Managing Cooling Tower Cycles of Concentration

Nick McCall, P.E., Woodard & Curran
Keynote Speaker

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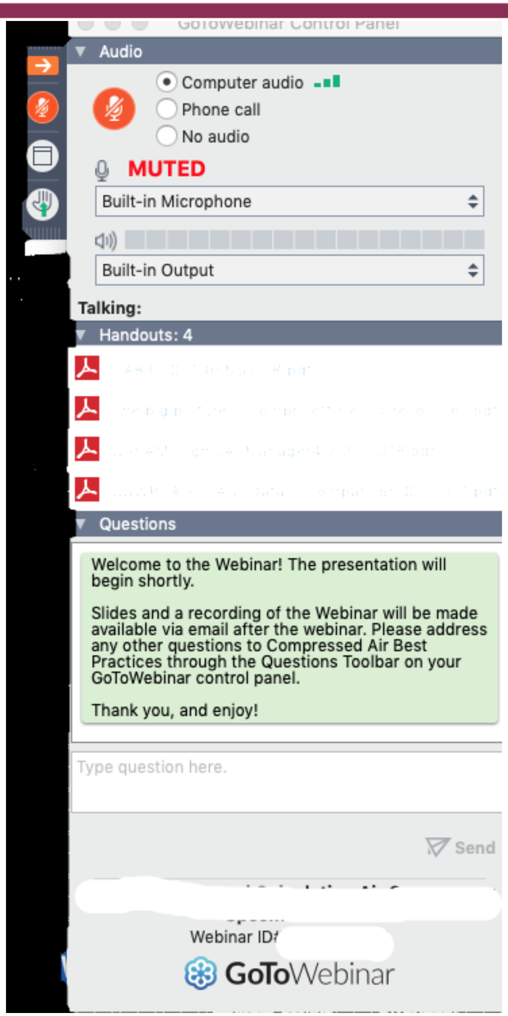
Q&A Format



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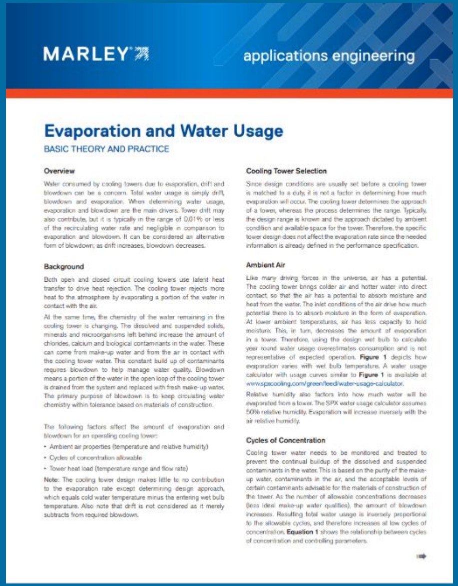
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Evaporation and Water Usage
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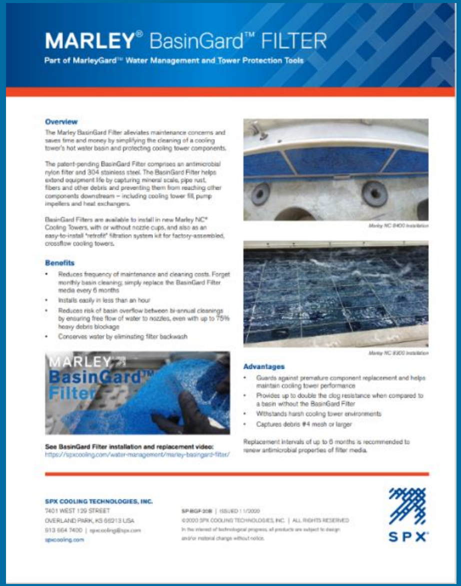
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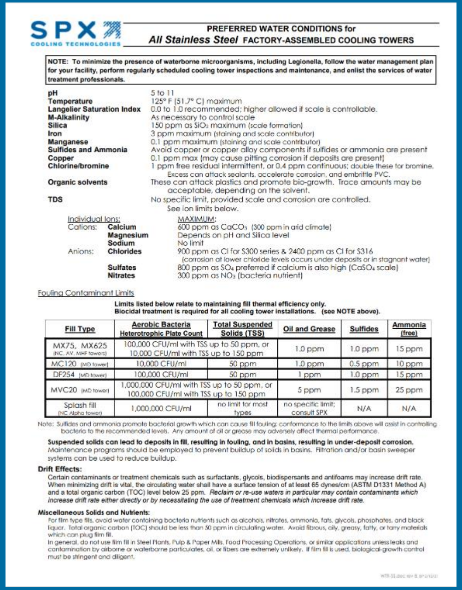
SPX COOLING TECHNOLOGIES
PREFERRED WATER CONDITIONS for
All Stainless Steel FACTORY-ASSEMBLED COOLING TOWERS

Disclaimer

All materials presented are educational. Each system is unique and must be evaluated on its own merits.

Managing Cooling Tower Cycles of Concentration

Introduction

Chiller & Cooling Best Practices® Magazine

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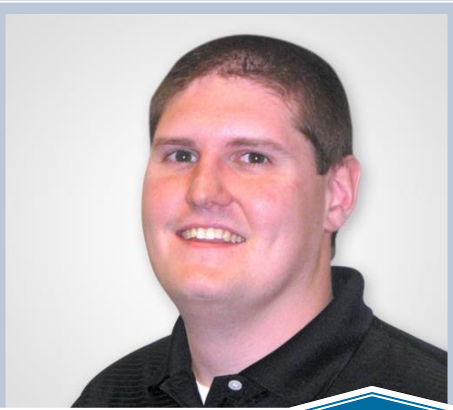
About the Speaker



Nick McCall, P.E.
Woodard & Curran

- Technical Manager, Woodard & Curran
- Utilities engineer since 2008
- Handle utilities installations including chillers, air compressors, dryers, boilers, and cooling towers as well as supporting utilities for manufacturing equipment

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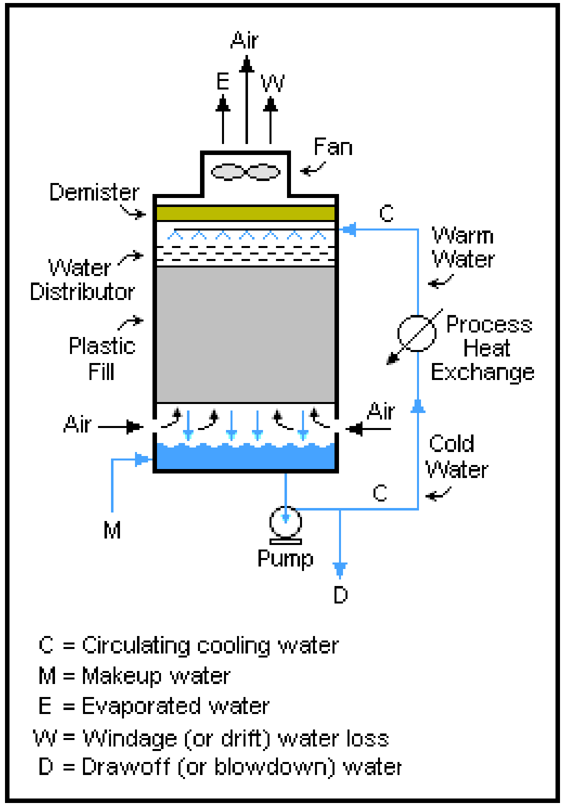
Cooling Tower Function Overview



- Cooling towers dissipate heat from processes, typically using water as the medium.
- Heat transfer due to conduction is approximately 20-30%, remaining 70-80% is the result of evaporative cooling.
- Rate of evaporation is approximately 1-2% of the recirculating water flow depending on temperature delta across the tower.
- Water lost due to evaporation, drift, system leaks, and blowdown is replaced via makeup water.

Cooling Tower Function Overview

Image courtesy SPX

Makeup Water Equation

- Cooling tower operation is described by the relationship between evaporation, blowdown, and makeup. Note: loss due to drift/system leaks is included in the blowdown flow rate.

$$M = B + E$$

$$M = makeup\ water\ flow\ rate$$
$$B = blowdown\ flow\ rate$$
$$E = evaporation\ rate$$

Cycles of Concentration Definition

- Cycles of concentration (COC) describes the relationship between the makeup water rate and the blowdown rate.
- It is also a measure of the total amount of minerals concentrated in the cooling tower water relative to the amount of minerals in the incoming makeup water.
- Higher COC is indicative of higher water use efficiency.
- Most tower systems operate with a COC between 3 and 10, 10 being more efficient.
- COCs tend to range between 5 and 7 due to cost efficiency.

Cycles of Concentration Equation

- COC can be calculated from makeup and blowdown flow rates as below:

$$C = \frac{M}{B}$$

$$C = COC$$
$$M = makeup\ water\ flow\ rate$$
$$B = blowdown\ flow\ rate$$

Cycles of Concentration Via Conductivity

- COC can also be determined via water analysis.
- This can be done by measuring the conductivity of the incoming makeup water and the recirculating cooling tower water (the recirculating water conductivity will be the same as the blowdown water.)

$$C = \frac{B_{cond}}{M_{cond}}$$

$$C = COC$$
$$B_{cond} = blowdown\ conductivity$$
$$M_{cond} = makeup\ conductivity$$

- Conductivity is commonly used to estimate COC.

Cycles of Concentration Management

- Simple rule: to increase COC, decrease blowdown; to decrease COC, increase blowdown.
- COC can be adjusted to allow for lower rates of water use, corresponding to lower rates of water chemical treatment use.

Blowdown Required Equation

- Water evaporation loss can be used to determine the blowdown rate needed to operate at a given COC. The relationship is as below:

$$B = \frac{E}{(C-1)}$$

$$B = blowdown\ flow\ rate$$
$$E = evaporation\ rate$$
$$C = COC$$

Evaporation Rate Rule of Thumb

- Evaporation rate typically is 1% of the recirculation rate for every 10 deg F temperature drop across the tower (rule of thumb.)
- Newer towers can have 0.75% of the recirculation rate for every 10 deg F drop.

Scale

- Scale is formed from minerals dissolved in the makeup water.
- Scale is a byproduct of water evaporation in the tower, making the concentration of the minerals higher in the remaining water.
- Minerals eventually come out of solution and deposit on surfaces in contact with the cooling tower water.
- Common scaling minerals include calcium carbonate, calcium phosphate, calcium sulfate, and silica (magnesium sulfate is also possible under certain conditions.)
- Most calcium and magnesium salts are more soluble in cold water than hot (“reverse solubility.”)
- Other salts such as silica are more soluble in hot water than in cold.
- Water temperature increase as the water moves through the system causes calcium and magnesium scale to form.
- Deposits can form anywhere in the system, but they are most likely on hot surfaces such as heat exchangers.
- Silica tends to form in the coldest parts of the system (cooling tower fill.)

Scaling Potential and Cycles of Concentration Limits

- Scaling potential is determined by the maximum solubility limit for dissolved minerals that can form scale given a particular set of conditions.
- Minimizing blowdown requires dissolved mineral levels to be maintained as close as possible to these maximum solubility levels (also referred to as total dissolved solids or TDS), and it is controlled by maintaining COC for the system at a level that is equal to the lowest COC allowable for the lowest solubility salt.
- Typically calcium carbonate or calcium phosphate, but it may also be silica under certain conditions.
- COC can be increased through proper cooling water treatment.
- Equations that follow are based on rules of thumb to establish rough limits on COC. Final operating COC will be dependent on system conditions and water treatment chemicals used in system.

Calcium Carbonate Scale

- Calcium carbonate scale is formed when calcium bicarbonate breaks down.
- Severity of scale depends on calcium level, bicarbonate alkalinity level, and water temperature in the system.

$$C = \sqrt{\frac{110{,}000}{TA \; x \; M_{Ca}}}$$

$$C = COC$$

$$TA = Total\ alkalinity\ as\ CaCO_3\ in\ makeup\ in\ ppm$$

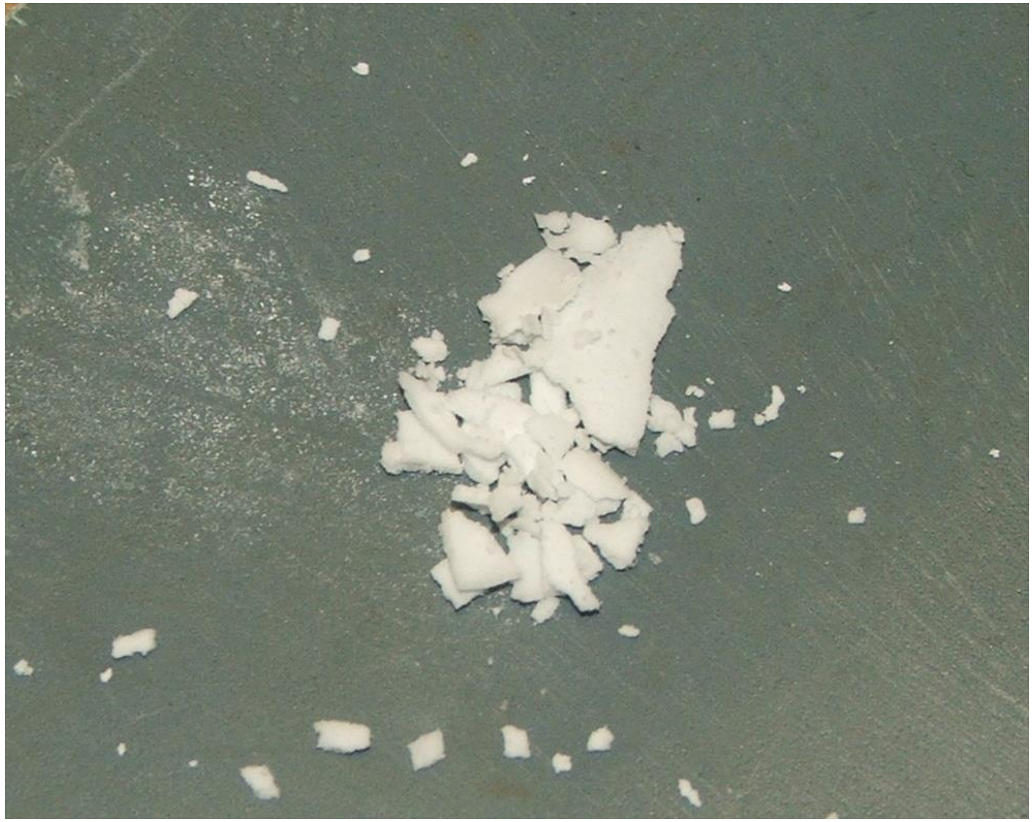
$$M_{Ca} = Calcium\ hardness\ as\ CaCO_3\ in\ makeup\ in\ ppm$$

Calcium Phosphate Scale

- Calcium phosphate scale occurs when calcium hardness reacts with phosphate in the system.
- Calcium hardness must be sufficiently high, and orthophosphate must be present and higher than 10 ppm in the cooling water.
- Calcium phosphate scaling potential can be roughly predicted by the below:

$$C = \frac{(105\ x\ (9.8 - B_{pH}))}{M_{Ca}}$$

$$C = COC$$
$$B_{pH} = blowdown\ pH$$
$$M_{Ca} = Calcium\ hardness\ as\ CaCO_3\ in\ makeup\ in\ ppm$$



Calcium Sulfate Scale

- Calcium sulfate scale occurs when calcium hardness reacts with sulfate in the water.
- Scaling potential can be roughly predicted by the below:

$$C = \sqrt{\frac{1{,}250{,}000}{M_{Ca} x M_{Su}}}$$

$$C = COC$$

$$M_{Ca} = \text{Calcium hardness as } CaCO_3 \text{ in makeup in ppm}$$

$$M_{Su} = \text{sulfate as } SO_4 \text{ in makeup in ppm}$$

Silica Scale

- Silica scale can occur when the maximum solubility for silica is exceeded in the cooling water. A conservative value for the solubility limit is 150 PPM as SiO2. However, the solubility limit for silica is dependent on pH and temperature. The limit ranges between 150-180 ppm in the temperature ranges typically encountered in tower systems (80 deg F to 130 deg F.) As pH increases, the solubility limit goes up. For example, the limit in a tower system with a pH of 9.0 would be approximately 250 ppm. Using 150 ppm as the limit, the below can be used to determine silica scaling potential:

$$C = \frac{150}{M_{Si}}$$

$$C = COC$$
$$150 = assumed\ solubility\ limit\ for\ silica\ in\ ppm$$
$$M_{Si} = silica\ as\ SiO_2\ in\ makeup\ in\ ppm$$

Maximum Cycles of Concentration

- Lowest calculated COC from the above equations is the controlling factor for operating cooling towers.
- Material with the lowest COC will be the first to precipitate out of solution, forming scale deposits in the system.
- System COC must be kept lower than this value for the above salts.
- Water treatment can be used to allow for higher COC values, increasing the water use efficiency of the system.

Example

- $R\ (recirculation\ flow\ rate)\ =\ 3500\ GPM$
- $T\ (delta\ across\ tower)\ =\ 13.5°\ F$
- $M_{Ca}\ =\ 255\ ppm\ as\ CaCO_3$
- $TA\ =\ 155\ ppm\ as\ CaCO_3$
- $Phosphate\ =\ 3\ ppm\ as\ PO_4$
- $B_{pH}\ =\ 8.5$
- $M_{Su}\ =\ 165\ ppm\ as\ SO_4$
- $M_{Si}\ =\ 5\ ppm\ as\ SiO_2$

Example

- $E = R\ x\ 0.01\ x\ \frac{T}{10}$
- $E = 3500\ x\ 0.01\ x\ \frac{13.5}{10} = 47.25\ GPM$
- Calcium carbonate: $C = \sqrt{\frac{110{,}000}{TA\ x\ M_{Ca}}} = \sqrt{\frac{110{,}000}{155\ x\ 255}} = 1.67$
- Calcium phosphate: phosphate level < 10 ppm, N/A
- Calcium sulfate: $C = \sqrt{\frac{1{,}250{,}000}{M_{Ca}\ x\ M_{Su}}} = \sqrt{\frac{1{,}250{,}000}{255\ x\ 165}} = 5.45$
- Silica: $C = \frac{150}{M_{Si}} = \frac{150}{5} = 30$
- Calcium carbonate returns the lowest value, therefore $C = 1.67$
- $B = \frac{E}{(C-1)} = \frac{47.25}{(1.67-1)} = 70.52\ GPM$
- $M = B + E = 47.25 + 70.52 = 117.77\ GPM$

Summary

- Cycles of concentration (COC) describes the relationship between the makeup water and blowdown, both in rate and mineral concentration.
- Higher COC is indicative of higher water/chemical use efficiency. Most systems operate between 3-10 COC.
- Simple rule: to increase COC, decrease blowdown; to decrease COC, increase blowdown.
- COC can be adjusted to control scaling and allow for lower rates of water/chemical use.
- Scaling potential can be estimated based on makeup water quality parameters.
- COC can be increased through proper cooling water treatment.

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About the Speaker

Mark Pfeifer
SPX Cooling Technologies, Inc.

- Senior Manager of Technical Services, SPX Cooling Technologies, Inc.

- 30 year of cooling tower experience

- Secretary of ASHRAE's Technical Committee for Cooling Towers and Evaporative Condensers (TC8.6)

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Cycles of Concentration – A Manufacturers Perspective

May 20, 2021

SPX

Agenda

1. Why Evaporative Cooling?
2. Why should I Maximize Cycles of Concentration?
3. Other water saving methods
4. How manufacturers can help

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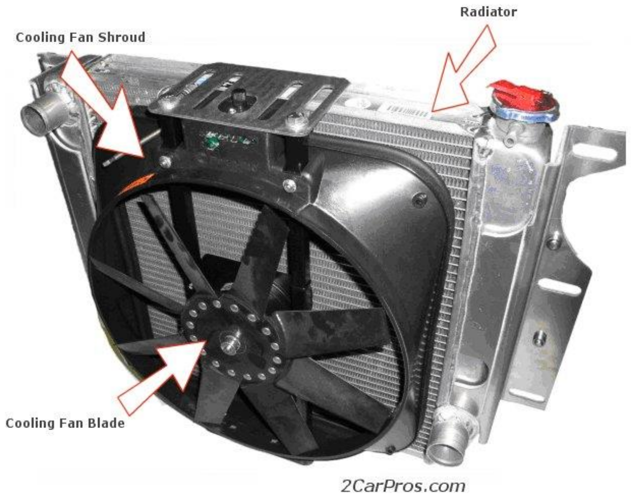
The "Cooling" in Cooling Towers

Sensible (aka dry cooling)

- **<u>Sensible Cooling</u> of 1 lb of water 1ºF rejects <u>1 btu</u>.**
- Dry Bulb temperature is the driving force
- Hard to cool 95º water with 95º air
- Example: Car radiator



Latent (aka evaporative cooling)

- **<u>Evaporating</u> that same 1 lb of water rejects <u>1,000 btu!</u>**
- Example: Perspiration evaporating

The “Cooling” in Cooling Towers

Evaporative cooling

- Can cool water approaching the wet bulb temperature
  - providing colder water to process
  - **Providing additional system efficiency**

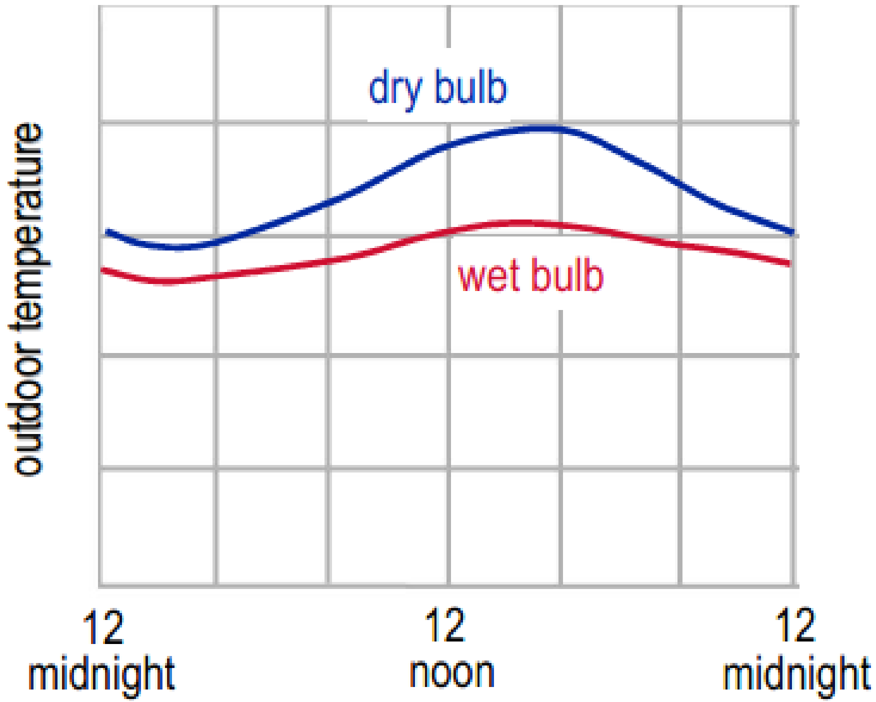


Image courtesy Trane Technologies

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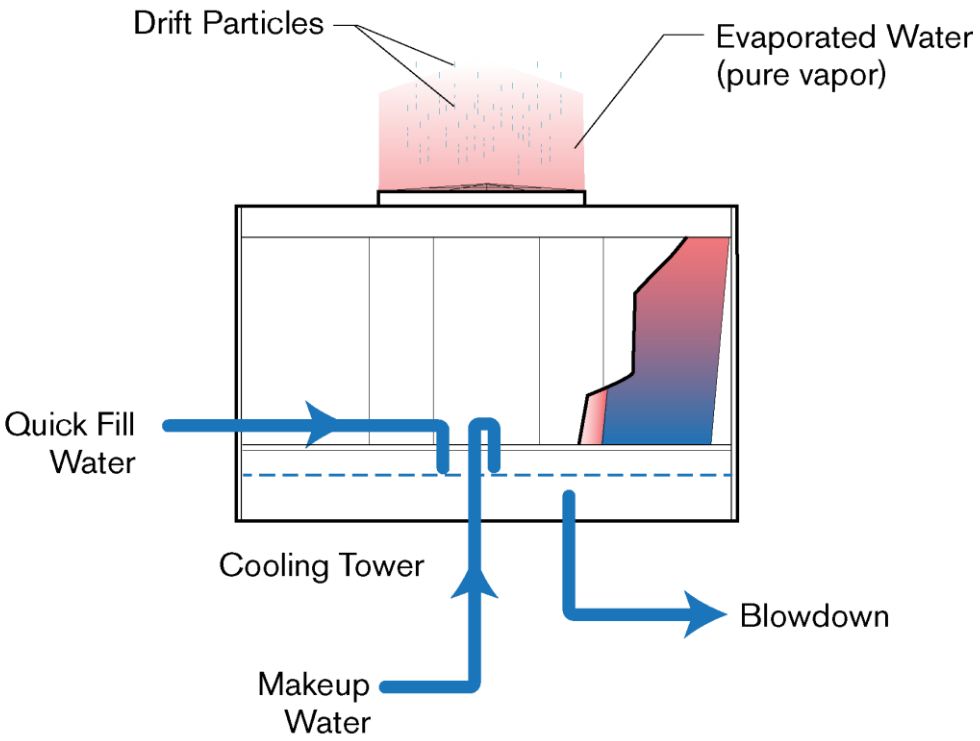
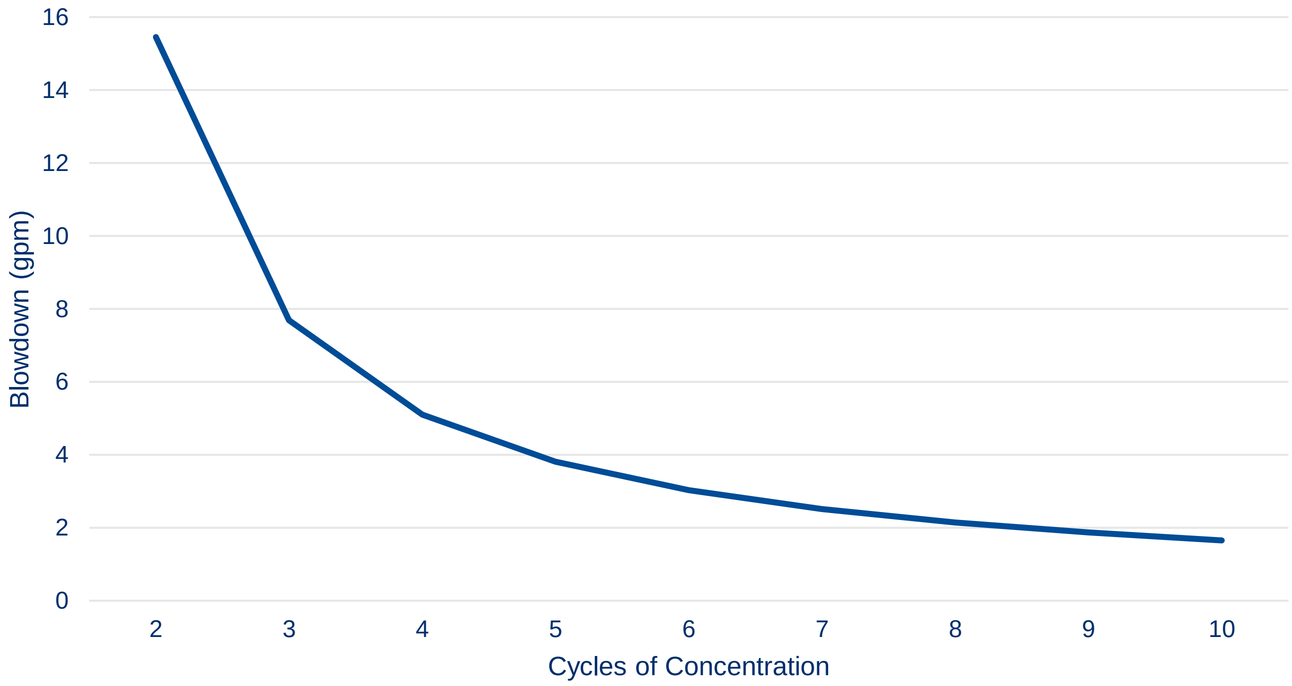
Water Use in Evaporative Equipment

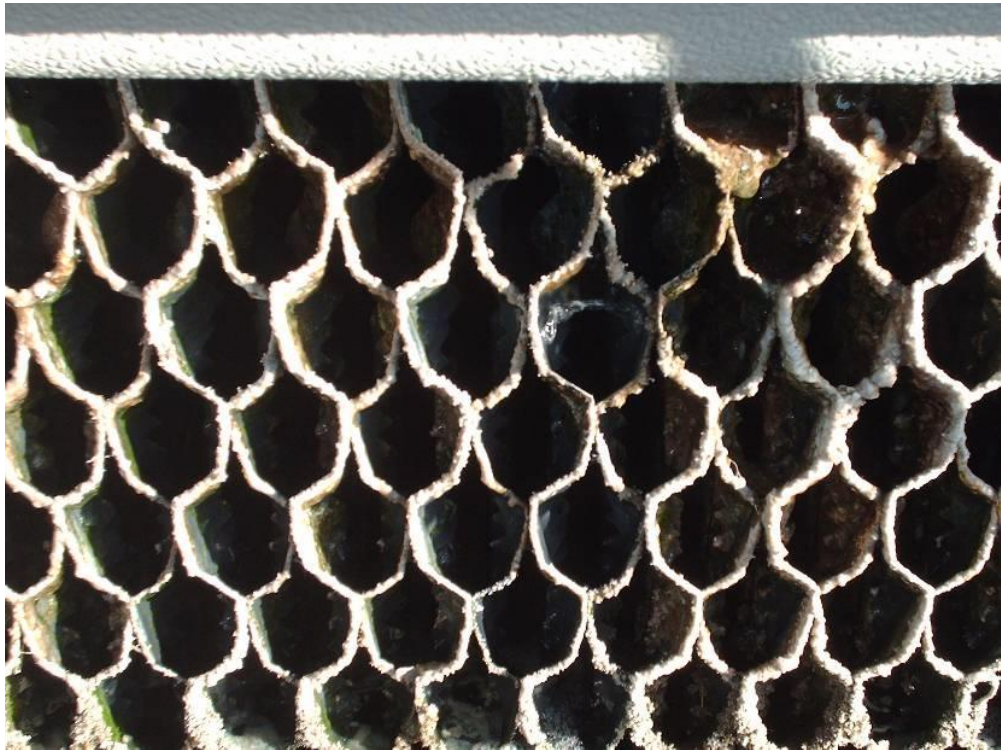


Cycles of Concentration

- Number of times the dissolved solids in a particular volume of water are concentrated through evaporation
- Regulated by adjusting the blowdown rate



Water Quality – Scale



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Condensate Recovery

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Condensate from cooling coils

Optimal use of condensate as cooling tower makeup:

- Condensate production occurs when tower is active
- No storage tank
- No additional water treatment
- Reduced blowdown

Reference: "Quality of Condensate From Air-Handling Units," *ASHRAE Journal,* December 2016, Glawe and Wooten

Condensate Recovery

Potential ANNUAL condensate volume from air handlers per cfm of airflow in different climates:

- Athens, GA 12.5 gal
- Houston, TX 22.4 gal
- Boston, MA 4.5 gal
- Sacramento, CA 1.3 gal
- Denver, CO 0.5 gal

Reference: "Capturing Condensate by Retrofitting AHU's," *ASHRAE Journal,* January 2010, Lawrence, Perry and Dempsey

Grey and Reclaimed Water Use

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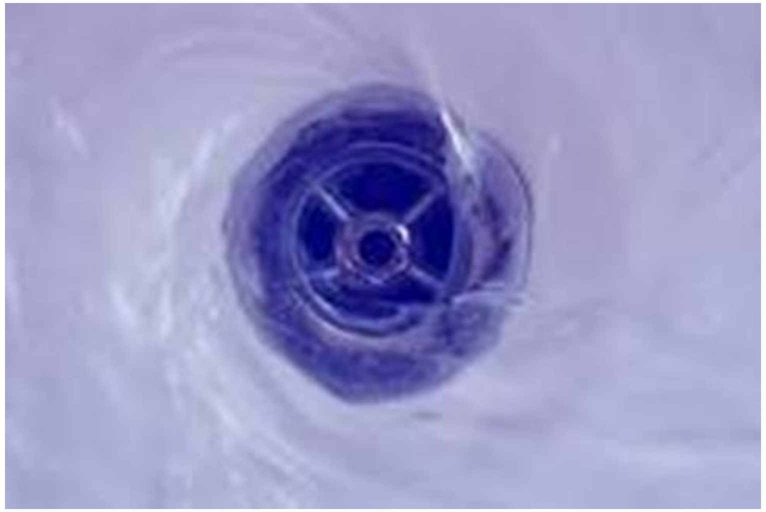
Grey: household wastewater (as from a sink or bath) that does not contain serious contaminants (as from toilets)[1]

Reclaimed: Waste water treatment plant effluent, generally having been the subject of significant water treatment for removal of "nutrients, toxic compounds, (TSS) [total suspended solids], and organics."[2]



(1) https://www.merriam-webster.com/dictionary

(2) Florida Water Resources Journal, "Comparison of Water Quality Parameters from South Florida Wastewater Treatment Plants", Bloetscher & Gokgoz, 6/01

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Fluid Cooler Products – Dry Capacity





Fluid Cooler Type	First Cost	Dry Capacity
Hybrid Crossflow	$$$	--
Hybrid Counterflow	$$	-
Bare Coil only Counterflow	$$$	+
Finned Coil only Counterflow	$$$$	++
Adiabatic Fluid Cooler	$$$$$	+++

- Products available to meet varying dry operation goals
  - Water savings / water treatment
  - Basin freeze prevention / wintertime operation
  - Operational flexibility / redundancy

↑ Coil Surface Area = ↑ Dry Capacity

↑ Airflow = ↑ Dry Capacity

↑ Coil Surface Area = ↑ Cost

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Tools - Water Guidelines

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Reference cooling tower manufacturer's guidelines to help monitor the quality of your water

Provides limits to minimize:

1. Scale
2. Corrosion
3. Deposits
4. Biological Growth

SPX COOLING TECHNOLOGIES

PREFERRED WATER CONDITIONS for
***All Stainless Steel* FACTORY-ASSEMBLED COOLING TOWERS**

NOTE: To minimize the presence of waterborne microorganisms, including Legionella, follow the water management plan for your facility, perform regularly scheduled cooling tower inspections and maintenance, and enlist the services of water treatment professionals.

pH	5 to 11
Temperature	125° F (51.7° C) maximum
Langelier Saturation Index	0.0 to 1.0 recommended; higher allowed if scale is controllable.
M-Alkalinity	As necessary to control scale
Silica	150 ppm as SiO_2 maximum (scale formation)
Iron	3 ppm maximum (staining and scale contributor)
Manganese	0.1 ppm maximum (staining and scale contributor)
Sulfides and Ammonia	Avoid copper or copper alloy components if sulfides or ammonia are present
Copper	0.1 ppm max (may cause pitting corrosion if deposits are present)
Chlorine/bromine	1 ppm free residual intermittent, or 0.4 ppm continuous; double these for bromine. Excess can attack sealants, accelerate corrosion, and embrittle PVC.
Organic solvents	These can attack plastics and promote bio-growth. Trace amounts may be acceptable, depending on the solvent.
TDS	No specific limit, provided scale and corrosion are controlled. See ion limits below.

Individual Ions:		MAXIMUM:
Cations:	**Calcium**	600 ppm as $CaCO_3$ (300 ppm in arid climate)
	Magnesium	Depends on pH and Silica level
	Sodium	No limit
Anions:	**Chlorides**	900 ppm as Cl for S300 series & 2400 ppm as Cl for S316 (corrosion at lower chloride levels occurs under deposits or in stagnant water)
	Sulfates	800 ppm as SO_4 preferred if calcium is also high ($CaSO_4$ scale)
	Nitrates	300 ppm as NO_3 (bacteria nutrient)

Tools - Water Use Calculator

Water Calculator

Click in one of the form fields below and change one of the Operating Conditions to match your scenario. Then **press your tab key** to see how your Water Usage data changes.

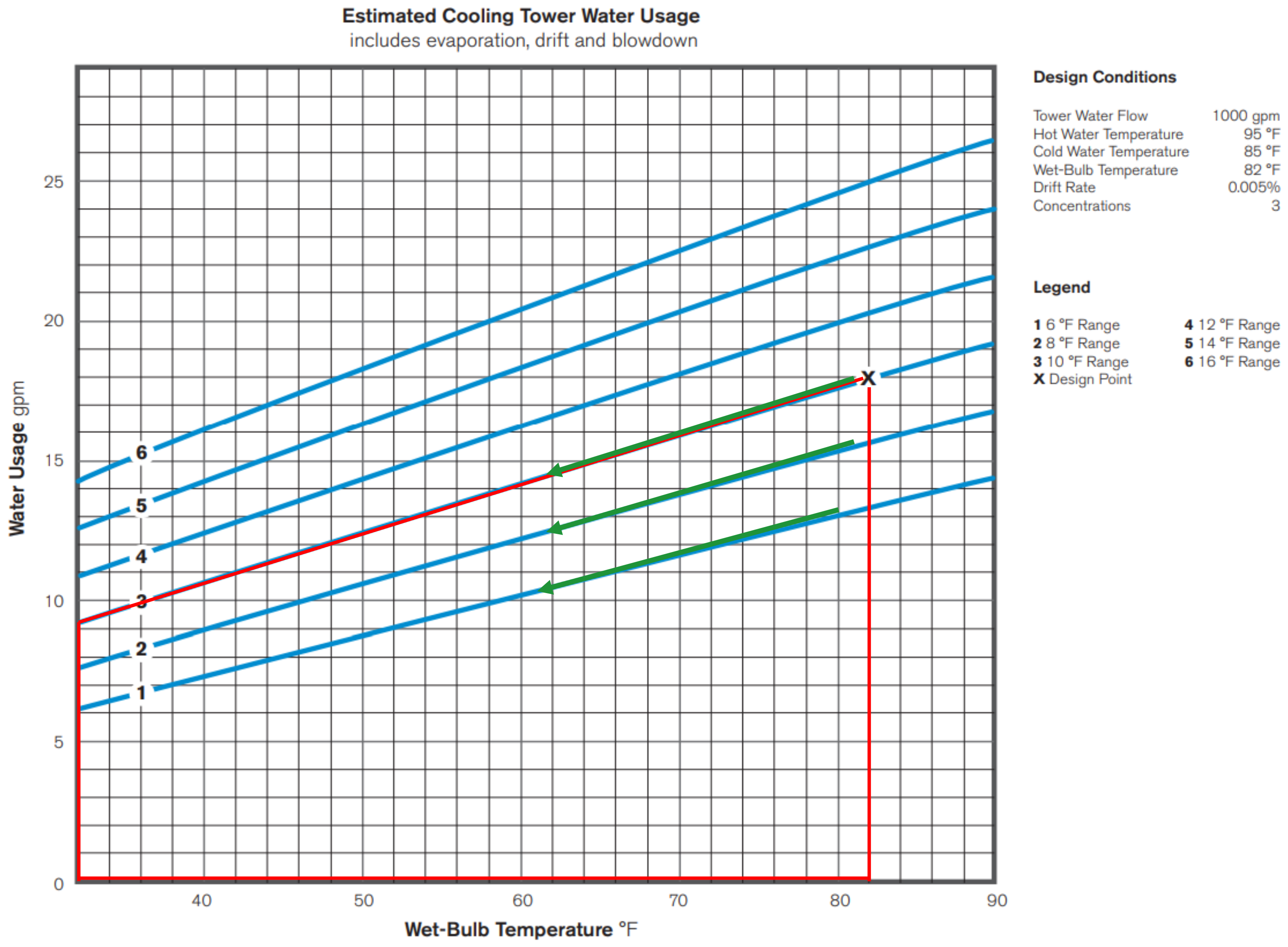
Operating Conditions

Tower Water Flow	1000	*gpm*	227	m^3/h
Hot Water Temperature	95.00	°F	35.00	°C
Cold Water Temperature	85.00	°F	29.44	°C
Wet-Bulb Temperature	78.00	°F	25.56	°C
Drift Rate	0.005	%		
Concentrations	3			

Water Usage

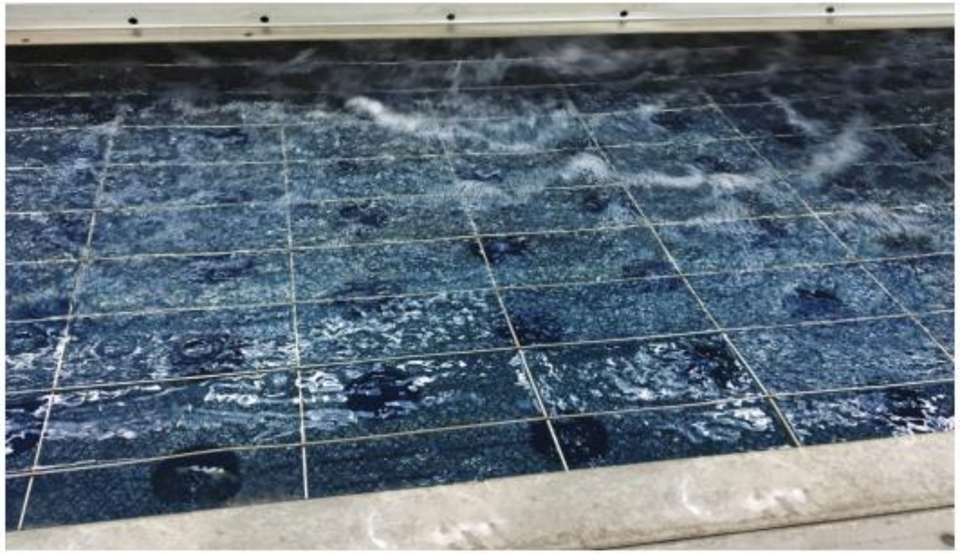
Evaporation	10.35	*gpm*	2.35	m^3/h
Drift	0.05	*gpm*	0.01	m^3/h

Tools - Water Use Calculator



Tower Options – Water Management Accessories

- Conductivity controllers
- Blowdown water valves and meters
- Makeup water valves and meters
- Water level controllers
- Basin filtration



Tower Options - Sweeper Piping

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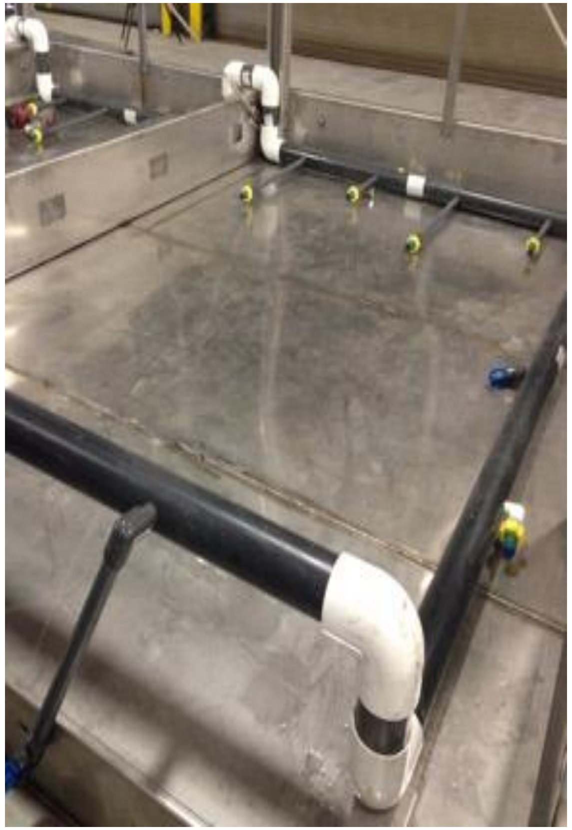
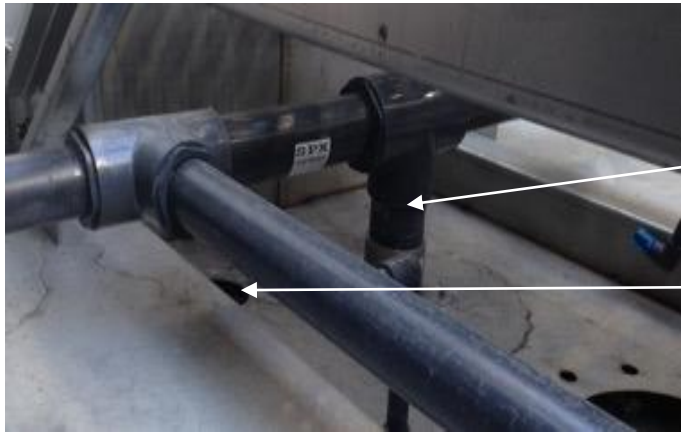


Counterflow Basin

Crossflow Basin

- Provides piping system in collection basin with nozzles to move debris and sediment from the basin
- Outlet is connected to centrifugal separator or filtration system



Sweeper Inlet

Sweep Outlet

Thank You.

Questions?

Additional content found at spxcooling.com

Mark.Pfeifer@spx.com – Technical Services

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Q&A

Please submit any questions through the Question Window on your GoToWebinar interface, directing them to Chiller & Cooling Best Practices Magazine. Our panelists will do their best to address your questions and will follow up with you on anything that goes unanswered during this session.

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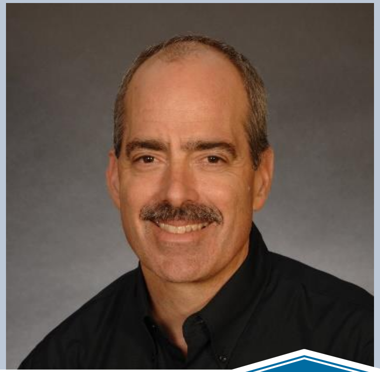

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