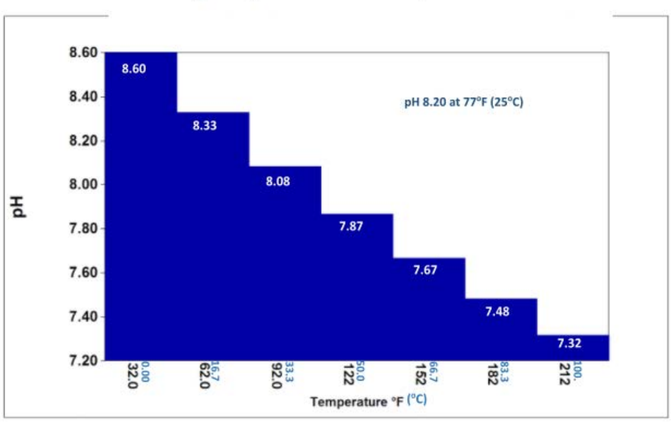


Figure 6 pH Corrected to Temperature



THEORETICAL CONSIDERATIONS

Kw is the dissociation constant for water that changes with temperature, resulting in the "neutral" pH change.

$$K_w = \{H\}\{OH\} \quad (1)$$

$$pK_w = -\log10(K_w) \quad (2)$$

$$pH = -\log10\{H\} \quad (3)$$

Figure 7 profiles the change of pKw with temperature, while Figure 8 profiles the neutral" pH versus temperature. The neutral pH at 25oC (77oF) and infinite dilution would be calculated as follows.

$$pK_w\ 25C = 14.0 \quad (4)$$

$$\{H\}\{OH\} = 10^{-14.0} \quad (5)$$

$$\text{At neutral pH, } \{H\} = \{OH\} \quad (6)$$

$$\{H\}^2 = 10^{-14.0} \quad (7)$$

$$\{H\} = 10^{-7.0} \quad (8)$$

$$pH = -1.0 * \log10(\{H\}) = 7.0 \quad (9)$$

Figure 7 pK_w versus Temperature

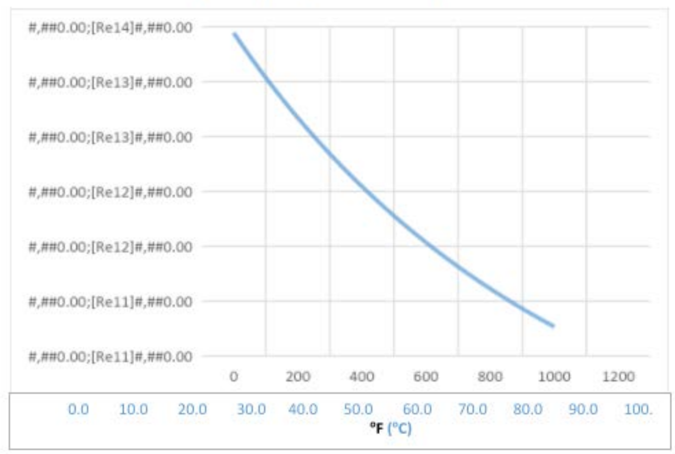
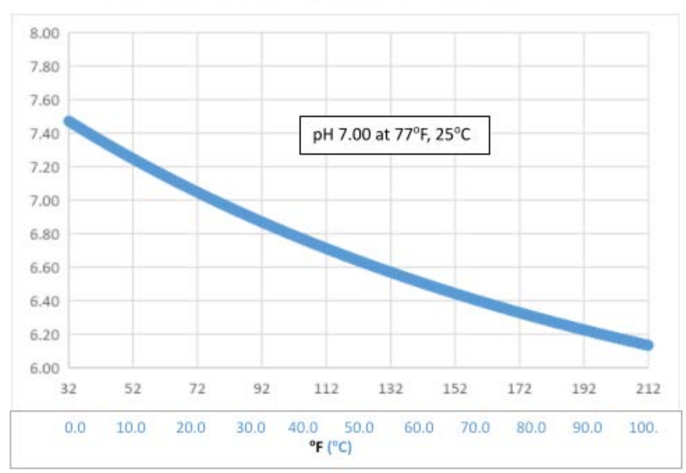


Figure 8 "Neutral" pH versus Temperature



The solubility of the calcite polymorph of CaCO3 (Ksp) is defined as:

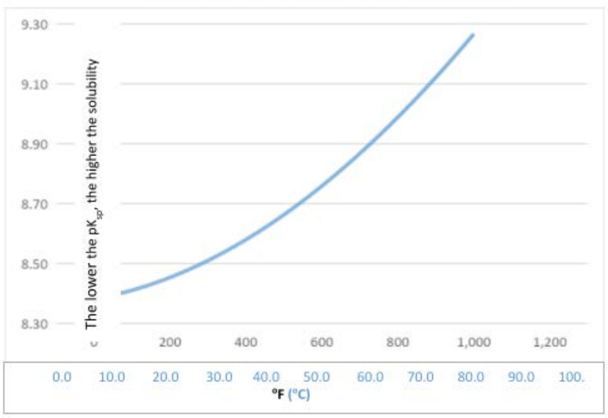
$$\{Ca\}\{CO_3\} = K_{sp} \text{ at equilibrium} \quad (10)$$

If a water is left unperturbed for an infinite period of time, it will dissolve, or precipitate, calcite until the condition of equation 10 is satisfied. All useful indices for prediction calcium carbonate scale have been derived from equation 4, or a variation. A Saturation Ratio shows where a water is with respect to equilibrium.

$$\text{Saturation Ratio} = \frac{\{Ca\}\{CO_3\}}{K_{sp\ Calcite}} \quad (11)$$

It can be shown that the Langelier Saturation Index is the log10 of Saturation Ratio, using simple activity corrections, analytical values for calcium and alkalinity, and simple Debye-Hueckel activity corrections.

Figure 9 Calcite pK_{sp} versus Temperature



Data plotted in Figure 10 is calculated from Equation 11 and standard values of the Ksp at infinite dilution.

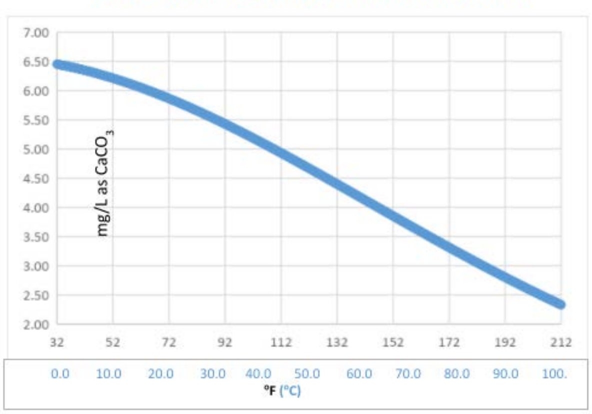
$$\{Ca\}\{CO_3\} = K_{sp}' \quad (12)$$

$$\text{Assume } \{Ca\} = \{CO_3\} \text{ at equilibrium.} \quad (13)$$

$$CaCO_3 = \text{sqrt}(K_{sp}) \quad (14)$$

The molal values are converted to mg/L as CaCO3 for the graph. Note that the solubility decreases with temperature, when the variation of Ksp with temperature is the only variable included in the calculations. More sophisticated models also incorporate the impact of parameters outline in Table 1.

Figure 10 Calcite Solubility versus Temperature



PRACTICAL IMPACT OF PH PHENOMENA ON CHEMISTRY EVALUATION, TREATMENT AND PH CONTROL

PH Prediction in Cooling Water

A common question encountered from those beginning to model water chemistry is "Why is the pH of the recirculating water at one cycle not the same as the makeup water pH?" Two makeup waters anecdotes can be used to provide the explanation: cold lime softened Mississippi River Water, and a deep well water with a high partial pressure of CO2.

Cold lime softened Mississippi river water is CO2 deficient with respect to equilibrium with the atmosphere, and may have a pH well above 9. As it recirculates, the water re-carbonates by adsorbing CO2. And the pH drops at least one unit. So in this case it would not be unusual to have a makeup water pH of 9.8 and a recirculating water pH of 8.6 at one cycle.

Deep well water presents the opposite case form the lime softened water example. It has a high partial pressure of CO2 at the well head, and may have a pH in the low sixes (e.g. 6.0 – 6.6). As it recirculates, CO2 flashes to the atmosphere and the pH of the water at one cycle would be expected to rise to the mid 7's (e.g. 7.2 – 7.6).

In both cases, for the cold lime softened makeup and the deep well water makeup, alkalinity would be conserved as the CO2 moves towards equilibrium with the atmosphere.

PH Prediction in Oil Field Applications

Both temperature and pressure play critical roles in profiling pH in a production well from bottom hole conditions to the well head. Temperature from bottom hole to the well head can vary by hundreds of degrees resulting in a substantial increase from bottom hole pH to the well head. In most cases pH sensitive scales are saturated (or under saturated) at bottom hole conditions.

The pCO2 effect must also be considered. The high partial pressure of CO2 at bottom hole conditions further decreases the bottom hole pH by increasing dissolved CO2 and forcing carbonic acid equilibrium towards dissolved CO2 and HCO3.

The combination of temperature decrease, and pCO2 decrease as a brine transits form bottom hole to the wellhead can result in a dramatic increase in pH from bottom hole to the well head, increasing the saturation ratio of pH sensitive mineral scales. A further increase in pH is encountered as the CO2 flashes to atmospheric pressure after the separator.

A thorough evaluation of pH in a production well involves "accounting" for CO2 and H2S partitioning between the oil, gas, and water phases. Bottom hole pressures can be well above the bubble point further complicating the modelling.

PH Control in Reverse Osmosis versus An Open Recirculating Cooling System

Acid requirement for pH reduction can be drastically different for the same water chemistry in a closed versus open system. A closed system does not exchange CO2 or other gasses such a H2S with the atmosphere, while an open system has free exchange of these gasses with the atmosphere. A reverse osmosis system is typically a closed system, while an open recirculating cooling system is, by definition, an open system with respect to CO2 exchange with the atmosphere.

In the case of a closed system, acid addition shifts carbonate to bicarbonate, and bicarbonate to carbonic acid and CO2. CO2 builds up in the gas phase in the system as a result.

$$pH = pKa + \log 10 \frac{\{CO_3 - Acid\}}{\{HCO_3 + Acid\}} \qquad (15)$$

PH change is governed by the change in ratio between carbonate and bicarbonate. Total molar carbon (Ct) is conserved.

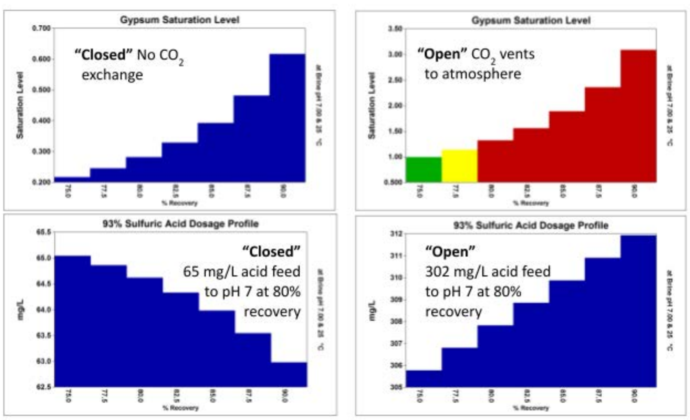
In the case of a cooling tower, acid feed drives

$$CO_3 \rightarrow HCO_3 \rightarrow CO_2 \qquad (16)$$

and the CO2 flashes, reducing Ct.

Figure 11 compares acid requirements for a closed and open system, for the same chemistry, and same target pH. It should be noted that approximately five times more acid is required for the same pH reduction for an open system than for a closed system.10 This emphasizes the need to survey a reverse osmosis system and determine if it is closed or open. The difference is sufficient to create a calcium sulfate scale problem. Modeling software should be capable of treating a system as "closed" or "open" to assure that sulfate scale potential is evaluated accurately.

Figure 11: pH Control in Closed versus Open Systems



SUMMARY

A thorough evaluation of scale potential in water treatment should include the impact of temperature on pH as well as solubility product for pH sensitive scales such as calcite. Scale formation is a reaction. An evaluation of the impact of temperature on all reactant parameters should be performed. Old rules of thumb may not adequately describe the impact of temperature on scale potential. The methods and chemistry outlined in this paper should be applied to all pH sensitive scales in an evaluation, including calcium phosphates and where applicable, iron carbonates, barium carbonates plus any other mineral scales deemed relevant.

The correction of pH for temperature and solution effects is not new technology, but it has become overlooked technology that could allow increased cycles and improved water reuse when applied to scale potential and control evaluations.

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REVIEW OF NEW 2019 CTI ATC 105 ACCEPTANCE TEST CODE FOR COOLING TOWERS

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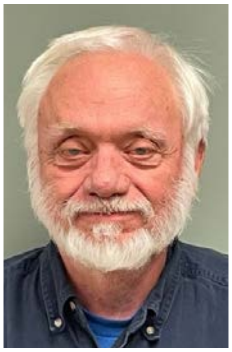
CLEANAIR ENGINEERING



Introduction

Typically, the primary goal of a cooling tower thermal performance test is to determine the cooling capacity of a cooling tower when operated at its design conditions of water flow, range, fan motor power (mechanical draft), dry bulb temperature (natural draft), and barometric pressure.

For a mechanical draft tower, cooling capability is defined as the ratio of circulating water flow rate (corrected to design fan motor power consumption) to the predicted water flow rate as determined by the cooling tower manufacturer's performance curves. Because the manufacturer's performance curves are equivalent representations of the tower performance at various operating and environmental conditions, the predicted waterflow rate is the flow rate of a cooling tower with 100% capability. Thus, the ratio of predicted water flow rate to the adjusted circulating waterflow rate is a constant which means tower capability is a constant despite testing at off design conditions. Said another way, the cooling tower test translates the performance of the tower at test conditions to an equivalent performance at design conditions.

COMMERCIAL CONSIDERATIONS

Timing of the Acceptance Test

The 2019 version of CTI ATC-105 requires that a contractual acceptance test be performed within 12 months of construction and that cooling towers with film type fill be operated for a minimum 1000 hours (about 6 weeks) with a heat load unless otherwise specified in the contract. The requirement for operation of the cooling tower under heat load requirement is specified because film fill performance will increase slightly as the tower ages and releasing agents in the surface of the fill are removed which changes the "wettability" of the fill and improves fill performance. The ATC-105 test code also requires that the acceptance test be performed at a wet bulb temperature within 15ºF of the design value. If the cooling tower design wet bulb is based on a 1 or 2 percent summer wet bulb temperature, code compliant wet bulb temperatures for most regions can be expected between late spring and early fall.
Taken together, these requirements place significant constraints on the window during which a code level acceptance test can be performed. The acceptable test window could collapse entirely if a tower is built several months before heat load is available. One way of avoiding this difficulty would be to include a contractual provision to extend the acceptance testing window to 18 months following tower construction. Alternately contractual provisions could tie the timing of the acceptance test to the operation of cooling tower rather than the completion of construction.

Test Tolerance

As defined by CTI ATC-105, a test tolerance is permitted deficiency in tower performance specified in the contract between the tower purchaser and the tower buyer. As long as the tower meets or exceeds the performance guarantee corrected for tolerance, the performance guarantee is deemed to have been filled. For instance, if there was a 3.2 percent tolerance specified in the contract, a cooling tower with a test capability of 97 percent would be contractually acceptable. The test tolerance should be specified in the tower purchase contract even if the value of the tolerance is zero. The test tolerance should not be confused with test uncertainty which is an estimation of the potential error in the test result (capability) due to errors in the test measurements.

Performance Curves

The performance curves provided by the manufacturer are integral in the evaluation of cooling tower performance. These curves are used to translate the measured performance during the test to the expected performance at design conditions. Therefore, the accuracy of the test result is dependent on the accuracy of the performance curves. The CTI ATC-105 test code recommends that performance curves be evaluated by the purchaser before the contract is signed. The authors recommend that the performance curves be required as part of bid submittal package and the review of the curves be part of the bid evaluation process. This will enable curves presented by different manufacturers to be compared for consistency. Session 4 of the 2018 CTI Education Seminar addresses the evaluation of cooling tower performance curves and is available from cti.org as a free download.

CONDUCT OF THE TEST

Preparation for the Test

The CTI ATC-105 test code requires that the cooling tower be prepared for testing in accordance with CTI PGT-156 Preparation for a Thermal Performance, Plume Abatement, or Drift Test. This document, available from CTI as a free download, specifies the preparations necessary for the performance of a thermal performance test. The CTI ATC-105 code requires that a contractual acceptance test be performed by a CTI-licensed test agent in the presence of the owner and manufacturer, if they desire to be present. For an acceptance test, these representatives shall be given adequate (undefined) notice prior to the test. The manufacturer shall be given permission and adequate (again undefined) notice to inspect and prepare the cooling tower for testing. This preparation would include balancing the water flow and insuring that the fan motor power is within code requirements. In the opinion of the authors, two to three weeks (more is better) should be given in order to fulfill the requirement for adequate notice.

Allowable Deviations from Design Conditions

The maximum deviation of test parameters from design conditions are summarized in Table 1.

Table 1 Allowable Deviation from Design Conditions

Parameter	Maximum Deviation from Design Conditions
Water flow rate	±10 percent of design flow
Fan motor power[1]	±15 percent of design motor power
Range	±20 of design range
Heat load	±20 of design heat duty
Wet bulb temperature	±8.5°C (15°F) from the design wet bulb temperature
Dry bulb temperature[2]	±14°C (25°F) from the design dry bulb temperature
Barometric pressure	±3.5 kPa (1 inHg)
Wind speed	4.5 m/s (10 mph)

[1] corrected to design air density
[2] applicable only to natural draft and wet/dry cooling towers

The 2019 version of the ATC-105 test code increases allowable deviation for fan motor power to 15 percent compared to 10 percent in the 2000 version. It should be noted that a deviation of 15 percent in fan power corresponds to a 5 percent variation in air flow rate.

Based on historical data from the CTI Annual Reports, in more than 30 percent of the new tower tests, the fan motor power was outside the test code limit. While the increase in the allowable deviation should reduce the percentage of towers failing to meet this requirement, the fan power for many acceptance tests is more than 15 percent below the design value. The new tower purchase contract should also specify which party is responsible for pitching fans to a value which will produce a fan motor power within the code limits.

Stability Requirements

The CTI ATC-105 test code also places restrictions on the variation of test parameters within a test period. The test parameter variation limits specified by the CTI ATC-105 test code are summarized in Table 2.

Table 2 Maximum Variation in Test Parameters

Parameter	Limit of Variation
Water flow rate (deviation)	±2 percent
Cooling Range (deviation)	±5 percent
Cooling Range (rate-of-change)	±5 percent
Wet bulb temperature (rate-of-change)	±1°C (2°F)
Wet bulb temperature (deviation)	±1.5°C (3°F)
Dry bulb temperature (rate-of-change)[1]	±3°C (5°F)
Dry bulb temperature (deviation)[1]	±4.5°C (7.5°F)

[1] applicable only to wet/dry or natural draft cooling towers

Deviation limits specify the permissible difference between individual readings and the average value of all readings for a specific parameter. Rate-of-change limits specify the permissible difference between the end points of a linear least-squares regression line fit of a time plot of a test parameter.

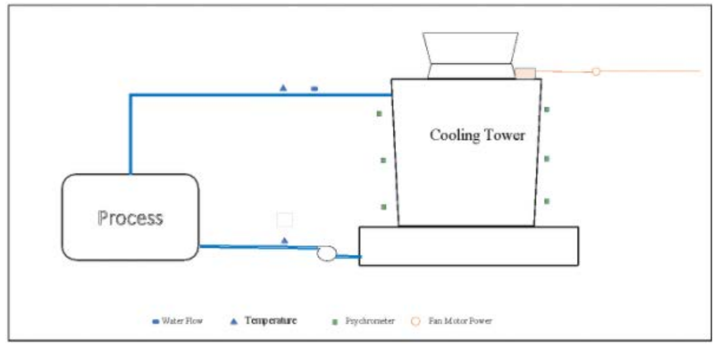
The 2019 version of CTI ATC-105 code clarifies the permissible cooling range deviation. In the 2000 version it was unclear whether the cooling range deviation was calculated from maximum-to-minimum or variation from parameter average. The new code version also adds a permissible rate-of-change for cooling range.

For most cooling towers, the water flow rate is measured with a pitot tube. For pitot tube flow measurements, the differential pressure between the total and static ports is measured by traversing the pipe at 10 points (20 points per diameter for large pipes) across two perpendicular diameters of each pipe carrying hot water to the tower. Each flow measurement takes from 1 to 4 hours depending on pipe size and access. For most multi-cell towers, it is necessary to traverse multiple risers to determine the water flow rate. Typically, water flow delivered to counterflow towers is measured in each hot water riser. For these measurements, monitoring the stability of water flow with the pitot tube is impractical and alternative measurements such as pump discharge pressure or condenser differential pressure must be used.

Test Instrumentation

The placement of the test instruments for a cooling tower thermal performance test is illustrated in Figure 1.

Figure 1 Primary Test Measurements



Inlet wet bulb temperature (and dry bulb temperature, if required) are measured with calibrated temperature sensors in mechanically aspirated psychrometers placed within 1.5m (5ft) from the air inlets. The required characteristics of the psychrometers are newly defined in Appendix O of the new test code. The number and placement of the psychrometers is specified in Appendix G, which has been extensively edited for the 2019 version of the test code.

Cold water temperature is typically measured downstream of the pumps. At this location, the water is well mixed so a representative temperature can be obtained by a single measurement in a flowing or thermal well at the outlet of each pump. A small correction, detailed in Appendix I of CTI ATC-105, is used to correct the measured temperature for the throttling and heat added by the pump. An array of submersible temperature sensors may be placed in the cooling tower outfall or flume to obtain a representative cold water temperature when 1) the pumps are remote from the cooling tower, 2) multiple towers share a common pump system, or 3) the primary heat source is between the tower and the pumps. When makeup water or auxiliary flow streams enter the circulating water system or cold water basin upstream of the cold water measurement, the measured cold water temperature must be corrected for the influences of these streams. Since the measured cold water temperature is generally insensitive to cooling tower makeup, makeup flow and makeup temperature measurements are frequently made with plant instruments. The magnitude of the possible error in cold water temperature due to measurements of pump pressure, makeup temperature, and makeup flow is detailed in Appendix U-1 of the revised test code.

Since the cooling tower is typically far removed from the heat generation process, measurement of the hot water temperature at a single location near the tower is usually sufficient. In some cases, the hot water temperature may not be well mixed at the tower when the cooling tower serves multiple processes with separate hot water return pipes. When the hot water streams at the tower are not well mixed, flow-weighted temperature measurements of pump pressure, makeup temperature, and makeup flow is detailed in Appendix U-1 of the revised test code.

Since the cooling tower is typically far removed from the heat generation process, measurement of the hot water temperature at a single location near the tower is usually sufficient. In some cases, the hot water temperature may not be well mixed at the tower when the cooling tower serves multiple processes with separate hot water return pipes. When the hot water streams at the tower are not well mixed, flow-weighted temperature measurements of each stream are used to determine the average hot water temperature.

Water flow rate may be measured at either the inlet or outlet of the cooling tower. By far the most common method of water flow measurement utilizes a calibrated pitot tube at the tower inlet. Measurement with a pitot tube requires two pitot taps installed 90° apart in a straight run of pipe. Guidelines for the installation of pitot taps are found in CTI PTG-156. Since 2018, CTI-licensed test agents have been required to use pitot tubes incorporating a new elliptical design. This tube design is much less sensitive to positive bias caused by disturbed flow at the measurement location compared to the Simplex design which was previously used. Other methods for the measurement of water flow, detailed in CTI STD-146 Water Flow Measurement (currently under revision) are acceptable if properly installed and suitably calibrated.

Fan motor power consumption is generally measured in the motor control center for each fan motor with a calibrated hand-held meter. Since this measurement requires that MCC be opened under power, safety procedures require that these measurements be done by qualified (plant) personnel wearing flash protective gear. The CTI ATC-105 test specifies that the measured motor power be corrected for the voltage loss between the measurement point and fan motor. Methodology for the line loss correction is found in Appendix N (new in the 2019 test code). Because fan motor power consumption specified by the tower OEM in the development of performance curves may be based on either input or brake horsepower, care must be used to ensure that the test fan motor consumption used in performance calculations is used in the same manner as was used to generate the performance curves.

For the mechanical draft cooling towers, wind speed is to be measured at an elevation ½the difference between the cold water basin curb and the air discharge elevation (e.g. fan stack exit plane) in an unobstructed location at least 30 m (100 ft) from the cooling tower.

Instrument Accuracy

The instrument accuracy and calibration frequency requirements established by CTI ATC-105 Section 3 are presented in Table 3.

Duration of the Test

For mechanical draft towers, a single one-hour test run is required. The normal practice is to record temperature data continuously during the manual measurements of water flow and fan motor power. When multiple hours of meeting code requirements of stability and proximity to design conditions are available, the licensed test agent may select the most stable hour for analysis. One method for selecting the most stable test period is presented in Appendix P (new in the 2019 version of the test code).

Table 3 Instrument Accuracy and Calibration Frequency

Measurement	Minimum Accuracy SI Units	Minimum Accuracy IP Units	Example Instruments	Calibration Frequency
Temperature[1]	0.05°C	0.10°F	100 Ω RTD	3 months
Water flow rate[2]	3%		Pitot tube	3 years[3]
Fan motor power	3%		Power meter	1 year
Barometric pressure	0.34 kPa	0.1 inHg	Barometer	Not specified
Water pressure	1%		Manual gage	Not specified
Differential pressure (pitot)	1%		Manometer	NA
Wind speed	0.5 m/s	1 mph	Anemometer	1 year

[1] lower accuracy devices may be used for measuring makeup and blow down temperature
[2] lower accuracy devices may be used for makeup and blowdown flow
[3] if undamaged

For natural draft cooling towers, six 1-hour periods collected over two days are required.

Natural Draft Cooling Towers

The performance of natural draft cooling towers is influenced by the wind speed at the cooling tower outlet and the temperature gradient of the atmosphere. The CTI ATC-105 test code recommends that values for the wind speed at the elevation of the tower outlet and the atmospheric temperature gradient for the performance test be established by contract. The code sets default values for these parameters if they are not specified in the contract. If no value for wind speed is established by contract, the default limit for windspeed at the elevation of the cooling tower air outlet is 10 mph. If no atmospheric temperature gradient is established by contract, the test code requires the dry bulb temperature gradient to be at least -0.65℃/100m (-3.5℉/1000 ft).

For cooling towers with safe access to the top of the shell, wind speed stations can be placed at the top of the cooling tower. The authors recommend at least two stations to assure that at least one station will be on the upwind side of the tower. When it is not possible to measure the wind speed at the cooling tower outlet elevation, the upper level wind speed must be evaluated based on visual observation of the plume or by correcting the wind speed measured at ground level to the elevation of the top of the cooling towers. Methods to correct wind speed for elevation are included in Appendix L of the new test code.

When practical, the test code requires the atmospheric temperature gradient be measured at 60m (200 ft) intervals up to 1.5 time the height of the cooling tower. This measurement requires a tethered balloon and will rarely be practical. In the absence of directly measured values for temperature gradient, the test code specifies that temperature at the upper level of the air inlet be at least 0.15℃ (0.25℉) lower than the temperature at the lowest level of the air inlet.

In some cases, alternative measurements of upper level wind speed and air temperature gradient are available. For instance, nuclear plants are required to make these measurements on a continuous basis using annually calibrated instruments. The authors strongly recommend that methods used to evaluate upper level wind speed and air temperature gradient be detailed in a site-specific test plan for any natural draft cooling tower acceptance test.

EVALUATION OF RESULTS

Corrections to Cold Water Temperature

When the cold water temperature is measured using a flowing well downstream of the circulating water pump, the measured cold water temperature is corrected for throttling and heat added by the pump by:

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* - Thirty-six (36) month standard warranty applies, refer to standard T&C's.

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$$T_{cw,c} = T_{cw,m} - c_g \frac{P_g}{\eta_{pump}}$$

Where

$T_{cw,c}$ = corrected cold water temperature, °C (°F)
$T_{cw,m}$ = measured cold water temperature, °C (°F)
P_g = gage pressure at pump discharge, kPa (psig)
η_{pump} = fractional pump efficiency, dimensionless
c_g = conversion factor, 0.000239 °C/kPa (0.002966 °F/psi)

The correction for a flowing well at the discharge of a pump with pressure of 35 psig is approximately 0.1°F. If cold water temperature is measured in thermowell, the cold water correction is negligible.

When makeup is added upstream of the measurement of cold water temperature, the cold water temperature is corrected by:

$$T_{cw} = \frac{Q_{wt}T_{cw,c} - Q_{mu}T_{mu}}{Q_{wt} - Q_{mu}}$$

Where

Q_{wt} = circulating water flow rate
Q_{mu} = makeup water flow
T_{mu} = makeup water temperature

Fan Motor Power Corrections

The fan motor power is usually measured at the motor control center (MCC) rather than the motor terminals. In this case, the measured motor power must be corrected for the line loss between the MCC and the motor terminals. New example line loss calculations are provided in Appendix N in the new version of the CTI ATC-105 test code. The design fan motor power provided in the cooling tower specification is normally the brake motor power. If this is the case, the measured motor power is multiplied by the name plate efficiency of the fan motor.

Performance Curve Analysis

The CTI ATC-105 test code provides two different methods of analysis which use the test data and correction curves provided by the manufacturer to determine the performance of the cooling tower at design (contract) conditions of water flow, fan motor power, wet bulb temperature, and heat duty.

By far the most commonly used of these, is the performance curve method. The performance curves provided by the manufacturer consist of prediction of the cold water temperature as a function of wet bulb temperature. The test code specifies that performance curves are to be provided at 80 percent, 100 percent and 120 percent of design range for 90 percent, 100 percent and 110 percent of design water flow. The format of these curves is illustrated in Figures 2, 3, and 4.

Figure 2 Performance Curve at 90% Flow

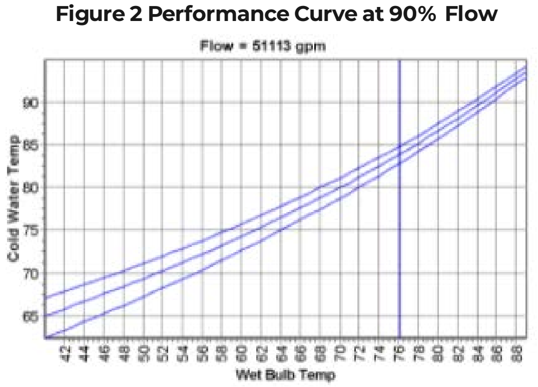


Figure 3 Performance Curve at 100% Flow

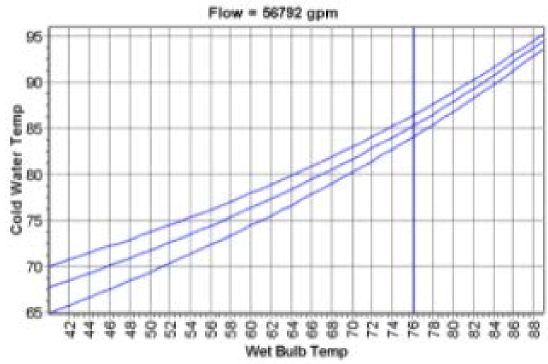
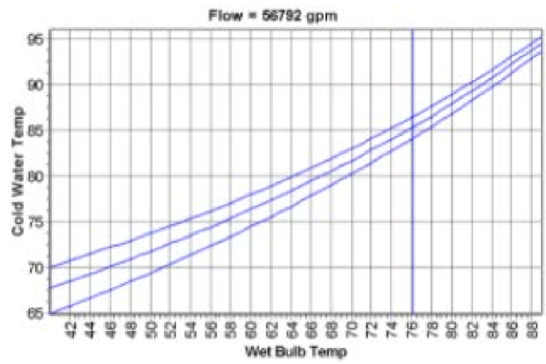
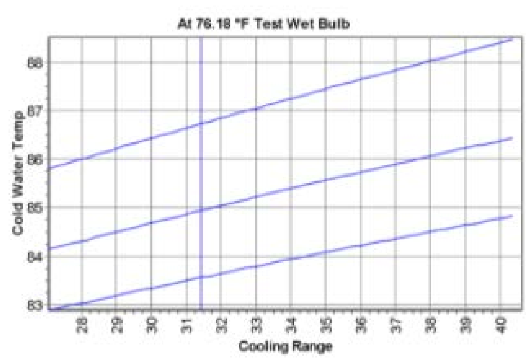


Figure 4 Performance Curve at 110% Flow



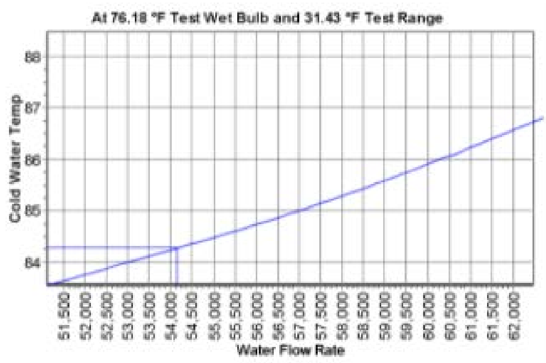
The performance curves are read at the test wet bulb to determine the predicted cold water at each design range and water flow. These values are interpolated to determine the predicted cold water at the test range. This interpolation process is illustrated in Figure 5.

Figure 5 Cold Water Temperature at Test Range



The cold water values are interpolated to determine the predicted water flow at the test cold water temperature. The interpolation process is illustrated in Figure 6.

Figure 6 Predicted Cold Water Temperature



The measured cold water flow is adjusted based on the test fan motor power by:

$$Q_{wt,adj} = Q_{wt}\left(\frac{W_d}{W_{t,c}}\right)^{1/3}\left(\frac{\rho_t}{\rho_d}\right)^{1/3}$$

Where

Q_{wt}	=	measured cold water flow
W_d	=	design fan motor power
$W_{t,c}$	=	measured fan motor power, corrected for line loss if necessary
ρ_d	=	design air density at fan inlet
ρ_t	=	test air density at fan inlet

For induced draft fans, the test air density is calculated by heat balance based on the measured psychrometric conditions, the test water flow, and the design L/G ratio. The capability of the cooling tower is calculated by:

$$C = \frac{Q_{wt,adj}}{Q_{wt,pred}} \times 100$$

CTI provides a program, CTI Toolkit®, for the analysis of mechanical draft cooling tower performance. The output of this program is illustrated in Figure 7. The Toolkit program is used by most CTI-licensed test agents for the analysis of mechanical draft cooling tower test data.

Figure 7 Toolkit® Output

Tower Performance Report

Big Megawatt Station 09/12/19

Owner: New Era Power Company
Project: Big Megawatt Station
Location: Off the Highway
Manufacturer: Thuridon Cooling Towers
Tower Type: Induced Draft

Cooling Tower Design and Test Data

Parameters	Design	Test
Water Flow Rate	56792.0 gpm	57426.0 gpm
Hot Water Temp.	120.92 °F	115.70 °F
Cold Water Temp.	87.08 °F	84.27 °F
Wet Bulb Temp.	78.80 °F	76.18 °F
Dry Bulb Temp.	86.36 °F	77.94 °F
Fan Driver Power	143.40 bhp	151.50 bhp
Barometric Pressure	29.921 in. Hg.	29.180 in. Hg.
Liquid to Gas Ratio	1.300	1.301

Cold Water Temperatures vs. Range

At 76.18 °F Test Wet Bulb

Range	51112.8 gpm	56792.0 gpm	62471.2 gpm
27.07 °F	82.88 °F	84.14 °F	85.81 °F
33.84 °F	83.91 °F	85.37 °F	87.23 °F
40.61 °F	84.87 °F	86.49 °F	88.53 °F

Cold Water Temperature vs. Water Flow

At 76.18 °F Test Wet Bulb and 31.43 °F Test Range

51112.8 gpm	56792.0 gpm	62471.2 gpm
83.55 °F	84.94 °F	86.73 °F

Exit Air Properties

	Wet Bulb Temp	Density	Sp. Vol.	Enthalpy
Design	107.32	0.06782	15.5500	86.3249
Test	104.16	0.06665	15.7648	81.1835

Test Results

Adjusted Flow	Predicted Flow	CWT Deviation	Tower Capability
56057.4 gpm	54152.3 gpm	-0.50 °F	103.5%

This test result is only certified by CTI if the test data was collected by a CTI Licensed Testing Agency. See www.cti.org for an agency list.

Appendix D.bbp\Appendix D Test Data

Produced by CTI Toolkit© 3.0

The 2019 version of the ATC-105 test code provides expanded insight into the analysis of "helper" cooling towers. Helper cooling towers do not operate on a closed cooling water cycle. Helper cooling towers cool the water prior to discharge into a receiving water body. For helper cooling towers, the cooling tower range and heat duty are not solely a function of plant load but are also a function of wet bulb temperature and cooling tower performance. The analysis method for helper cooling towers is identical to that described the preceding paragraphs with the exception that the performance curves are provided as a function of hot water temperature instead of range. The methodology for analysis of helper cooling towers is specified in Section 11 and illustrated in Appendices Q and R of the 2019 test code.

The methods used to determine the performance for natural draft and wet/dry cooling towers are very similar to that described in the preceding paragraphs. At this time, the analysis of natural draft, wet/dry and helper cooling towers is not supported by CTI Toolkit®. Licensed CTI test agents use their own proprietary software for performance analysis of these types of cooling towers.

Uncertainty Analysis

The reported values from any measurement include some error. These errors are limited by using the quantity and quality of instruments specified in Appendix G and Section 3 of CTI ATC-105. The best use of the uncertainty analysis is as an estimate of the accuracy of the test. The uncertainty of a test conducted with code level instrumentation will vary depending on the design of the cooling tower, the atmospheric conditions at the time of the test, and the configuration of piping at the flow measurement location.

Some contractual requirements specify that an acceptance test is to be performed under the guidelines of the ASME PTC-23 test code which is a seldom-used alternative to the ATC-105 test code. The CTI ATC-105 test code differs from ASME PTC 23 code in that ATC-105 does not require an uncertainty analysis. However, Appendix U of ATC-105 does provide a detailed method for performing a cooling tower uncertainty analysis. The methodology used is consistent with ASME PTC 19.5 which determines a two-tailed 95% confidence interval.

To illustrate, consider a hypothetical cooling tower testing at a capability of 96% with a test uncertainty of 4%. For this tower, the probability that the actual performance of the cooling tower would meet or exceed its guarantee would be 2.5 percent (i.e. there is a 97.5% chance that the tower did not meet the contractual specification). The statistical implications of the uncertainty interval should be carefully considered before adopting the test uncertainty as a tolerance. An example of a summary of a cooling tower uncertainty analysis is provided in Table 4. In this example, the major contributors to the overall uncertainty are the systematic uncertainties for the water flow and wet bulb temperature which are approximately 3 percent each.

Table 4 Example Uncertainty Analysis

				Systematic Uncertainty				Random Uncertainty	
Parameter	Units	Sensitivity	Units	Instrumental	Spatial	Total	Capability	Total	Capability
Water Flow	gpm	7.15E-04	%/gpm	3346	2841	4389	3.14	NA	NA
Hot Water Temperature	°F	2.240	%/°F	0.17	NA	0.17	0.38	0.050	0.11
Cold Water Temperature	°F	-7.105	%/°F	0.17	0.1	0.20	1.40	0.026	0.19
Wet Bulb Temperature	°F	3.435	%/°F	0.34	0.74	0.82	2.81	0.022	0.08
Fan Motor Power	bhp	-0.172	%/hp	3.8	NA	3.78	0.65	NA	NA
Barometric Pressure	inHg	1.320	%/inHg	0.05	NA	0.05	0.07	NA	NA
Total Systematic Uncertainty		**4.50**	**%**						
Total Random Uncertainty		**0.23**	**%**						
Total Uncertainty		**4.51**	**%**						

Reporting

Scope

The CTI ATC-105 test code requires that test report must include:

- A summary including results and the design test values of test parameters
- Identification of any parameters that were out of code
- Capability analysis documentation
- The manufacturer's performance curves
- A sketch of the instrument layout
- Notation of building or heat sources in the vicinity of the cooling tower
- Original log sheets of test data

Distribution

For contractual acceptance tests, a single page preliminary report including all important data and the test result must be issued within 10 days of the test to parties to the test. The parties to an acceptance test include, at minimum, the cooling tower owner, tower rebuilder or manufacturer and the test agency. It is normal practice for CleanAir to issue this preliminary report before leaving the test site. The final test report is also issued to all test parties.

Conclusions

The 2019 version of the CTI ATC-105 represents an incremental change from the 2000 version. The changes do not significantly alter the conduct of the test, but constraints are placed on the test timing. The new test code makes small changes to the envelope of acceptable test conditions and codifies standard industry practice with respect to the measurement of wet bulb temperature.

AIR FLOW MODIFICATIONS FOR OPTIMIZATION OF NATURAL DRAFT COOLING TOWERS

CHRISTIAN WAWZESZYK
FRAMATOME GMBH

INTRODUCTION

During the early 2000s, the two Swiss nuclear power plants, NPP Leibstadt and NPP Goesgen, investigated potential improvements in their cooling tower performance. R&D programs were carried out in cooperation with other plants and external engineering consultants [2]. Several test facilities were set-up around or as part of the circulating water systems to perform simulations. At the Goesgen plant, for example, a dedicated test field was set-up inside the tower, which allowed measurement of the tower's performance as well as the performance of the individual tower internals (cooling fills, spray nozzles etc.).

While monitoring the overall pressure and temperature profiles of the tower the R&D team realized that in addition to the correct choice of tower internals, the aerodynamic layout of the air inlet had a significant impact on tower operation. Both plants operated cooling towers with a sharp-edged cooling tower shell. At NPP Gösgen the tower columns also had a rectangular shape and at NPP Leibstadt the tower basin was elevated to approximately 1.2 m (4 ft) above the ground level.

Each of these three factors (sharp-edged inlet, rectangular tower columns, and elevated tower basin) negatively influenced the air flow entering the tower. Further investigations dedicated to the air inlet aerodynamics were carried out to determine the overall impact on tower operation and to develop potential counter-measures.

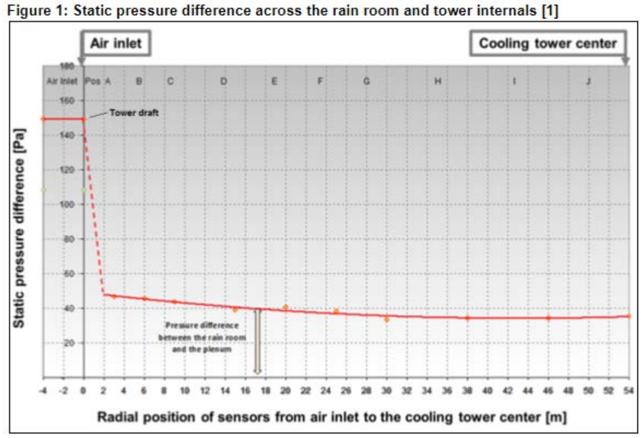
PRESSURE LOSS OF THE AIR INLET

Part of the test field in the Gösgen cooling tower included small protected pipes which stretched from the tower plenum into the rain room. Using these pipes, real-life operating profiles of the pressure and temperature field could be gathered to analyze mass and heat transfer inside the tower.

By analyzing recorded data of the tower draft and the pressure field from outside to inside of the tower, it became obvious from the available tower draft that a large portion was lost around the air inlet and this decreased overall tower performance..

Figure 1 illustrates some of the recorded data. The red trend line highlights the profile of the static pressure difference between rain room and the plenum of the cooling tower. On the left, it can be seen that the available pressure difference, or tower draft, from the ambient to the tower plenum is approximately 150 Pa. Approximately two thirds, or 100 Pa, was lost within the first 3 m (10 ft) after the air inlet [1]. Afterwards, the profile of pressure difference from the area close to the tower shell (left side of the graph) to the tower center (right side of the graph) is relatively constant.

Figure 1: Static pressure difference across the rain room and tower internals [1]



This result was surprising considering the overall dimensions of the tower and the air flow conditions inside the rain room and the tower installations. In contrast to earlier assumptions, it became obvious that the flow conditions at the entrance to the tower were the main detractor of tower efficiency rather than flow resistance in the rain room and tower internals.

The recorded data provided insight into the overall impact on tower performance of the pressure losses around the air inlet. To analyze these results further, tests were performed to determine the air flow conditions at the cooling tower inlet.

AERODYNAMIC CONDITIONS OF THE AIR INLET

A simplified representation of the air flow conditions around the cooling tower air inlet can be seen by observing the rainfall, visible from the outside of the cooling tower. Generally, within the first 1-2 m (3-6 ft) below the cooling fills, the rain water falls straight downwards. Afterwards, it becomes diverted from the airflow toward the tower center. To highlight the corresponding air flow conditions more clearly smoke tests were performed on the cooling tower at Leibstadt. Figure 2 and Figure 3 depict these smoke tests.

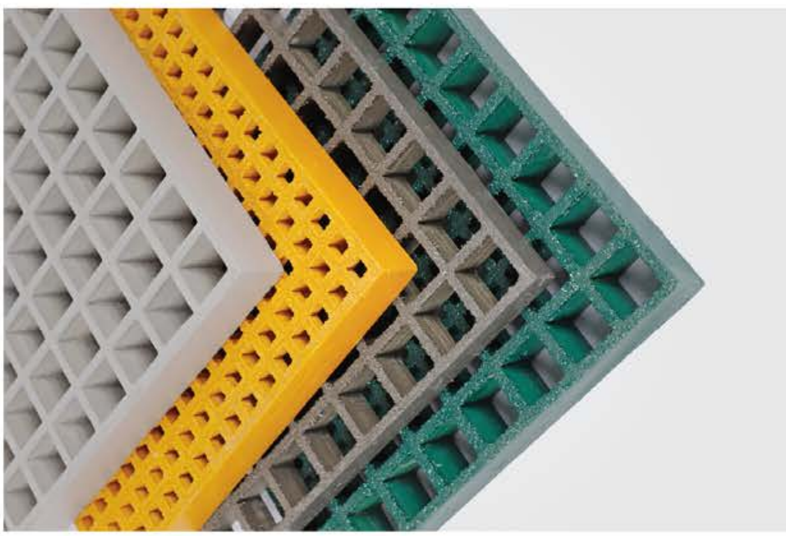


Figure 2: Smoke test of the air inflow conditions at the cooling tower basin of the Leibstadt (upper photos show normal air inflow – lower photos demonstrate improved air inflow using a simple wooden plank)

It can be seen in Figure 2, that an air vortex was present with the existing layout of the basin. The highest elevation is about 1.2 m (4 ft) above the ground level, representing a strong resistance for the entering air flow. Looking at the right picture of the upper row the red scale is more or less fully covered by the smoke used for the test. The smoke here reveals the air vortex which causes a reduction in the overall air flow entering the tower.

Using a simple wooden plank as a guide for the air flow up to the top of the tower basin, an immediate improvement of the air flow condition could be observed as indicated by the now fully visible red scale which was previously obstructed by the vortex.

A similar smoke test was also performed for the air inflow conditions around the cooling tower shell. It can be seen in Figure 3 that an air vortex is present, similar to the observation at the tower basin. Rounding the sharp-edge layout of the concrete shell with simplified spoilers also yielded an immediate improvement of the air inflow into the tower. Using such an installation, turbulence was reduced, thereby improving flow into the cooling tower.

The conclusion of both smoke tests is that with the as-found tower layout, vortices are present both at the upper edge of the tower and at the tower basin. Each vortex creates a small backflow area which has the effect of reducing the overall air flow entering the tower. This also serves to explain the large tower draft pressure losses measured within the first 3 m (10 ft) after the air inlet [1] .

The effect of air flow restriction can be described by the academic term "vena contracta", which occurs when an incompressible fluid flows past a sharp-edged flow restriction. However, vena contracta can also be present for compressible gases such as air, if the pressure changes of the air flow are small. Considering the given overall tower draft of approximately 150 Pa and the measured overall pressure loss of approximately 100 Pa between the rain room and tower plenum, appropriate conditions are present for the cooling towers studied.

Figure 3: Smoke test of the air inflow conditions at the cooling tower shell at Leibstadt (left side with normal air inflow – right side with improved air inflow using a simplified spoiler)

The consequence of the vena contracta is a reduction of the free or effective cross-section being available for the fluid flow. In general, restrictions of 60 % to 80 % of the physically available cross-section are possible. The impact of the vena contracta on the overall pressure loss between rain room and tower plenum was estimated to be approximately 30 % of the overall aerodynamic losses of the tower.

After estimating the impact of the vena contracta on the tower performance and the costs of modifications to the air inlets, both NPP Gösgen and NPP Leibstadt decided to modify their inlets, thereby providing the opportunity to measure the actual impact of the vena contracta on the cooling tower performance.

MODIFICATION OF THE AIR INLET

To modify the air inlet around the cooling tower basin, NPP Leibstadt performed some earth works as illustrated in Figure 4. Using gravel and street asphalt, the entire circumference of the tower basin was filled, re-shaped and smoothed to provide optimal inflow conditions for the entering air flow.

Figure 4: Modification of the air inlet around the tower basin of the NPP Leibstadt

Using aerodynamic spoilers constructed from plastic materials (GRP, glass-fiber reinforced plastic), the entire perimeter of the concrete shell was also remodeled, see Figure 5. Before designing and producing a spoiler for the shell, the area around the tower basin was modified which provided the opportunity to independently measure the impacts of each modification on the tower operation.

Figure 5: Modification of the air inlet around the tower shell of NPP Leibstadt

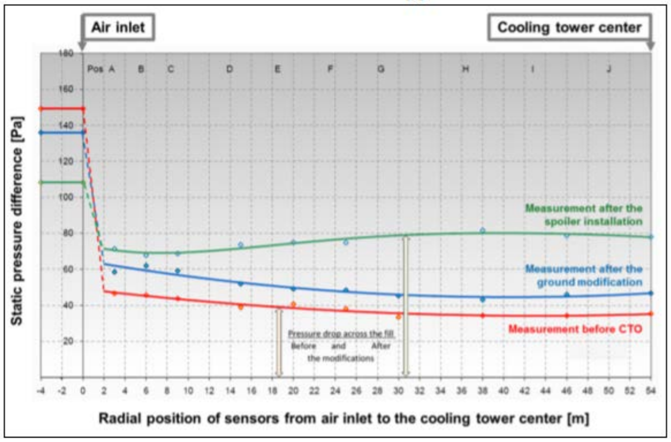
RESULTS OF THE AIR INLET MODIFICATION

Reviewing the changes in tower performance with the measurement set-up installed for the R&D programs, Figure 6 demonstrates the positive effect of each modification of the air inlet on the cooling tower performance. Performing the ground modification of the tower basin initially recovered approximately 15 Pa or 10 % of the original tower draft. The modification of the tower shell with aerodynamic spoilers additionally helped to recover approximately 10 Pa or 6.5 % of the original tower draft.

Hence, the measured available static pressure difference between the tower plenum and the rain room could be increased from approximately 35 to 50 Pa (red graph) to approximately 70 to 80 Pa (green graph) after performing both modifications of the air inlet. Thus, with each modification, a considerable improvement of the tower draft could be achieved.

The effect of vena contracta in the case of NPP Leibstadt, therefore, was a pressure loss of approximately 25 Pa, which represented approximately 25 % of the original loss of pressure difference between the tower plenum and the rain room. Considering the now available 70 to 80 Pa between those points, the reduction of vena contracta could increase the available pressure difference by approximately 30 %.

Figure 6: Static pressure difference across the rain room and tower internals before and after the modifications of the air inlet of NPP Leibstadt [1]



By also considering the reduction of dynamic losses besides the recovery of static pressure difference, the overall aerodynamic losses of the cooling tower could be reduced by approximately 45 %. As a consequence the air flow entering the tower increased, leading to an improved cooling performance.

With the equipment installed inthe test fields, the static pressure difference between tower plenum and rain room could be monitored and information could be recorded with respect to temperature profiles, water distribution, and the general tower behavior throughout warm and cold seasons. The resulting impact of the modifications of the air inlet in terms of tower performance for the NPP Leibstadt can be summarized as follows:

- Ground modification: Mean temperature reduction of re-cooled water of 0.4°C (0.7°F)
- Spoiler installation: Mean temperature reduction of re-cooled water of 0.54°C (1.0°F)
- Total mean temperature reduction of re-cooled water: 1.0°C (1.7°F)
- Resulting average performance increase of the plant: 4.5 MWel

Considering the economic boundary conditions of the Swiss market, the corresponding return on investment period of both improvements were 18 months.

COOLING TOWER OPTIMIZATION FOR OTHER PLANTS

After finalizing the cooling tower modifications, NPP Gösgen and NPP Leibstadt applied to patent the aerodynamic spoilers which can be attached to the edge of the concrete shell:

- USA: US 2013/0228941 A1 (patent pending)
- Rest of the world: PCT/EP2011/069205 (patent pending)

FRAMATOME acts as licensee, promoting and implementing Cooling Tower Optimization (CTO) by means of cooling tower inlet modifications for clients worldwide. Implementation is realized without a test field similar to the ones of NPP Gösgen and NPP Leibstadt, but using a 5-step approach:

First, measurements are performed on-site and inside of the cooling tower. The measurements are made manually, recording a data set of the current operating condition of the tower. The data collected includes among others the continuous tower draft, an air velocity profile in the tower plenum, and an air temperature profile in the tower plenum.

Second, with the data gathered inside the tower together with some operating data from the circulating water system (i.e. circulating water mass flow, tower inlet and outlet temperature) an aerodynamic analysis of the current cooling tower condition is conducted. This analysis includes a CFD simulation of the tower to check and determine the detachment of the inflowing air, which in turn represents the determination of the given vena contracta. Afterwards, the CFD allows the computational improvement of the air flow with aerodynamic spoilers on the tower shell and ground modifications around the basin (if necessary) to determine the potential increase of the air flow entering the tower.

Third, the CFD results and the data gathered at the site are used to perform a thermodynamic analysis of the tower. Here the current tower performance is analyzed (i.e. relative to its original design point) and the potential temperature decrease of the re-cooled water is estimated. Furthermore any other potential irregularities detected during the measurements (e.g. inhomogeneous air velocity profile in the tower) are analyzed.

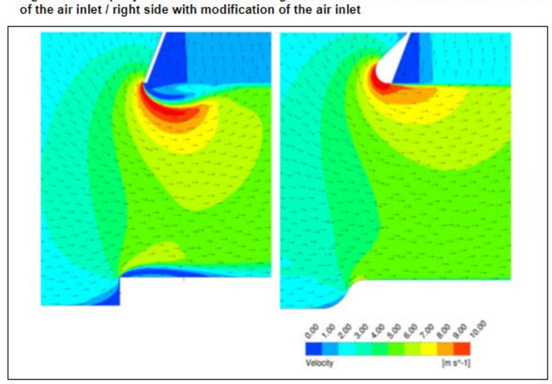
All three steps above are analyzed to decide if a further CTO implementation is reasonable. Furthermore, potential irregularities detected by the measurements can be analyzed, which hamper the current tower operation and a possible CTO implementation (e.g. inhomogeneous air velocity profile in the tower). Using this information, the individual return-on-invest of the tower can be determined, considering its respective economic boundary conditions.

The fourth step is to install the aerodynamic spoilers on the tower shell and to re-model the ground area around the tower basin (if necessary). Depending on the operator preferences, these works could be completed during a plant outage. However, an installation with the cooling tower in operation is also possible.

After installing the aerodynamic spoilers and re-modelling the ground area, the fifth step is to repeat the measurements of the cooling tower condition to validate the effectiveness of the CTO implementation.

Performing a CFD analysis helps to illustrate the effect of vena contracta. Looking at Figure 7 it can be seen in the left picture how the sharp-edged concrete shell and the sharp-edged tower basin restrict the air flow by creating a notable air vortex in their downstream areas. Areas with flow detachment occur with relatively low flow velocities, which reduce the remaining free area of the air inlet to draw in ambient air.

Figure 7: Exemplary CFD results of a cooling tower air inlet – left side without modification of the air inlet / right side with modification of the air inlet



Modelling an aerodynamic spoiler to the given tower geometry and re-modelling the area around the tower basin as in the right picture, illustrates the potential improvement for the air flow profile at the air inlet. The restriction of the air flow is significantly less, providing more free area for the air to enter the tower.

Derived from these results, an estimate of the air flow increase can be provided to the operator. Generally an increase of approximately 10 % is possible by modifying the tower air inlet. The consequential decrease of the cooling water temperature depends upon the operating conditions of the tower at the given site and is part of the CTO analysis.

On the American market an air flow optimization is currently under way with a major US nuclear utility. Preliminary investigations estimate a potential temperature reduction of approx. 0.7°C (1.4°F) of the re-cooled circulating water.

CONCLUSION

The measurements and investigations at the two nuclear power stations, NPP Gösgen and NPP Leibstadt demonstrated that the aerodynamics of the air inlet have a significant impact on the operation of a cooling tower. The natural draft cooling towers of both plants operated with a sharp-edged cooling tower shell at the air inlet. At the NPP Gösgen the tower columns also had a rectangular shape, which was not the case for the NPP Leibstadt. At NPP Leibstadt, however, the tower basin was elevated to approximately 1.2 m (4 ft) above the ground level which restricted the air flow into the tower.

Each of these three factors negatively influenced the air flow entering the tower. Further investigations dedicated to the air inlet aerodynamics proved the presence of a significant vena contracta at both plants, leading to a notable restriction of the entering air flow. In contrast to assumption that the rain room and following tower internals were the main obstruction for the air flow, the results demonstrated the dominant contribution of the tower air inlet geometry.

The positive effect of this finding is that with appropriate measurements and analysis, the air inlet geometry can be adjusted, allowing optimization of the overall cooling tower performance. For example, an increase of the static pressure difference between rain room and tower plenum by 30 % was achieved for NPP Leibstadt. With recovery of the static pressure difference and also the reduction of dynamic losses, the overall aerodynamic losses of the cooling tower were reduced by approximately 45 %.

This performance enhancement of the tower leads to a corresponding improvement in the efficiency of the plant, resulting in a higher electrical output to the electrical grid.

The method described for Cooling Tower Optimization (CTO) with the addition of aerodynamic spoilers to the tower shell and a re-modelling of the ground around the tower basin is a relatively simple and cost effective improvement, which leads to a sustainable performance increase of the plant. In the European market, the ability to generate additional plant output, while consuming the same amount of fuel is often referred to as an achievement of “green Megawatts”. Speaking from marketing point of view, this is an ecological argument for an economic reason to increase the plant efficiency.

The simplicity and durability of CTO implementation, requiring no further effort in terms of operational resources or maintenance, should be applied to all cooling towers working with the same or similar types of air inlet geometry.

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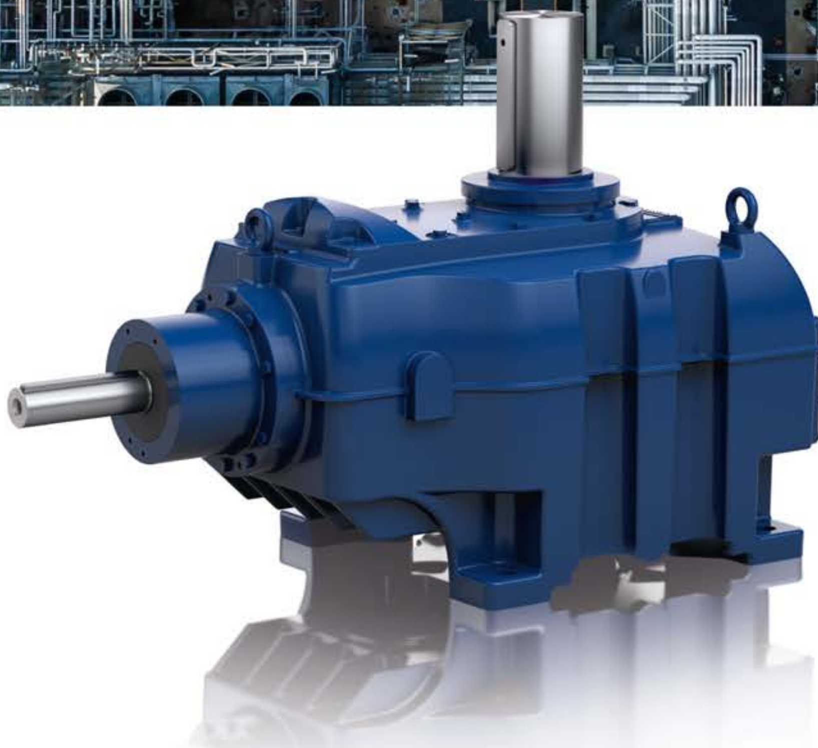

A DETAILED THERMAL ANALYSIS AND OPTIMIZATION OF AN EXISTING FIELD-ERECTED COOLING TOWER

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A field erected cooling tower located in the dense urban area of downtown Chicago was identified by the owner as a proper candidate for an upgrade. The tower was original to the district energy plant that was constructed in 1995 and was integrated with the architectural design of the plant. During the first twenty years of operation, it was discovered that the tower was performing significantly below both the predicted and original commissioning tested thermal performance. Due to the systems demand to increase capacity to accommodate increased market demand, a project was proposed in 2018 to improve and upgrade the tower to bring it up to the original design conditions.

The original tower was built as a three cell induced draft counterflow tower with approximate overall dimensions of 46' x 120'. The tower was designed to cool 36,000 GPM of water from a hot water temperature of 98.6°F down to 85°F at a wet bulb of 78°F. The tower was originally designed with 176.0 design brake horsepower per cell and had a restriction of 70 DbA for the operating noise level. The original tower was built using fiberglass reinforced plastic (FRP) structure, a fill depth of 7' and 28' diameter fan assemblies. The tower was installed with a substantial air inlet visual screen wall and low sound fans to minimize the towers operational characteristics in the downtown environment.

This paper summarizes the process of evaluating the current condition of the existing tower, investigating the areas of the tower that were impeding tower performance and designing an upgrade that overcame the restrictions of the existing tower general arrangement and design restrictions. During the evaluation, potential improvements to the reliability of the existing design were identified along with areas where overall tower performance and efficiency could be improved. An upgrade plan was designed and proposed, with the end user comparing the cost of rebuilding the tower to that of new packaged cooling towers. Due to the estimated costs and project complexity, the decision was made to rebuild the existing cooling tower. The process of rebuilding along with the measured results in efficiency and performance are detailed and included. An image of the subject cooling towers is located in figure one.

Figure 1: Subject cooling towers

The owner's operation team had experience with the existing tower for over twenty years and was very familiar with the deficiencies associated with the original design. The owner had started to evaluate the tower in detail five years prior to the project, and was investigating options to upgrade the tower system. Utilizing the fill manufacturer's characteristic curve, the owner had discovered that the airflow of the tower was substantially lower than the original design. Initial theories were that the fill material had become fouled with scale and sediment over time causing the tower performance to diminish. The owner put together a plan to restore the fill material to original condition and bring the tower performance back to the original design conditions. Following the execution of both cleaning and ultimately replacing the fill material, it was discovered that the tower was still significantly underperforming. Eliminating the fill material as the deficient component, further evaluation discovered that the air moving system (fan, gearbox, driveshaft and motor) were providing far less airflow than needed for the tower to perform at the original design criteria. An image of the original fan assembly is located in figure two.

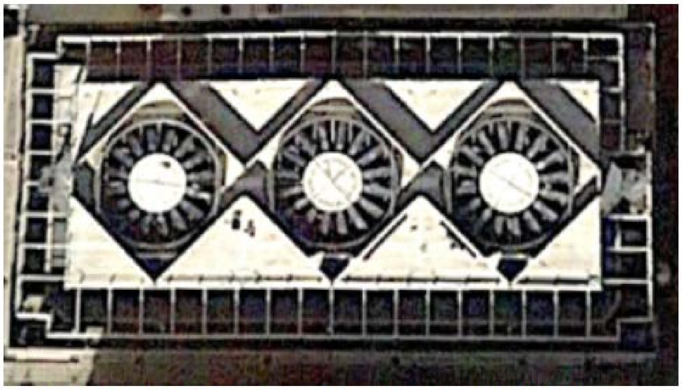


Figure 2: Aerial view of fan assembly installed inside the cooling tower.

The project commenced with an initial inspection of the cooling tower internals to identify areas where potential performance improvement could be realized. Initial inspection concurred with the owner's team concern that the air moving system was deficient with respect to the original design conditions. There were four significant areas that were identified as either opportunities for improvement or limiting factors towards upgrading the tower performance. The factors are listed in table one along with the associated effect of each.

AREA OF CONCERN / LIMITING FACTOR	ASSOCIATED EFFECT ON TOWER THERMAL PERFORMANCE
Air inlet restrictions caused by the presence of the architectural screen wall and a limited air inlet opening.	The architectural screen wall was located very close to the air inlet of the tower and presented a significant obstruction for the incoming air to pass as it entered the cooling tower. A conservative evaluation of the air inlet static pressure restriction was necessary to appropriately calculate potential airflow through the tower
Proximity of distribution nozzles to fill material, the spray pattern of the nozzles, the size and the number of distribution nozzles in the tower.	The distribution was found to be located very close to the top plane of the fill section, this coupled with the projected spray pattern, the small lateral size and quantity of the existing nozzles revealed that the distribution system was not efficiently spreading the recirculating water over the fill section.
The blade pitch of the fan assembly and the diameter of the fan assembly air seal disc with respect to the diameter of the fan assembly.	The blade pitch was found to be extremely aggressive leading to the concern that the fan could be in a "Stall" condition. In addition, the seal disc of the fan assembly was approximately 40% of the fan diameter which is not common on modern fan assemblies.
The depth of the fill material and the relatively large air travel with respect to the fill material manufacturer's recommended operating fill depth	The air travel was found to be 7' at the time of inspection. This is the maximum practical fill height as specified by the fill manufacturer. This large air travel could potentially be contributing more airflow restriction which could be more detrimental than the advantage that the additional surface area provided by the additional fill depth.

Table 1: Areas of performance deficiency identified during the initial tower inspection.

The first area of concern that was identified during inspection as a limiting factor to the performance of the cooling tower was the architectural screen wall that was installed to improve the visual appearance of the tower and also decrease the noise associated with the falling recirculating water. The architectural screen wall was constructed of solid FRP material and was greater in height than the height of the tower air inlet. The proximity of the screen wall to the air inlet was closer than industry norm and in some areas the wall encroached even closer on the air inlet, further increasing the static pressure load on the tower. Images of the tower from the city street level, the architectural screen wall and the proximity to the air inlet are located in figures three, four and five respectively.

Figure 3: Street view of the chiller plant with the subject cooling tower on top.

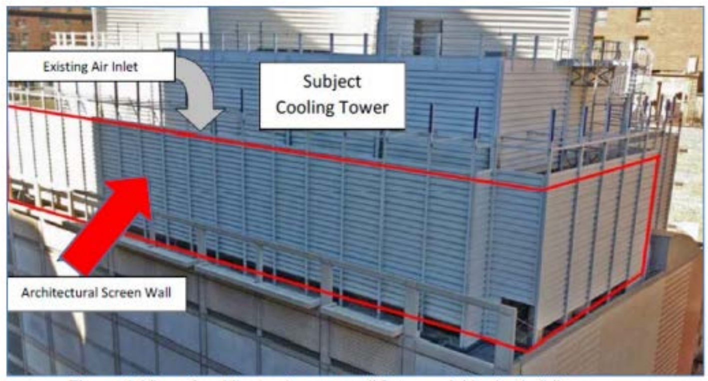


Figure 4: View of architectural screen wall from a neighboring building

Figure 5: Internal view of air inlet and proximity to architectural screen wall.

The second area of concern that was identified during the inspection process was the efficacy of the existing distribution system. The original distribution system utilized a relatively small nozzle which has been surpassed in recent years with larger more efficient nozzles since the tower was originally built. The nozzles were also found to be very close to the fill material and were installed in an irregular pattern with respect to plan. These factors in combination, led to a net resultant distribution system which was not effectively wetting the fill material. An image of the original nozzles and distribution system is located in figure six.

Figure 6: The bottom of the existing nozzles was found to less than 10" from the top of the fill section.

The tower owner had operated the tower for over twenty years and was very confident that the existing fan assemblies had never operated correctly for the required tower design. One significant concern was the size of the fan assemblies' blades with respect to the overall diameter of the fan. Inspection of the tower revealed that the owner's suspicions were true and that the fan blades were installed with extensions used to increase the diameter of the fan. The use of fan blade extensions, required an oversized air seal disc which lead to an undesirable seal disk to fan diameter ratio. This poor ratio required the fan blades to be pitched to the point that the fan was operating in a stall condition. A second concern was the original fan was set to run at a very low speed to meet the local noise restrictions. This low speed was detrimental to the fan efficiency and further exacerbated the poor performance of the fan assembly. Images of the original fan assembly in the tower are located in figure seven and eight.

Figure 7: The existing fan assembly employed blade clamp extensions to increase the diameter of the fan assembly.

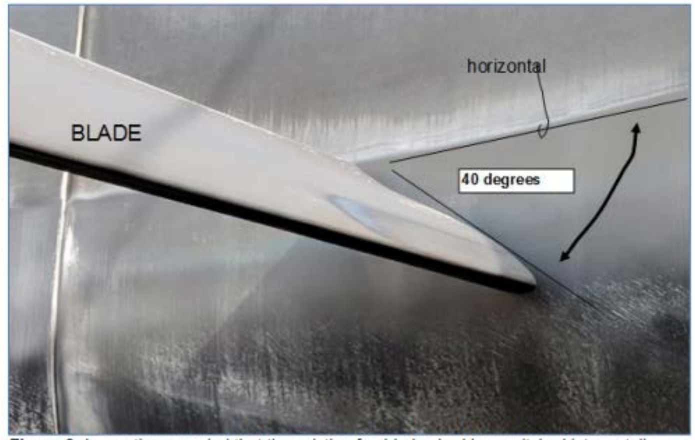


Figure 8: Inspection revealed that the existing fan blades had been pitched into a stall condition.

The last area of the tower that was found to be a concern was the fill section. There was concern that the utilization of the manufacture's recommended maximum fill depth of 7' was contributing to excessive static pressure and the increased static pressure was more than offsetting any performance gains achieved by the additional fill surface area. By removing a foot of fill, the static pressure would be reduced, improving the fan and motor's ability to move air. In addition to reducing the static pressure on the fan, the reduction of the fill depth would allow the distribution to have more distance from the top of the fill section promoting an overlapping spray pattern and improving the distribution of the water over the fill section. An image of the fill section during the initial inspection is located in figure nine.

Figure 9: The existing tower had a film fill depth of seven feet which was found to be detrimental to airflow.

Engineering and Design of Cooling Tower Rebuild

Following the owners review of the inspection and the identified deficiencies, a design team was assembled to engineer the rebuild and performance upgrade process. One strict stipulation from the owner was the tower overall geometry and dimensions had to be maintained including the architectural screen wall. The supply power to the tower could be increased but the noise restriction had to be observed, with the rebuilt tower maintaining the existing sound characteristics.

The first step was to model the towers characteristics utilizing thermal software to reflect the conditions of the existing tower arrangement and geometry. The most critical parameter for modeling the performance conditions of the tower was to estimate the effect of the air inlet restriction caused by the architectural screen wall. Utilizing this model, the tower parameters were then matched with the latest in fan technology to find an effective way to move the needed air through the tower. Modeling revealed that increasing the available cell horsepower from 200 HP to 250 HP was feasible and favorable for tower performance. In order to effectively transmit the drive motor power into airflow, it was imperative that the correct fan assembly was selected.

During the engineering review it was determined that the existing fans were installed with an operating speed much lower than industry norms as compared to similar fans of the same diameter. It is believed that during the original design of the tower, there was an attempt to decrease the speed of the fan to limit the noise effects. The proposed solution to rectify the original deficiencies, was to increase the speed of the fans, limiting the aggressive fan blade pitch and improving the overall fan efficiency. The advances in fan technology allowed for the new fan to effectively move the required air at the stated sound restriction. The selected fan curve and the associated sound calculation are located in figures ten and eleven.

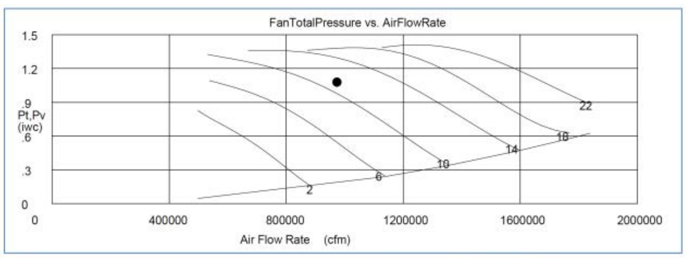


Figure 10: The new fan assembly was selected with significant margin to allow for additional static pressure from the conservative assumption in the thermal model. The new blade pitch was specified to be 11° opposed to the ~40° aggressive pitch angle that was revealed during the tower inspection.

The equation below is the formula utilized to calculate the SPL noise level (Lp) value from a PWL noise level (Lw)

$$L_p = L_W - \left| 10 \cdot \log\left(\frac{Q}{4\pi \cdot r^2}\right) \right|$$

Lw = PWL Noise Level = 104.1 dBA *(See Fan Selection Data)*
Q = Directivity Factor = Assume Value of 1 For Spherical Propogation
r = Distance From Sound Source In Meters = 120 ft = 36.576 m
Lp = Calculated SPL Noise Level = SPL of **61.8 dBA** at 120 ft

From the logarithmic calculation above, it can be shown that the new proposed fan with a 104.1 PWL noise level is calculated to produce a SPL noise level slightly below the existing fan which is at 62 dBA at 120 ft.

Figure 11: The calculation used along with the fan manufacturer's rating to verify the new fan assembly would adhere to the local noise restriction.

With a proper fan selection that not only met the required airflow but also had significant flow margin to account for any system unknowns, the design team was able to focus on the fill and the distribution system to further optimize performance. The distribution was a concern due to the type of nozzle, the proximity of the nozzle to the top of the fill and the size of the laterals. The size of the laterals were found to be too small, causing the water velocity through the piping to be higher than a target velocity of 7.5 ft/sec which is an industry practical limit for good fluid flow. The project engineering team elected to remove 1' of fill material to reduce the air travel to 6' and give the nozzles an additional 1' of spray zone resulting in a better spray pattern. In addition, the reduced fill height decreased the static load on the fan, thus improving airflow. An image of the distribution design is located in figure twelve.

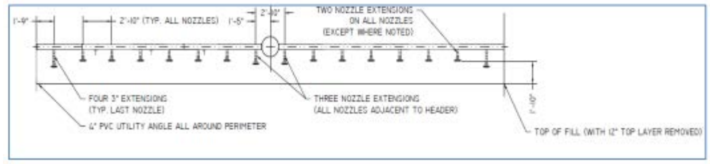


Figure 12: Upgraded distribution design with improved nozzles and proper geometry designed to maximize the distribution of water over the fill section.

Performance and Process of the Cooling Tower Upgrade:

The construction schedule of the cooling tower upgrade was specified to be ten weeks. This was based upon the restriction of material lead times and the need of the plant to have the tower up and running before the warmer Chicago spring season. Due to the tower being located in a downtown environment, the first step of the project was to obtain the applicable traffic control and street permits needed to handle material as part of the repair and replacement of components. In addition to the street closure study an engineering study utilizing ground penetrating radar was performed to verify that the appropriate crane and positioning was used. An image of the surveyed street substrate is located in Figure eleven.

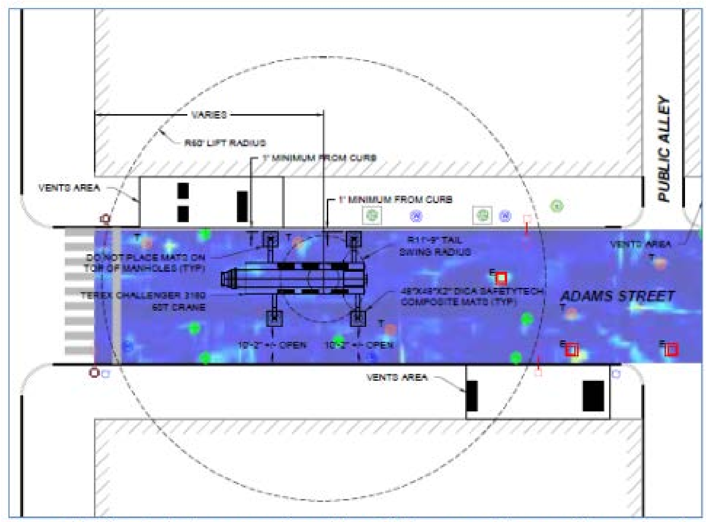


Figure 11: Geophysical survey performed to verify the appropriateness of the construction equipment with respect to the existing street and sub terrain.

Following the permitting process and safety plans, a full logistics plan was assembled to allow for the new and old material to be delivered to and from the plant. The scope of work included replacing the fan assembly, fan stack, the gearbox, the driveshaft and the fan motor along with removing 1' of fill material and an entirely new distribution system in each of the cells. In addition the concrete cold water basin was restored with a new membrane and the fan deck was replaced to remedy a deteriorated balsa core FRP fan deck that had deteriorated to an unsafe condition. Images of the upgrade project and progress are located in figures twelve, thirteen and fourteen.

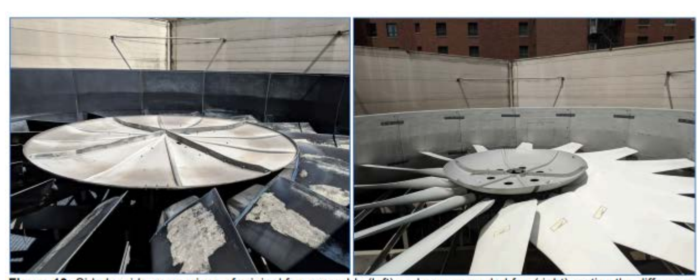


Figure 13: Side by side comparison of original fan assembly (left) and new upgraded fan (right), notice the difference in diameter of the air seal disc in the center of the fan.

Figure 12: Mechanical components being removed in the congested downtown location.

Figure 14: The concrete cold water basin was resurfaced and a new waterproofing membrane was installed to extend the life of the basin.

The most significant challenge identified during the execution of the cooling tower rebuild was the coordination and logistics of the crane and material handling equipment in the downtown location. The existing mechanical equipment supports were reused and the new gearboxes were supplied with mechanical oil pumps to allow the new system to operate with a variable speed drive. New adapter plates were supplied to allow for oil pump clearance and to bring the fans into a more desirable throat location of the fan stacks. The detailed engineering that was performed on the front end of the project limited issues in the field and provided for a strong project execution. An image of the final installed mechanical equipment set is located in figure fifteen.

Figure 15: New mechanical equipment installation with adapter plate.

Commissioning / Measured Improvements:

The cooling towers were commissioned in the early spring and were run for approximate sixty days before acceptance testing was implemented. The owner's team elected to test the towers in early July when the wet bulb temperatures were elevated and the tower environment was at design conditions. The cooling towers heat load is generated by a combination of electric chillers that have a total output capacity of 17,000 tons. The plant also utilizes thermal storage to build ice in the evening during the lower power demand period to maximize the total output of the plant to 20,000 tons during peak operation. The plant equipment is operated in a variety of configurations to match the demand of the surrounding customers. Due to this operational scenario, the plant's operation team developed their own verification procedure for the upgraded cooling tower performance. A graph of the cooling tower acceptance test results is located in figure sixteen.

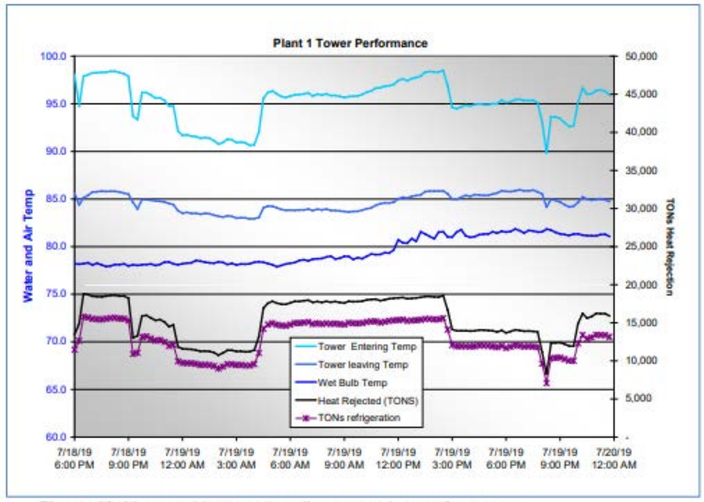


Figure 16: Measured improved cooling tower plant performance

The rebuild design performance was measured using plant instrumentation and was found to improve overall tower performance by approximately 21%. In Addition, the improvement in fan system operating efficiency measured to save approximately 500,000 kWh (500 MWh) over the first season of the towers operation. This energy savings was calculated to be an annual monetary savings of $79,000 USD. In addition, the plant recorded a noticeable reduction in "start/stop" sequences of the mechanical equipment. This reduction is believed to prolong the life of the new mechanical equipment.

Conclusion:

The process of evaluating and upgrading an existing field erected cooling tower has proven to be effective from both a cost and performance measured result. When considering the upgrade of any cooling tower, it is imperative that the process utilizes empirical methods and strong engineering principles to improve the towers operating performance and reliability.

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, or dry fluid coolers, offered for sale by a specific Manufacturer will perform thermal ly 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*.

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 thor oughly 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' incep tion in 1983 (see graphs that follow). A total of 75 cooling tower manufacturers are currently active in the program. In addition, 17 of the manufacturers also market products as private brands through other companies.

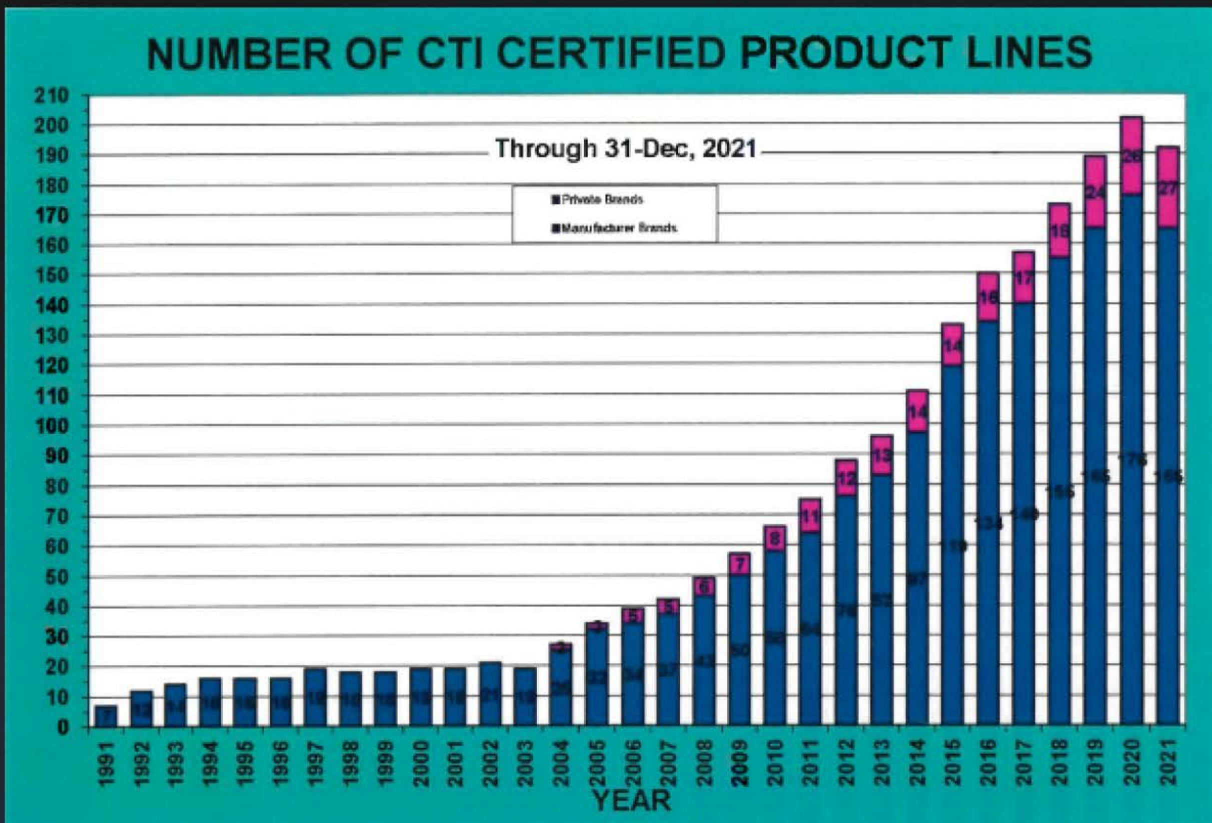
While in competition with each other, these manufacturers benefit from knowing that they each achieve their published performance capability and distinguish themselves by providing the Owner/Operator's required thermal performance. The participating manufacturers currently have 165 certified product lines plus 27 product lines marketed as private brands which result in approximately 53,500 CTI Certified cooling tower models to select from.

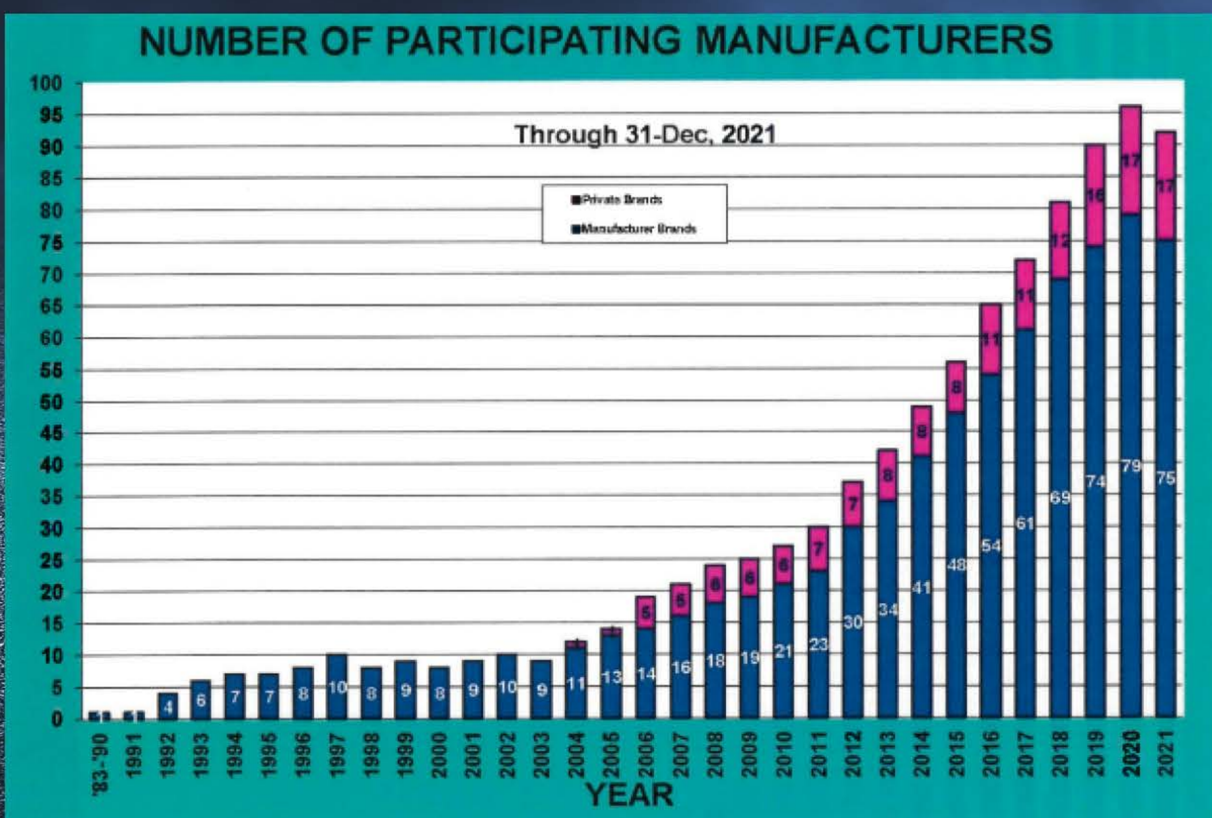
For a complete listing of certified product lines, and listings of all CTI Certified models, please see www.cti.org.

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.

*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.

Thermal Certification Program Participation





Current Program Participants

(as of December 31, 2021)

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:

https://www.coolingtechnology.org/certified-towers

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

A

Advance Cooling Towers, Pvt.,Ltd.
Advance 2020 Series A *Validation No. C31A-07R03*
NTM Line *Validation No. C31B-19R00*

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

Amcot Cooling Tower Corp.
AST *Validation No. C106A-19R00*
Series R-LC *Validation No. C20E-11R03*

American Cooling Tower, Inc.
ACF Series *Validation No. C38D-18R00*
ACX Series *Validation No. C38C-18R00*

AONE E&C Corporation, Ltd.
ACT-C Line *Validation No. C28B-09R02*
ACT Line *Validation No. C28A-05R07*

Approach Engineering Co., Ltd
NSA Line *Validation No. C76B-20R00*

Axima (China) Energy Technology Co., Ltd.
EWX Line *Validation No. C72A-15R03*

B

Baltimore Aircoil Company, Inc.
FXT Line *Validation No. C11A-92R02*
FXV Line *Validation No. C11J-98R10*
NXF Line *Validation No. C11Q-18R01*
PF Series *Validation No. C11P-12R02*
PT2, PTE & PCT Series *Validation No. C11L-07R05*
Series V Closed *Validation No. C11K-00R02*
Series V Open *Validation No. C11B-92R06*
Series 3000, S15E, Compass & Smart *Validation No. C11F-92R20*

Bell Cooling Tower Pvt, Ltd
BCTI Line *Validation No. C43A-12R03*

Brapu (China) Cooling Equipment Co., Ltd
BPC-DE/CH Series *Validation No. C110A-20R00*
BPO-DE/CH Series *Validation No. C110B-20R00*

C

Cenk Endüstri Tesisleri Imalat Ve Taahüt A.Ş.
LEON Line *Validation No. C89A-17R03*
LISA Line *Validation No. C89B-17R02*
ODIN Line *Validation No. C89D-20R02*

Chongqing Yinengfu Technology Co., Ltd
YNF Series *Validation No. C103A-18R01*

Classik Cooling Towers
CCF-SQS Line *Validation No. C119A-21R00*
CCF-CCT Line *Validation No. C119C-21R00*

Composite Cooling Solutions Inc.
PhoenixPL *Validation No. C79B-20R01*

Cool Water Technologies
RTAi Line *Validation No. C52A-13R03*
RTi Line *Validation No. C52A-13R02*

D

Dalian Spindle Environmental Facilities Co., Ltd
DC Series *Validation No. C112A-19R00*
DF Series *Validation No. C112B-19R01*
DS Series *Validation No. C112D-21R00*
DX Series *Validation No. C112C-19R01*

Decsa
TMA-EU Series *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*

Dezhou Beitai Refrigeration Equipment Co. Ltd.
$DBHZ_2$ *Validation No. C104A-19R00*

Dezhou Zhongwei Liangji Cooling Equipment Co., Ltd.
JH Line *Validation No. C66A-15R03*
JHB Line *Validation No. C66B-20R00*

Dongguan Kuken Cooling Tower Co.,Ltd.
GXC Series *Validation No. C81B-16R01*
GXE Series *Validation No. C81A-16R01*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- Leading Cooling Tower Contractor

Dongguan Ryoden Cooling Equipment Co., Ltd
RT-L&U Series *Validation No. C71A-15R03*
RTM-L Series *Validation No. C71B-15R00*

E

Elendoo Technology (Beijing) Co., Ltd.
EL Line *Validation No. C50C-15R04*
ELOP Line *Validation No. C50B-14R04*

Ebara Refrigeration Equipment & Systems Co.
CDW Line *Validation No. C53A-13R04*
CNW Line *Validation No. C53C-18R00*
CXW Line *Validation No. C53B-14R05*

Evapco, Inc.
AT Series *Validation No. C13A-99R23*
ATWB Series *Validation No. C13F-09R10*
AXS Line *Validation No. C13K-15R03*
ESWA, ESWB, & ESW4 Series *Validation No. C13E-06R12*
L Series Closed *Validation No. C13G-09R04*
L Series Open *Validation No. C13C-05R03*

G

Genius Cooling Tower Sdn Bhd
MK Series *Validation No. C67C-18R01*
MT Series *Validation No. C67A-16R01*
MX Series *Validation No. C67B-16R00*

Guangdong EnZen Energy Saving Technology Co., Ltd
YZB Series *Validation No.C109B-21R00*

Guangdong Feiyang Industry Co., Ltd
RT-L&U Series *Validation No.C71A-15R03*

Guangdong Green Cooling Equipment Co., Ltd
GLR-E Series *Validation No.C97B-18R02*

Guangdong Zhaorin Industrial Co., Ltd
SRN Series *Validation No.C95A-17R01*

Guangdong Liangken Cooling and Heating Equipment Technology Co., Ltd
LRT Series *Validation No.C66A-15R03*
LYH Series *Validation No.C66B-20R00*

Guangzhou Goaland Energy Conservation Tech Co., Ltd.
GLH Series *Validation No. C96A-17R02*

Guangzhou Laxun Technology Exploit Co., Ltd.
LC Line *Validation No. C45F-16R01*
LMB Line *Validation No. 12-45-02*
PG Line *Validation No. C45G-17R00*
PL Line *Validation No. C45E-16R03*

Guangzhou Single Beam All Steel Cooling Tower Equipment Co., Ltd.
SLH Line *Validation No.C91E-16R02*

H

Hanf Cooling Equipment Co., Ltd
GTC Series *Validation No. C101B-19R01*
GTN Series *Validation No. C101A-18R01*
GTS Series *Validation No. C101C-20R00*

Hon Ming (Guang Dong) Air Conditioning Equipment Company, Ltd.
HM Series *Validation No. C66B-20R00*
MK Series *Validation No. C66A-15R03*

Hunan Yuanheng Technology Company, Ltd.
YCH-F Line *Validation No. C40C-16R02*
YCN-F Line *Validation No. C40D-18R00*
YHD Line *Validation No. C40B-15R00*
YHW Line *Validation No. C40E-18R00*

HVAC/R International, Inc.
Therflow Series TFC *Validation No. C28B-09R02*
Therflow Series TFW *Validation No. C28A-05R07*

I

İMAS KLİMA SOĞUTMA MAKİNA SANAYİ TİCARET ve MÜMESSİLLİK A.Ş.
TA Line *Validation No. C114B-20R00*
TAK Line *Validation No. C114A-20R00*

J

Jacir
DTC *Validation No. C46E-18R01*
VAP Line *Validation No. C46C-16R02*

Jiangsu i-Tower Cooling Technology Co., Ltd.
TMH Series *Validation No. C75A-16R02*

Jiangxi Ark Fluid Science Technology Co., Ltd.
FBNJ Line *Validation No. C78B-20R00*

Ji'Nan Chin-Tech Thermal Technology Co., Ltd.
CTHX Line *Validation No. C91E-16R02*

K

Kelvion B.V.
Polacel CF Series *Validation No. C25A-04R02*

KIMCO (Kyung In Machinery Company, Ltd.)
CKL Line *Validation No. C18B-05R04*
Endura Cool Line *Validation No. C18A-93R09*
GX Line *Validation No. C18D-18R01*

King Sun Industry Company, Ltd.
HKD Line *Validation No. C35B-09R06*
KC Line *Validation No. C35C-11R02*
KFT Line *Validation No. C35D-16R01*

Kongsung Machinery Co., Ltd.
SK-FCR Line *Validation No. C120A-21R00*

KSN Co., Ltd

KSNC Series *Validation No. C44A-12R03*
KSNX Series *Validation No. C44B-12R01*
KSNC-C Series *Validation No. C44C-14R01*
KSNX-C Series *Validation No. C44D-14R01*

L

Liang Chi Industry Company, Ltd.

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. C20E-11R03*
Series U-LC *Validation No. C20D-10R04*
Series V-LC *Validation No. C20C-10R01*
TLC Line *Validation No. C20G-16R00*
V-LN Line *Validation No. C20K-20R00*

M

Marley (SPX Cooling Technologies)

Aquatower Series *Validation No. 01-14-05*
AV Series *Validation No. C14D-98R03*
DTW Series *Validation No. C14N-16R02*
LW Series *Validation No. C14P-16R01*
MCW Series *Validation No. 06-14-08*
MD and CP Series *Validation No. C14L-08R10*
MH Series *Validation No. C14G-04R13*
NC Series *Validation No. C14A-92R21*
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*
MHD Series *Validation No. C26K-20R00*
MXC Series *Validation No. C26H-12R01*
MXR-KM, MXL, MXH Series *Validation No.C26C-08R09*

MITA S.r.l.

PM Series *Validation No. C56B-16R02*

N

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

HMP-NB Line *Validation No. C55A-14R02*

Nihon Spindle Manufacturing Company, Ltd.

KG Line *Validation No. C33B-12R05*

O

Ocean Cooling Tower Sdn Bhd

YC Series *Validation No. C86A-17R00*

OTT Company, Ltd.

OTTC Series *Validation No. C44A-12R03*
OTTX Series *Validation No. C44B-12R01*
OTTC-C Series *Validation No. C44C-14R01*
OTTX-C Series *Validation No. C44D-14R01*

P

Paharpur Cooling Tower, Ltd.

CF3 Series *Validation No. C51A-13R03*
OXF-30K Series *Validation No. C51B-14R00*
Series RXF *Validation No. C51C-19R00*

Protec Cooling Towers, Inc.

FRS Series *Validation No. 05-27-03*
FWS Series *Validation No. C27A-04R06*
FXS Series *Validation No. C27G-20R00*

Q

Qinyang Zhonghe Zhi Da Technology Co., Ltd.

HLO Series *Validation No. C99B-20R00*

R

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

HFC Line *Validation No. C22F-10R06*
RT & RTM Series *Validation No. C22G-13R08*

Rosemex, Inc.

RC (RCS/D) Series *Validation No. C54A-13R04*
RO (ROS/D) Series *Validation No. C94A-14R03*

RSD Cooling Towers

RSS Series *Validation No. C32A-08R01*

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*
FXS Series *Validation No. C27B-20R00*

S

Shandong Grad Group Co., Ltd.

GAT Series *Validation No. C88A-17R01*

Shanghai ACE Cooling Refrigeration Technology Col, Ltd.

AC Line *Validation No. C80A-17R02*

Shanghai Baofeng Machinery Manufacturing Co., Ltd.

BTC Line *Validation No. C49A-12R01*

Shanghai Liang Chi Cooling Equipment Co., Ltd.

LCP Line *Validation No. C62D-18R00*
LNCM Line *Validation No. C62B-16R00*
LRS Line *Validation No. C62C-16R00*
LRCM-DD Line *Validation No. C62E-19R00*

Shanghai Tyacht Cooling System Co.,Ltd.

TMC Line *Validation No. C93C-18R00*

Shanghai Wanxiang Cooling Equipment Co., Ltd.

FBH/HL Line *Validation No. C54A-13R04*
FKH/FKHL Series *Validation No. C94A-14R03*

Shanghai Zendia Cooling Equipment Co., Ltd.
ZHF-7000 Series *Validation No. C111A-19R00*

Sinro Air-Conditioning (Fogang) Company, Ltd.
CEF Line *Validation No. C37D-20R00*
CEF-A Line *Validation No. C37B-11R03*
SC-B Series *Validation No. C37C-11R02*
SC-H Series *Validation No. C37A-10R04*

ST Engineering & Cooling Co., LTD
SK-FCR Line *Validation No. C120A-21R00*

Sung Ji Air-Conditioning Technology Co., Ltd.
SJCO Series *Validation No. C74B-16R01*
SJMO Series *Validation No. C74A-16R00*

T

Ta Shin F.R.P. Company, Ltd.
TSS Series *Validation No. C32A-08R01*

The Cooling Tower Company, L.C
TCIA Series *Validation No. C29C-19R01*

Thermal-Cell sdn bhd
THW Line *Validation No. C40E-18R00*

Thermax Cooling Solutions Limited
Enerflow (CM) Line *Validation No. C117A-20R00*

Tower Tech, a div. of CPK Manufacturing, LLC
TTXL Line *Validation No. C17F-08R05*
TTXR Line *Validation No. C17F-15R00*

Truwater Cooling Towers Sdn Bhd
EC-S Series *Validation No. C41A-12R04*
EX-S and VX-S Series *Validation No.C41B-12R07*
TKS Series *Validation No.C41D-18R00*

W

Wuxi Ark Fluid Science Technology Co., Ltd.
FBN Series *Validation C78B-20R00*

Wuxi Fangzhou Water Cooling Equipment Co., Ltd.
FFB Line *Validation C64D-20R00*

Wuxi Sanjiu Cooling Equipment Co., Ltd.
GOM Line *Validation C45E-16R03*

Wuxi Zhishui Environmental Co., Ltd.
ZSBN Series *Validation C113A-20R00*

Y

YM Tech Co., Ltd.
Csta Line *Validation No. C108D-20R00*
Xsta Line *Validation No. C108B-19R01*
YFO Line *Validation No. C108A-19R00*
YFOL Line *Validation No. C108C-20R00*

Z

Zhejiang Dongjie Cooling Tower Co., Ltd.
DHC Line *Validation No. C63B-15R00*

Zhejiang Haicold Cooling Technology Co., Ltd
SFN Line *Validation No. C76B-20R00*

Zhejiang Jinling Refrigeration Engineering Co.,Ltd.
JFT Series *Validation No. C28C-16R03*
JNC Series *Validation No. C28B-09R02*
JNT Series *Validation No. C28A-05R07*

Zhejiang Ryoden Cooling Equipment Co., Ltd.
RT/SB Series *Validation No. C102A-18R00*

Zhejiang Shangfeng Cooling Tower Co., Ltd.
SFB Line *Validation No. C73A-15R01*
SFCFG Line *Validation No. C73B-20R00*

Zhejiang Wanxiang Science and Technology Company, Ltd.
WBH Line *Validation No. C96A-17R01*

Always Look For the CTI Certified Label with Validation Number on Your Equipment

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Certification Validation Number

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HOW DO I APPLY?

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WHEN IS THE DEADLINE?

Scholarship applications are due no later than May 31, 2022.

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