

Cooling Options Change for a Hot, Thirsty Industry

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The power industry's impact on freshwater resources cannot be denied. Power generation in the US uses 132,000-million gal/ day of freshwater -- about 39% of the country's total freshwater usage.

Approximately 98% of this water is for once-through cooling, and therefore is returned immediately to its source. The once-through system's higher return temperatures and the intakes' effect on aquatic species, however, has drawn increasing scrutiny from the public and spurred new regulations. The other 2% of the industry's freshwater usage, approximately 3300-million gal/day, is consumptive. A majority of this amount is guzzled by evaporative cooling systems (Fig 1).

More than ever, water issues are driving the power industry's cooling-technology options: once-through vs recirculating, wet vs dry, freshwater vs lower quality reclaimed water.

Modifying once-throughs When the Clean Water Act was passed in 1972, Section 316(b) required the use of the "best available technology" to minimize the aquatic impact of cooling water intake structures in once-through cooling systems. Eighteen years later, in November 2000, the US Environmental Protection Agency (EPA) signed an Amended Consent Decree with an environmental group that requires the agency to actually define "best available technology," and sets specific guidelines on acceptable once-through cooling technologies. Key concerns are the impingement and entrainment of fish, eggs, and larvae on traveling screens and the damage done to aquatic species as the water is heated in a powerplant condenser.

Phase I of the new regulations, finalized in November 2001, is focused on new power projects. The EPA estimates that Phase I will affect 121 facilities scheduled to be built over the next 20 years. The agency currently is working on Phase II of the new regulations, which will affect approximately 550 existing powerplants and cost an estimated \$ 182-million/yr to implement. The proposed Phase II regulation was published in April for public comment. Final action for Phase II is scheduled for the end of August 2003.

Phase III of the new regulations will include essentially all remaining US powerplants that use once-through cooling. A proposed Phase III regulation is scheduled to be published in June 2003, with final action to be taken by December 2004.

In their legal actions, environmental groups pushed the EPA to require dry cooling on all new facilities, but the agency opted to establish a variety of acceptable technologies based on the environmental sensitivity of the proposed cooling-water source. Estuaries and tidal rivers are deemed the most sensitive.

Boom in booms. To comply with the regulation for new facilities, plants designed with once-through cooling can reduce the intake velocity to less than 0.5 ft/sec, reduce the amount of water removed from the source, or put up a variety of screens and booms that prevent aquatic species from entering the cooling system. For instance, Mirant Co's (Atlanta, Ga) proposed Bowline project in New York will use aquatic filter barrier technology supplied by Gunderboom Inc, Anchorage, Ala.

In March, the New York State Dept of Environmental Conservation approved the use of hybrid cooling combined with wedge wire screens and a Gunderboom Marine Life Exclusion System as the "best technology available" for minimizing adverse environmental impacts at Bowline Pond. By creating a permeable barrier between cooling water intake structures and the open water, the Gunderboom system keeps aquatic life from being pinned against or pulled into the structures.

The Bowline plant will be the second facility to use the Gunderboom system to comply with the new Clean Water Act regulations. In February, New York State regulatory officials approved the system for the Bethlehem Energy Center project.

Note that rulings regarding these new definitions of "best technology available" are under scrutiny, and legal challenges to some have already been filed by environmental groups. Regardless of the courtroom outcomes, it's clear that fewer and fewer new projects will use once-through cooling, and existing once-through-cooled plants will have to modify their systems to meet tougher regulations.

Wet or dry As once-through cooling becomes less viable, the design decision moves to a choice of wet recirculating systems (cooling towers) vs dry technologies (air-cooled condensers). Each of these options provides effective cooling, but designers and operators must understand the pros and cons.

Cooling towers consume a large amount of freshwater, and present the question of what to do with the concentrated cooling-tower blowdown. Many plants now have a zero-liquid discharge requirement, meaning that every gallon of cooling tower blowdown has to be used or evaporated on site. Other disadvantages of cooling towers are the moisture plumes (the "drift") they emit, and their propensity for biofouling -- which must be controlled through complex water treatment systems. Health and safety concerns present more disadvantages to cooling towers -- storage and handling of acid for pH adjustment, potential for Legionella, etc.

Air-cooled condensers (ACCs), in contrast, use little water, generate no plume, and create no blowdown requirements. They are seen by local communities and environmental groups as the favorable alternative to wet cooling, so a specification for anything else can hinder the permitting and construction of a new powerplant. But dry cooling has its drawbacks too, predominately: higher capital cost, higher power consumption, and potential negative impact on turbine performance. To understand why, remember a few principles from your days in a heat-transfer course. Both once-through wet cooling and ACC systems rely on sensible heat transfer, or the direct heating of

water or air from ambient to the temperature of the steam in the condenser. Both of these technologies therefore are at the mercy of the temperature of the inlet water or air to produce the requisite heat transfer.

A recirculating tower, on the other hand, also uses the latent heat of water (evaporation) in the tower to achieve significantly more cooling than sensible heat alone could provide. Between 65 and 85% of the heat removal in cooling tower is because of evaporation. Dry cooling also is limited by lower heat-transfer rates between the condenser tubes and air -- compared to the heat-transfer rates between the condenser tubes and water. This makes the area required for a dry cooling system much larger than the commensurate footprint for a recirculating system.

A study conducted by Wayne C Micheletti Inc, Charlottesville, Va, compared the cost of wet vs dry cooling for a 250-MW combined-cycle plant. The study analyzed capital cost and operating expenses, including the energy penalty for the reduced performance of dry cooling towers during the summer when high dry-bulb temperatures increase the turbine backpressure. Since the cooling performance is different in different parts of the country, costs at five locations were determined. On average, capital cost for dry cooling was 140% higher than for wet; operating expenses were 94% higher (see table).

Proponents of dry cooling point out that, because of the additional capital cost, dry cooling systems tend to be designed with less tolerance for those "hottest day on record" events. However, if the decision to have dry cooling is known up-front and actively addressed, turbine designs can be selected that are more tolerant of high backpressure -- thus energy penalties can be reduced.

Fill 'er up If the wet vs dry question is settled in favor of wet cooling, economics continue to drive the next design decision: type of cooling-tower fill. The fill-selection process was simpler years ago, when the choice was either "splash" type for plants with low-quality makeup water, or "film" type, for plants with clean makeup water. Film fills offered higher heat-transfer efficiencies, but their cross-corrugated surfaces were more likely to foul. Today, a wide array of film-fill products must be evaluated for each specific powerplant in order to select one that will provide the best heat-transfer efficiency without incurring unacceptable fouling problems.

The design choices were analyzed extensively in a paper recently published by the Cooling Technology Institute, Houston, Tex: "Low-Clog Film Fill -- New Approaches" (see box). Authors Ken Mortensen and Steve Conley of Marley Cooling Technologies, Overland Park, Kan, studied fill designs and their fouling characteristics for various products marketed as either "low-clog" or "clog-resistant." The laboratory tests evaluated such differences as sheet texturing, tube shape, and the use of overlays (a section of high-efficiency, cross-corrugated fill, typically 1 ft in depth, laid on top of a proven "log-clog" fill). Among the authors conclusions:

-- Overlays should be used with caution, and specifically tested with their low-clog base.

-- Texturing should be used with caution, because it increased fouling under all conditions tested.

-- How manufacturers account for bottom support blockage must be carefully considered. Vertical-tube fills are substantially impaired by supports and require large area deductions for structure.

Hitting the sand traps More efficient types of film fill can be specified if the cooling water is filtered, and more filtration systems these days use sand. Another paper published by the Cooling Technology Institute, "High-Efficiency 0.5-Micron Sand Filtration," discussed this option. As author Bryan Hayward, Diamond Filtration Inc, Holyoke, Mass, explains, cooling towers require large volumes of air to promote the evaporation process. Dirt, dust, pollen, bacteria, and other airborne particulates can become entrained in the cooling water, and promote fouling.

High-efficiency filtration systems use ultra-fine sand, less than 0.2 mm in diameter, to provide nominal 0.5-micron filtration of the water. Hayward recommends that a variety of particulate loading factors be evaluated before specifying a sand filter, including:

-- Particle volume.

-- Particle count.

-- Particle surface area.

-- Total suspended solids.

-- Turbidity.

Air-cooled condensers Technology choices for ACCs begin with two basic classifications: dry-cooled and wet-surface cooled. Dry-cooled condensers are then further categorized by direct or indirect-acting. In the US market, direct-acting, dry-cooled systems are the most prevalent type of ACC.

The direct, dry-cooled type operates like an automobile radiator. From the outlet of the turbine, steam flows through external-finned tubes, and air blowing against the tubes condenses the steam. In the indirect type, the exhaust steam is condensed by a cooling water loop in a conventional surface condenser. The cooling water then rejects heat to the atmosphere in a dry tower. Whether direct or indirect-acting, dry-cooled ACCs share the distinguishing feature of externally finned tubes.

In wet-surface cooling, exhaust steam flows through smooth tubes, where it is condensed by a mixture of cascading water and air. The water and air move in a downward direction across the tube bundles; then, induced by a propeller fan, the air turns upward for discharge to the atmosphere. The cascading water continues

downward and collects in a cascade water tank before being pumped back up to restart the process.

One drawback to ACCs situated in cold climates is their potential for freezing damage. Steam condenses inside finned heat-exchanger tubes where noncondensable gas can collect under certain operating conditions, allowing condensate to freeze and rupture tubes. Manufacturers have attempted to alleviate the problem with different tube shapes, bundle arrangements, control schemes, and operating procedures.

Hudson Products Corp's (Sugar Land, Tex) freeze-resistant design uses ammonia heat pipes that it says allows for traditional steam condenser geometry without the need for complex control mechanisms, while simplifying noncondensable gas removal and condensate recovery. The new design, marketed as Steamflo, differs from Hudson's traditional Stackflo ACC, in which steam is condensed inside finned tubes (Fig 2). In the new Stackflo design, steam is condensed on the outside surfaces of heat-pipe tubes. While ice can still form on the outside surface, freezing and thawing will not result in any damage, according to Hudson.

The Stackflo system also incorporates a steam duct near grade that collects condensate that is always in contact with saturated steam. This minimizes subcooling of the condensate, which in turn improves overall cycle efficiency. Heat is rejected to the air from a conventional finned tube bundle (heat pipes) and induced draft axial flow fan. Ammonia heat pipes are the basic heat-transfer element of the new steam condenser, and consist of a sealed pipe containing ammonia working fluid.

ACC announcements. Dry cooling was selected in several recent new-construction projects, including two awarded to Black & Veatch, Kansas City, Mo. In January, Black & Veatch announced that it has joined with H B Zachry Co, San Antonio, Tex, in a joint venture agreement to provide full design, procurement, delivery, construction, startup, testing, and initial operation of Reliant Energy Co's (Houston, Tex) Choctaw County project, located near French Camp, Miss. The ACC will be supplied by GEA Power Cooling Systems Inc, San Diego, Calif.

According to Black & Veatch, use of the ACC will reduce the overall project water consumption to less than one-tenth of the water used for a corresponding combined-cycle plant using conventional cooling towers. The Choctaw County project will be one of the largest uses of an ACC on a combined-cycle plant in the US. The plant features a 3-on-1 design comprised of three GE 7FB gas-turbine generators; three triple-pressure reheat cycle heat-recovery steam generators, and one reheat condensing steam/turbine generator for a total nominal capacity of 800 MW. Commercial operation is scheduled for June 2003.

In March, Black & Veatch announced it has joined with Barton Malow in a joint venture agreement to provide full design, procurement, delivery, construction, startup, testing, and initial operation of another Reliant Energy project, Hunterstown, located near Gettysburg, Pa. The plant will be equipped with another GEA-supplied ACC, this one

featuring the manufacturer's new reduced-noise fans. The fans are designed for low-velocity air flows and are enclosed in unique hoods that cut noise. The lower air flows are compensated for by extra heat-exchange surface area to retain full condenser capacity. Like Choctaw County, Hunterstown will be a 3-on-1 combined-cycle design, nominally rated 800 MW, with commercial operation scheduled for June 2003.

A little of both in between wet and dry cooling there are several hybrid designs and modifications to existing systems. MassPower's Indian Orchard cogeneration plant has one such system, called a wet-surface air condenser. A large duct carries steam between the low-pressure turbine exhaust and tube bundles, where water is sprayed on the outside of the tube. The water falls to a basin. Fans in the middle of each cooling cell draw air horizontally through the tube bundles and then into the atmosphere (Fig 3). This configuration significantly reduces the plume and tower drift. Both were a concern, as the plant is located in a valley next to a major road. The plume and tower drift could have caused visibility problems and icy driving conditions.

Other hybrids include dry cooling systems fitted with spray nozzles to provide evaporative cooling on the hottest days, and recirculating systems with air coils similar to the dry systems located just below the tower's inductance fan. This not only provides additional cooling, it also decreases the plume.

RM300 Cost comparison of wet vs dry cooling*				
Location	Capital cost, \$1-million		Annual O&M cost, \$1-million	
	Wet	Dry	Wet	Dry
Albany, NY	25.2	60.0	0.94	1.82
Atlanta, Ga	23.2	56.2	0.92	1.78
Madison, Wis	25.4	60.7	0.94	1.83
Amarillo, Tex	21.3	52.1	0.90	1.74
Sacramento, Calif	28.0	66.0	0.96	1.88

* Source: Micheletti, Wayne C, IWC-01-38