COOLING TOWERS, PART 1: Siting, Selecting and Sizing

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An evaporative cooling tower can be an effective way to reject process heat. Here's a guide to some of the early design decisions.

Chemical manufacturing, petroleum refining, power generation, and various other industrial activities require large amounts of indirect cooling, typically by either air or water. Evaporative cooling towers achieve significantly lower water temperatures than air-cooled or closed-circuit cooling towers. Most process cooling towers are recirculating evaporative systems, in that they cool and reuse the heated water. A small percentage of process cooling towers are once-through systems that discharge heated water to a watershed or wastewater treatment facility.

An open, evaporative cooling tower distributes hot return water from the process downward through nozzles into labyrinth-like packing, or "fill." The fill may consist of multiple, mainly vertical, wetted surfaces upon which a thin film of water spreads (known as film fill), or several levels of flat horizontal slats that create a cascade of many small droplets with a large total surface area (splash fill).

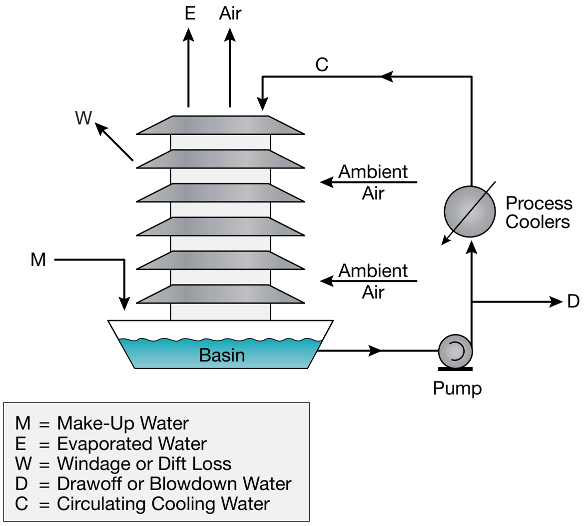
Nozzles evenly distribute the water into the fill, which disperses the water into small droplets, increasing the surface area for heat transfer from the water droplet to the surrounding air. A portion of the water evaporates, removing additional heat from the water stream. The cooled water accumulates in a basin below the fill and exits the tower through pumps.

As the water evaporates, the concentration of dissolved contaminants in the cooling water increases. A small stream of concentrated cooling water, known as blowdown or draw-off, is discharged to the drain to balance these dissolved solids. The blowdown water is then replaced with relatively fresh water that has lower concentrations of dissolved contaminants (make-up). This dilution prevents the formation of high concentrations of dissolved contaminants that would precipitate onto heat-transfer surfaces and reduce thermal efficiency. Baffles minimize uncontrolled water loss known as windage or drift that occurs when the airflow traps small droplets of cooling water. Water loss may also occur through splashing, misting, or the escape of water out the air inlet opening.

Figure 1 illustrates the mass balance given by:

$$M = E + W + D + L \qquad (1)$$

where M is make-up water, E is evaporated water, W is windage or drift loss, D is drawoff or blowdown water, and L is leakage.



▲ **Figure 1.** In an evaporative cooling water system, fresh make-up water replaces water lost to evaporation and windage.

The water-saturated air exiting the top of the cooling tower forms a plume that is visible when the water vapor it contains condenses upon contact with cooler ambient air. Under certain conditions, a cooling tower plume may present fogging or icing hazards in the drift eliminators and in the surrounding area.

A closed-circuit cooling tower uses air or a combination of air and water for cooling. The process fluid circulates through tubes and is cooled by forced air blown across the tubes. Some towers spray water on the outside of the tubes for additional heat transfer via evaporation; this water remains in the cooling tower, circulating between the basin and the spray nozzles.

Cooling towers may have a natural-draft or mechanical-draft system. In the common hyperbolic natural-draft cooling tower, buoyancy causes the air to rise through the tower's tall chimney and exhaust to the atmosphere. Natural-draft cooling towers operate most efficiently in climates with high humidity. In climates with lower humidity, designers may choose a fan-assisted natural-draft cooling tower to augment the buoyancy effect.

Mechanical-draft cooling towers have two primary designs: crossflow, in which the air moves horizontally and the water flows downward (Figure 2), and counterflow, in which the air and water travel in opposite directions (Figure 3).

Siting

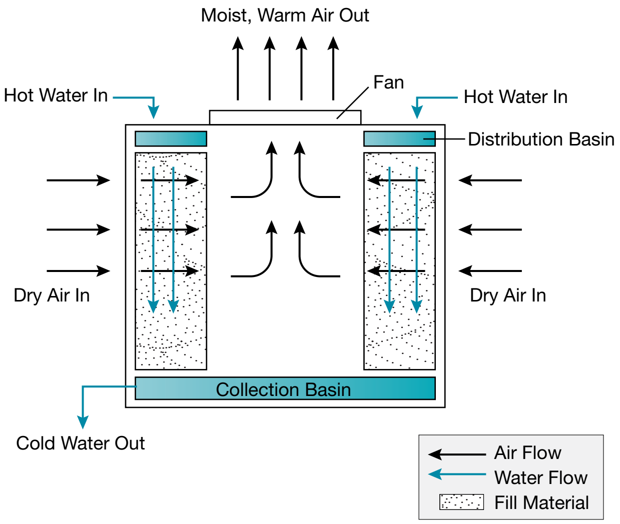
Most process cooling towers are large and require construction in the field. Project managers have more discretion when selecting a site for a new tower than for a replacement tower, although there are some limitations. Replacement towers are typically placed on the previous tower's site to allow reuse of foundations and minimize the impact to existing infrastructure, such as piping and electrical supply.

Siting decisions may depend on tower design: a crossflow tower requires a larger clearance around adjacent structures than a counterflow tower due to the inlet airflow requirements. Hyperbolic cooling towers are extremely large and require clearances similar to crossflow towers.

The tower orientation should match the direction of the prevailing winds to optimize the airflow into the tower. The location of a new tower should not be within the drift zone of an existing tower or in an area that would allow recirculation of the plume of an adjacent tower or other hot exhaust gases.

Designers should model the drift zone to assess the impact on the areas adjacent to the cooling tower. Drift is of particular concern because industrial cooling towers have been identified as sources of *Legionella pneumophila* — the bacterium that can cause legionellosis (Legionnaire's disease). Common in natural waters, *Legionella* bacteria, under certain conditions, may proliferate in the cooling water and be present in the drift of evaporative and spray cooling towers. Individuals with compromised immune systems are vulnerable to infection should they breathe air containing entrained contaminated water droplets.

The Cooling Technology Institute (CTI) has issued a guideline (www.cti.org/cgi-bin/download.pl) for reducing *Legionella* in cooling water systems, and is preparing a more-comprehensive set of recommendations that will constitute a new standard. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is also preparing a standard for reducing *Legionella* in building water systems, SPC 188. The ASHRAE standards committee has not made a final decision about the scope of the standard



▲ **Figure 2.** In a crossflow cooling tower, air moves horizontally through the fill as the water flows downward.

with respect to the inclusion of process cooling towers. (For more on *Legionella* and cooling towers, see "*Legionella:* An Invisible Risk," *CEP*, Apr. 2008, pp. 6–10.)

Selection

Selection of a cooling tower design depends on the quality of the make-up water, the fouling potential of the cooling water, heat load, site-specific limitations, previous operating and reliability experience, and cost. Critical design decisions include natural vs. forced or mechanical draft, film vs. splash fill, and crossflow vs. counterflow configuration. Critical components include fans, fan shrouds, fan drive motors, fill, drift eliminators, air louvers, and nozzles. Selection of materials of construction depends on the tower size, make-up water quality, and suitability for service. Most process cooling towers use steel and pressure-treated lumber, with stainless steel fan blades and drive shaft couplings. Small packaged cooling towers may use galvanized, fiberglass-reinforced plastic, or stainless steel components.

Some rules of thumb include:

- Towers serving cooling water circuits that are vulnerable to process intrusion should not use film fill due to the risk of fouling and fill failure.
- Facilities such as power plants that have very high heat loads require high recirculating water flowrates, and large cooling loads often use natural-draft towers with hyperbolic concrete shells.
- Sites with nearby obstructions or where there is a risk that the tower plume or combustion exhaust may be entrained should choose a counterflow configuration, and may require special air-intake designs.
- Variable-frequency fan drives increase capital costs and provide operating flexibility for cooling towers with more than two cells.

A recent CTI paper (*1*) provides additional information regarding design and procurement decisions for industrial cooling towers.

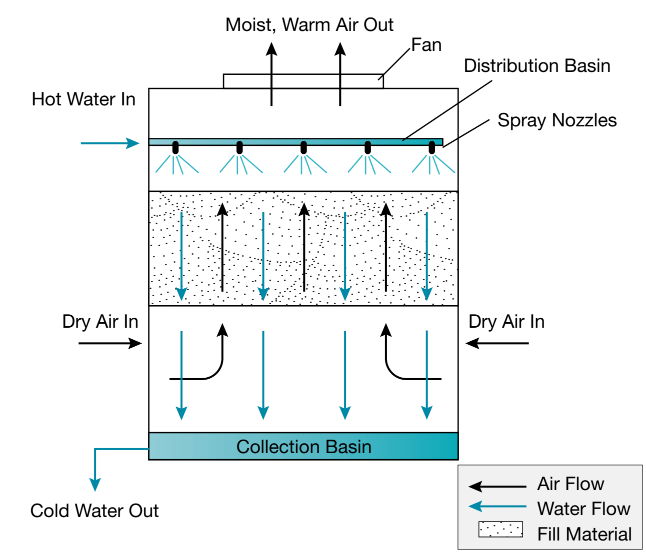
Sizing

The size of a cooling tower should match the cooling load — an oversized tower increases costs without providing additional measureable benefits. Sizing a tower requires an accurate assessment of the cooling load and the atmospheric conditions. Equations 2 and 3 are two ways to calculate the cooling load, *Q*. Engineers use both equations, depending on the availability of data.

$$Q = U \times A \times \Delta T \quad (2)$$

$$Q = PF \times SH \times \Delta T \quad (3)$$

where *Q* is the total heat flow, Btu/h; *A* is the area of the heat-transfer surface, ft^2 or m^2; *U* is the heat-transfer coefficient, Btu/h-ft^2-ºF or J/h-m^2; *T* is the log mean temperature difference between the two streams, °F or K; *PF* is the



▲ **Figure 3.** In a counterflow cooling tower, air travels upward through the fill, opposite the downward path of the water.

process flowrate, lb/h or kg/h; and *SH* is the specific heat of the process Btu/lb/°F or J/g-K.

Critical sizing parameters include the circulating water flowrate, the return (hot) water temperature, the required supply (cold) water temperature, wet-bulb temperature, and, sometimes, relative humidity. Cooling towers that use seawater or brackish waters must be approximately 5% larger than an equivalent freshwater system because seawater and brackish water have lower heat capacities than freshwater.

Equipment suppliers define process cooling towers by approach temperature and circulating water flowrate. Process cooling towers may be rated in Btu (British thermal units) or tons of cooling capacity. Note that the conversion factor for rated tons is different for process and comfort (*i.e.*, heating and air conditioning) applications. Cooling towers rated for comfort systems use a 15,000-Btu/ton conversion factor to account for the additional cooling capacity needed to match a chiller, whereas cooling towers rated for process systems use a 12,000-Btu/ton conversion factor. Designers should confirm the manufacturer's basis for rating small cooling towers.

Thermal performance testing

Plant personnel can confirm that a new tower meets the thermal performance specification by requiring CTI certification, which indicates that the tower has been tested under operating conditions and found to perform as rated by the manufacturer under those circumstances. It assures the buyer that the tower is not intentionally or inadvertently undersized by the manufacturer. CTI currently certifies 24 lines of cooling towers; 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.

However, CTI certification is not sufficient to assure you that the tower will perform satisfactorily in your situation. Certification is established under relatively controlled conditions, and actual operating conditions may be different due to the presence of nearby structures, machinery or enclosures, or the recirculation of effluent from other towers. Experienced suppliers will account for these site-specific effects in the tower design, but the buyer must obtain written confirmation that the cooling tower supplier will guarantee this real-world performance.

An independent testing company can confirm the thermal performance of an existing cooling tower. Such testing should be done in accordance with Acceptance Test Code 105 (ATC-105) published by CTI, or the Performance Test Code 23 (PTC-23) published by the American Society of Mechanical Engineers (ASME). CTI currently licenses four firms to conduct thermal performance tests on cooling towers (sidebar).

Conducting a thermal performance test on an existing cooling tower requires a significant amount of preparation: basic housekeeping, balancing the flows, confirming the availability of the required data and the accuracy of the instrumentation, and other adjustments to optimize performance. The actual test requires two to five days to gather data, followed by compilation of data, analysis and interpretation. Despite the effort and expense involved, industry experts recommend thermal performance testing to validate the performance guarantee for a new tower or to confirm the proper completion of tower rehabilitation or expansion.

A follow-up article that discusses the basics of operation, maintenance and monitoring of a process cooling tower is scheduled to appear in the November issue. CEP

Thermal Testing Agencies Licensed by the Cooling Technology Institute

These firms are licensed by CTI to conduct thermal performance tests on cooling towers:

- **Clean Air Engineering,** Powell, TN, www.cleanair.com
- **Cooling Tower Technologies Pty Ltd.,** Bexley North, New South Wales, Australia, coolingtwrtech@bigpond.com
- **Cooling Tower Test Associates, Inc.,** Stanley, KS, www.cttai.com
- **McHale & Associates, Inc.,** Knoxville, TN, www.mchale.org

Source. http://www.cti.org/licensedb.shtml

Literature Cited

1. **Willa, J. L.,** "Common Industrial Cooling Tower Errors and Omissions," Paper No. TP09-02, presented at the 2009 Cooling Technology Institute Conference, San Antonio, TX, www.cti.org, (Feb. 8–11, 2009).

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