Managing Cooling Tower Cycles of Concentration

Nick McCall, P.E., Woodard & Curran

Keynote Speaker

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Managing Cooling Tower Cycles of Concentration

Introduction

Chiller & Cooling Best Practices® Magazine
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
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:

\[ C = \frac{M}{B} \]

\[ C = COC \]

\[ M = \text{makeup water flow rate} \]

\[ B = \text{blowdown flow rate} \]
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.)

\[
C = \frac{B_{\text{cond}}}{M_{\text{cond}}}
\]

\[
C = \text{COC}
\]

\[
B_{\text{cond}} = \text{blowdown conductivity}
\]

\[
M_{\text{cond}} = \text{makeup conductivity}
\]

- 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 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.

\[ C = \frac{110,000}{\sqrt{TA \times M_{Ca}}} \]

\[ C = COC \]

\[ TA = \text{Total alkalinity as CaCO}_3 \text{ in makeup in ppm} \]

\[ M_{Ca} = \text{Calcium hardness as CaCO}_3 \text{ in makeup in ppm} \]
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:

\[ C = \frac{(105 \times (9.8 - B_{pH}))}{M_{Ca}} \]

\[ C = COC \]

\[ B_{pH} = \text{blowdown pH} \]

\[ M_{Ca} = \text{Calcium hardness as CaCO}_3\text{ in makeup in ppm} \]
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:

\[ C = \sqrt{\frac{1,250,000}{M_{Ca} \times M_{Su}}} \]

\[ C = COC \]

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

\[ M_{Su} = \text{sulfate as } SO_4 \text{ in makeup in ppm} \]
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 SiO2 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 \( \text{CaCO}_3 \)
- \( TA \) = 155 ppm as \( \text{CaCO}_3 \)
- Phosphate = 3 ppm as \( \text{PO}_4 \)
- \( B_{pH} \) = 8.5
- \( M_{Su} \) = 165 ppm as \( \text{SO}_4 \)
- \( M_{Si} \) = 5 ppm as \( \text{SiO}_2 \)
Example

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

Nick McCall, PE
nmccall@woodardcurran.com
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)
Cycles of Concentration – A Manufacturers Perspective

May 20, 2021
1. Why Evaporative Cooling?
2. Why should I Maximize Cycles of Concentration?
3. Other water saving methods
4. How manufacturers can help
Agenda

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

Sensible (aka dry cooling)

- **Sensible Cooling** of 1 lb of water 1°F rejects 1 btu.
- Dry Bulb temperature is the driving force
- Hard to cool 95°F water with 95°F air
- Example: Car radiator

Latent (aka evaporative cooling)

- **Evaporating** that same 1 lb of water rejects 1,000 btu!
- 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
1. Why Evaporative Cooling?

2. Why should I Maximize Cycles of Concentration?

3. Other water saving methods

4. How manufacturers can help
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

Blowdown (gpm) vs. Cycles of Concentration
Water Quality – Scale
Agenda

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

**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)

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(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
### Fluid Cooler Products – Dry Capacity

<table>
<thead>
<tr>
<th>Fluid Cooler Type</th>
<th>First Cost</th>
<th>Dry Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid Crossflow</td>
<td>$$$</td>
<td>--</td>
</tr>
<tr>
<td>Hybrid Counterflow</td>
<td>$$</td>
<td>-</td>
</tr>
<tr>
<td>Bare Coil only Counterflow</td>
<td>$$</td>
<td>+</td>
</tr>
<tr>
<td>Finned Coil only Counterflow</td>
<td>$$$</td>
<td>++</td>
</tr>
<tr>
<td>Adiabatic Fluid Cooler</td>
<td>$$$$$</td>
<td>+++</td>
</tr>
</tbody>
</table>

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

![Legend](chart.png)
Agenda

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

<table>
<thead>
<tr>
<th>Operating Condition</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
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</thead>
<tbody>
<tr>
<td>Tower Water Flow</td>
<td>1000</td>
<td>gpm</td>
<td>227</td>
<td>m³/h</td>
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<tr>
<td>Hot Water Temperature</td>
<td>95.00</td>
<td>°F</td>
<td>20.09</td>
<td>°C</td>
</tr>
<tr>
<td>Cold Water Temperature</td>
<td>85.00</td>
<td>°F</td>
<td>29.44</td>
<td>°C</td>
</tr>
<tr>
<td>Wet-Bulb Temperature</td>
<td>78.00</td>
<td>°F</td>
<td>25.56</td>
<td>°C</td>
</tr>
<tr>
<td>Drift Rate</td>
<td>0.005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentrations</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Water Usage

<table>
<thead>
<tr>
<th>Type</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation</td>
<td>10.35</td>
<td>gpm</td>
<td>2.35</td>
<td>m³/h</td>
</tr>
<tr>
<td>Drift</td>
<td>0.05</td>
<td>gpm</td>
<td>0.01</td>
<td>m³/h</td>
</tr>
</tbody>
</table>
Tools - Water Use Calculator

Estimated Cooling Tower Water Usage
includes evaporation, drift and blowdown

Design Conditions
- Tower Water Flow: 1000 gpm
- Hot Water Temperature: 65 °F
- Cold Water Temperature: 80 °F
- Wet-Bulb Temperature: 82 °F
- Drift Rate: 0.0005%
- Concentrations: 3

Legend
- 1: 4°F Range
- 2: 8°F Range
- 3: 10°F Range
- 4: 12°F Range
- 5: 14°F Range
- 6: 16°F Range
- X: Design Point

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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

• 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
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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