Cooling and Heating

The use of cooling towers represents the largest use of water in industrial and commercial applications. Cooling towers remove heat from air conditioning systems and from a wide variety of industrial processes that generate excess heat. While all cooling towers continually cycle water in a closed loop, they still can consume 20 to 30 percent, or more, of a facility’s total water use. Optimizing operation and maintenance of cooling tower systems can offer facility managers significant savings in water consumption.
Cooling Tower Design

Warm water is recirculated continuously from a heat source, such as an air conditioning system or process equipment, to the cooling tower (see Figure 4-7). In most cooling tower systems, warm water (or water to be cooled) is pumped to the top of the tower where it is sprayed or dripped through internal fill. The fill creates a large surface area for a uniform thin film of water to be established throughout the tower. Fans pull or push air through the tower in a counterflow, crossflow or parallel flow to the falling water in the tower. Water is evaporated carrying away the heat. For most efficient cooling, the air and water must mix as completely as possible. Cooling is reduced when dew points are high.

Evaporation

Cooling occurs in a tower by the mechanisms of evaporative cooling and the exchange of sensible heat. The loss of heat by evaporation (approximately 1,000 British thermal units per pound of water) lowers the remaining water temperature. The smaller amount of cooling also occurs when the remaining water transfers heat (sensible heat) to the air.

The rate of evaporation is about one percent of the rate of flow of the recirculating water passing through the tower for every 10°F decrease in water temperature achieved by the tower. The decrease in water temperature will vary with the ambient dew point temperature. The lower the dew point, the greater the temperature difference between water flowing in and out of the tower. Another rule of thumb for estimating the rate of evaporation from a cooling tower is as follows: evaporation equals three gallons per minute per 100 “tons” of cooling load placed in the tower. The term “ton,” when used to describe cooling tower capacity, is equal to 12,000 Btu per hour of heat removed by the tower. When the dew point temperature is low, the tower air induction fans can be slowed by using a motor speed control or merely cycled on and off, saving both energy and water evaporation losses.
Blowdown

Blowdown is a term for water that is removed from the recirculating cooling water to reduce contaminant buildup in the tower water. As evaporation occurs, water contaminants, such as dissolved solids, build up in the water. By removing blowdown and adding fresh makeup water, the dissolved solids level in the water can be maintained to reduce mineral scale build-up and other contaminants in the tower, cooling condensers and process heat exchangers. Thermal efficiency, proper operation and life of the cooling tower are directly related to the quality of the recirculating water in the tower.

Water quality in the tower is dependent on make-up water quality, water treatment and blowdown rate. Optimization of blowdown, in conjunction with proper water treatment, represents the greatest opportunity for water efficiency improvement. Blowdown can be controlled manually or automatically by valves actuated by timers or conductivity meters.
**Drift Losses**

Drift is a loss of water from the cooling tower in the form of mist carried out of the tower by an air draft. A typical rate of drift is 0.05 to 0.2 percent of the total circulation rate. Reduction in drift through baffles or drift eliminators will conserve water, retain water treatment chemicals in the system, reduce “spotting” around the tower area and improve operating efficiency.

**Make-up Water**

Make-up water is water added to the cooling towers to replace evaporation, blowdown and drift losses. The amount of make-up water added directly affects the quality of water in the systems. The relationship between blowdown water quality and make-up water quality can be expressed as a “concentration ratio” or a “cycle of concentration.” This ratio is shown in Figure 4-8.

The most efficient use occurs when the concentration ratio increases and blowdown decreases.

**Water Balance**

A simple water balance on a cooling tower system can be determined if three of the four following parameters are known: make-up, evaporation, drift and blowdown. (See Figure 4-9 for a description of the cooling tower water balance.)

**Water Efficiency Options for Cooling Towers**

**Blowdown Optimization**

Water consumption of cooling towers can be reduced significantly by minimizing blowdown in coordination with an integrated operation and maintenance program. Blowdown is minimized when the concentration ratio increases. Historical concentration ratios are 2-to-3, and generally can be increased up to six or more with generic treatment options. Automation and 24-7 online monitoring can often allow cycles to be pushed to ten.

Some states have passed laws governing the quality level in a cooling tower as an attempt to promote efficient cooling tower water use.

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**FIGURE 4-10**

**Percent of Make-Up Water Saved**

<table>
<thead>
<tr>
<th>New Concentration Ratio (CR)</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Concentration Ratio (CR)</td>
<td>1.5</td>
<td>33%</td>
<td>44%</td>
<td>50%</td>
<td>53%</td>
<td>56%</td>
<td>58%</td>
<td>60%</td>
<td>61%</td>
<td>62%</td>
<td>63%</td>
</tr>
<tr>
<td>2</td>
<td>--</td>
<td>17%</td>
<td>25%</td>
<td>30%</td>
<td>33%</td>
<td>38%</td>
<td>40%</td>
<td>42%</td>
<td>43%</td>
<td>44%</td>
<td>45%</td>
</tr>
<tr>
<td>2.5</td>
<td>--</td>
<td>--</td>
<td>10%</td>
<td>16%</td>
<td>20%</td>
<td>25%</td>
<td>28%</td>
<td>30%</td>
<td>31%</td>
<td>33%</td>
<td>34%</td>
</tr>
<tr>
<td>3</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>7%</td>
<td>11%</td>
<td>17%</td>
<td>20%</td>
<td>22%</td>
<td>24%</td>
<td>25%</td>
<td>26%</td>
</tr>
<tr>
<td>3.5</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>5%</td>
<td>11%</td>
<td>14%</td>
<td>17%</td>
<td>18%</td>
<td>20%</td>
<td>21%</td>
</tr>
<tr>
<td>4</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>6%</td>
<td>10%</td>
<td>13%</td>
<td>14%</td>
<td>16%</td>
<td>17%</td>
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<tr>
<td>5</td>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>4%</td>
<td>7%</td>
<td>9%</td>
<td>10%</td>
<td>11%</td>
</tr>
<tr>
<td>6</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>3%</td>
<td>5%</td>
<td>6%</td>
<td>7%</td>
</tr>
</tbody>
</table>
The volume of water saved by increasing the cycles of concentration can be determined by this equation:

\[ V = M_i \times \frac{CR_i - CR_f}{(CR_f)(CR_f - 1)} \]

- **V** = volume of water conserved
- **M_i** = initial make-up water volume (before modification)
- **CR_i** = concentration ratio before increasing cycle
- **CR_f** = concentration ratio after increasing cycles

For example, increasing concentration ratio from two to six will save 40 percent of the initial make-up water volume. Figure 4-10 allows users to easily estimate potential water savings.

The maximum concentration ratio at which a cooling tower can still properly operate will depend on the make-up water quality, such as pH, TDS, alkalinity, conductivity, hardness and microorganism levels. The use and sensitivity of a cooling system will also control how much blowdown can be reduced. Scale, corrosion, fouling and microbial growth are four critical parameters that must be controlled in cooling towers. Minimum blowdown rates must be determined in tandem with the optimum water treatment program for the cooling tower.

### Controlling Blowdown

To better control the blowdown and concentration ratio, facilities can install submeters on the make-up water feed line and the blowdown line. Submetering allows operators to carefully control water use. In some areas, evaporative water loss, as determined by

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**Practical Guidance for Working With a Service Contractor**

- Work closely with your chemical vendor or contracted service provider to reduce blowdown. Because reducing blowdown also reduces chemical purchasing requirements, facility personnel must keenly set up performance-based service contracts.
- Require vendors to commit to a predetermined minimum level of water efficiency. Have them provide an estimate of projected annual water and chemical consumption and costs.
- Tell your vendor that water efficiency is a priority, and ask about alternative treatment programs that will help reduce blowdown.

When purchasing chemicals for treating cooling tower water, have the chemical vendor explain the purpose and action of each chemical. Your vendor should provide a written report of each service call. Be sure the vendor explains the meaning of each analysis performed, as well as the test results.
CASE STUDY

Cooling Tower Reduces Usage
Chem-tex laboratories in Concord installed two new tanks, pumps and a small cooling tower to cool and recycle water that was formerly sent to the city of Concord wastewater treatment plant after one use. The small cooling tower and tank system cost less than $15,000 and reduced water usage by approximately 60 percent (~20,000 gallons per day), and also reduced the plant’s wastewater effluent sent to the city’s treatment plant by about 85 percent. Total cost savings are between $35,000 and $40,000 per year.

submetering and water balances, can be subtracted from local sewer charges. Submeters can be installed on most cooling towers for less than $1,000.

Recirculating water systems are blown down when the conductivity of the water reaches a preset level. Blowdown can be done manually or automatically. Automation generally allows for higher cycles. Typically, towers are blown down in a “batch” process, releasing water to lower the tower volume until the make-up turns on and begins to reduce the concentration in the tower. Once tower levels are replenished the cycle repeats. This produces a saw tooth pattern. If the mechanicals and tower load allow it to be done, proportional or continuous make-up and blowdown systems can reduce the saw tooth and increase overall cycles.

Recovering Sewer Charges
Because all cooling towers lose significant quantities of water through evaporation, some wastewater utilities allow these evaporative losses to be subtracted from utility bills. The utilities that allow this billing adjustment typically will require that a submeter be installed on the make-up water line to the cooling tower(s). Some system of reading this submeter monthly and requesting a reimbursement can be established where allowed. Submeters can be installed on most cooling towers for less than $1,000.

Cooling Tower Water Treatment
Almost all well-managed cooling towers use a water treatment program. The goal of a water treatment program is to maintain a clean heat transfer surface and preserve capital while minimizing water consumption and meeting discharge limits. Critical water chemistry parameters that require review and control include pH, alkalinity, conductivity, hardness, microbial growth, biocide and corrosion inhibitor levels.

Depending on the quality of the make-up water, treatment programs may include corrosion and scaling inhibitors, such as organophosphate types, along with biological fouling inhibitors. Historically, chemicals have been fed into the system by automatic feeders on timers or actuated by conductivity meters. Automatic chemical feeding tends to decrease chemical dosing requirements. Current technology allows chemicals to be monitored and controlled online 24-7 in proportion to demand. This ensures results and can allow cycles to be increased. Where overfeed is prevalent, it can reduce chemical feed, too.

Sulfuric “Acid” Treatment
Sulfuric acid can be used in cooling tower water to help control scale buildup. When properly applied, sulfuric acid will lower the water’s pH and help convert the calcium bicarbonate scale to a more soluble calcium sulfate form. In central North Carolina, most plants will be able to operate six to 10 cycles
of concentration without acid feed. Along our coasts, acid can be used to increase cycles as water tends to be harder and higher in alkalinity. The same can be said if hard alkaline well water is used as tower make-up.

Important precautions need to be taken when using sulfuric acid treatment. Because sulfuric acid is an aggressive acid that will corrode metal, it must be carefully dosed into the system and must be used in conjunction with an appropriate corrosion inhibitor. Workers handling sulfuric acid must exercise caution to prevent contact with eyes or skin. All personnel should receive training on proper handling, management and accident response for sulfuric acid used at the facility.

### CASE STUDY

**Reverse Osmosis Water Use**

A pharmaceutical company in Clayton substantially reduced city water consumption for cooling towers by reusing the “reject” stream from its reverse osmosis water treatment process. By reusing the RO “reject” water to replace cooling tower evaporative losses, the company is saving 10 million gallons of water per year.

#### FIGURE 4-11

### Summary of Cooling Tower Water Efficiency and Treatment Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation improvements to</td>
<td>Low capital costs</td>
<td>None</td>
</tr>
<tr>
<td>control blowdown and</td>
<td>Low operating costs</td>
<td></td>
</tr>
<tr>
<td>chemical additions</td>
<td>Low maintenance requirements</td>
<td></td>
</tr>
<tr>
<td>Sulfuric acid treatment</td>
<td>Low capital cost</td>
<td>Potential safety hazard</td>
</tr>
<tr>
<td></td>
<td>Low operating cost</td>
<td>Potential for corrosion damage if overdosed</td>
</tr>
<tr>
<td></td>
<td>Increased concentration ratio, when alkalinity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>limited</td>
<td></td>
</tr>
<tr>
<td>Side stream filtration</td>
<td>Low possibility of fouling</td>
<td>Moderately high capital cost</td>
</tr>
<tr>
<td></td>
<td>Improve operation efficiency</td>
<td>No effectiveness on dissolved solids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Additional maintenance</td>
</tr>
<tr>
<td>Ozonation</td>
<td>Reduced chance for organic fouling</td>
<td>High capital investment</td>
</tr>
<tr>
<td></td>
<td>Reduced liquid chemical requirements</td>
<td>Complex system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Possible health issue</td>
</tr>
<tr>
<td>Magnet System</td>
<td>Reduced or eliminated</td>
<td>Novel technology</td>
</tr>
<tr>
<td>Reuse of water within the</td>
<td>Reduced overall facility water consumption</td>
<td>Controversial performance claims</td>
</tr>
<tr>
<td>facility</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Potential for increased fouling,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>scale or corrosion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Possible need for additional water treatment</td>
<td></td>
</tr>
</tbody>
</table>
Side Stream Filtration

In cooling towers that use make-up water with high suspended solids, or in cases where airborne contaminants such as dust can enter cooling tower water, side stream filtration can be used to reduce solids build-up in the system. Typically, five to 20 percent of the circulating flow can be filtered using a rapid sand filter or a cartridge filter system.

Rapid sand filters can remove solids as small as 15 microns in diameter while cartridges are effective to remove solids to 10 microns or less. High efficiency filters can remove particles down to 0.5 microns. Neither of these filters are effective at removing dissolved solids, but can remove mobile mineral scale precipitants and other solid contaminants in the water. The advantages of side stream filtration systems are reduced particle loading on the tower. This ensures heat transfer efficiency and may reduce biocide or dispersant demands.

Ozone

Ozone can be a very effective agent to treat nuisance organics in the cooling water. Ozone treatment also is reported to control the scale by forming mineral oxides that will precipitate out to the water in the form of sludge. This sludge collects on the cooling tower basin, in a separation tank or other low-flow areas. Ozone treatment consists of an air compressor, an ozone generator, a diffuser or contactor and a control system. The initial capital costs of such systems are high but have been reported to provide payback in 18 months.

Magnets

Some vendors offer special water-treating magnets that are reported to alter the surface charge of suspended particles in cooling tower water. The particles help disrupt and break loose deposits on surfaces in the cooling tower system. The particles settle in a low-velocity area of the cooling tower – such as sumps – where they can be mechanically removed. Suppliers of these magnetic treatment systems claim that magnets will remove scale without conventional chemicals. Also, a similar novel treatment technology, called an electrostatic field generator, is also reported.

Alternative Sources of Make-Up Water

Some facilities may have an opportunity to reuse water from another process for cooling make-up water. Clean internal wastewater streams such as reverse osmosis (hypermuration) reject water is suitable for in-process reuse. In some cases treated in-process effluent can be used as cooling tower make-up if the concentration ratio is maintained conservatively low. Similarly, blowdown streams may be suitable for use as in-process water in some applications.

North Carolina’s Environmental Management Commission rules allow the use of reclaimed water, or tertiary treated municipal wastewater, for cooling tower make-up water (see p. 67). In reuse and reclaimed water applications for cooling towers, water quality and system dynamics must be fully understood. Factors such as mechanical design, metallurgy, water chemistry and fluid flow dynamics must be considered.

CASE STUDY

Eliminating Once-Through Cooling

A small medical equipment manufacturer in Arden was using a continuous tap water flow of 12 gpm to cool a 20-horsepower vacuum pump. After a water efficiency audit, the company installed a chiller water recirculating system. The company is now saving 6.6 million gallons of water per year, an estimated $30,500 annual savings in water and sewer costs.
**Eliminate Once-Through Cooling**

Many facilities use “once-through” water to cool small heat-generating equipment. Once-through cooling is a very wasteful practice because water is used only one time before being sent to the sewer system. Typical equipment that may be using once-through cooling includes: vacuum pumps, air compressors, condensers, hydraulic equipment, rectifiers, degreasers, X-ray processors, welders and sometimes even air conditioners. Some areas of the country prohibit the use of once-through cooling practices. Options to eliminate once-through cooling are typically very cost effective. They include:

- Connect equipment to an existing recirculating cooling system. Installation of a chiller or cooling tower is usually an economical alternative. Sometimes excess cooling capacity already exists within the plant that can be utilized.

<table>
<thead>
<tr>
<th>Ideas to Reduce Potable Make-up to a Cooling Tower</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Catch air handler condensation and route it to the tower, be sure to check for bio compatibility</td>
</tr>
<tr>
<td>- Catch rinse waters from processes such as softeners, demineralizers, etc. and route as tower make-up</td>
</tr>
<tr>
<td>- Catch rain water, filter and test appropriately to feed tower</td>
</tr>
<tr>
<td>- Consider advance recycle techniques such as ultrafiltration</td>
</tr>
<tr>
<td>- Consider other water reuse sources and quality, such as centrifuge blow-down</td>
</tr>
<tr>
<td>- Ensure the tower is set up to minimize or eliminate overflow during intermittent operation when headers may drain to the sump</td>
</tr>
</tbody>
</table>

**CASE STUDY**

**Tertiary Treated Reclaim Water**

A Triangle-area comfort cooling plant has been using tertiary treated reclaim water for cooling tower make-up for more than five years. Careful monitoring of biogrowth, corrosion rates and system efficiency ensure long-term success.

- Consider replacing water-cooled equipment with air-cooled equipment. One example is switching from a water-cooled to an air-cooled ice making machine. This must be balanced against energy costs.

**CASE STUDY**

**Condensate Water Reuse in Towers**

The Fulton County Health Center in Wauseon, Ohio, is capturing HVAC condensate water and reusing this high quality water in its cooling towers. The 280,000 sq. ft. hospital complex is reusing more than 353,000 gallons per year of condensate water. The condensate water has several positive characteristics for reuse that include 1) being cold (around 45°F), 2) not requiring any treatment (i.e., very clean with low solids), 3) has a pH of 8.2, and 4) increases in flow as cooling tower demand increased. The water was able to be gravity fed to towers systems and total project cost was less than $1,500.
Steps to Evaluate Streams to Reduce Potable Make-up to a Tower

- Analyze the sample
- Model the water against the application
- Balance the results vs. the investment to make it work
- If the cost is large, test the results in a pilot application

CASE STUDY

Instantaneous Hot Water System

Smithfield Packing Corporation in Wilson significantly reduced water usage while still experiencing an increase in production. The facility installed an instantaneous hot water system which allows the facility to decommission its boilers, saving approximately 11,000 gallons of water per production day; equal to an 8.9% reduction in usage and a cost avoidance of approximately $8,000 per year. The facility has also decreased natural gas usage by 6,269 MCF, resulting in an approximate cost avoidance of $85,550 per year and reduced annual greenhouse gas emissions by 720 tons. Total cost avoided by this project is approximately $93,550 per year.
CASE STUDY

Condensate Used for Irrigation

The Ford Foundation uses water from steam condensation; condensate off cooling coils and roof drains to supply cooling towers and provide garden irrigation. Rain runoff flows into 3,000 and 13,000 gallon tanks. The 3,000 gallon tank is used for watering plants and trees in the building’s atrium, using about 900 gallons a week. This tank is easily replenished from the cooling condensate and/or rainwater within one day of use. The 13,000 gallon tank is used for the cooling towers. Warmer summers requiring more work of the cooling towers to maintain the building temperature create more condensation, thus more water for the tanks. When the tanks get low, the foundation uses water from the New York water system. The foundation receives a utility credit from the city for this water, because it is evaporated, rather than sent into the sewer system.