Tech Byte 21: Cooling Tower Design - Energy Management

How the design of a cooling tower impacts energy usage and operating costs

Introduction

A variety of cooling tower technologies and configurations exist in the market today. Each type can offer different component technologies, different materials of construction, and different means of achieving the interaction of process water with outdoor air. The choice or selection of these characteristics in a given cooling tower will inevitably affect a variety of important performance attributes, such as:

- *Cooling Tower Longevity*
- *Fan Motor Energy Consumption*
- *Process Pump Energy Consumption*
- *Variable Flow Compatibility*
- *Recirculation Potential*
- *Performance in Cold Weather Environments*
- *The Costs of Maintenance*
- *Accessibility for Maintaining the Tower*
- *The Maintenance Capabilities Without Tower Shutdown*
- *Water Treatment*

In this paper, we will focus on how design and configuration of a given cooling tower impacts the amount of energy required for it to operate.

Nearly as important as the level of performance a given product offers is its ability to deliver that performance while maintaining a high level of energy efficiency. Today, energy efficiency is one of the more significant focus items for designers, end users, and equipment manufacturers as they seek to reduce equipment operational costs to strengthen their position in a competitive marketplace. Cooling towers are no different from any other product in this regard. In a cooling tower, energy is consumed in driving the fan or fans, necessary to achieve proper air movement through the tower. Also, the pump head requirement of a cooling tower contributes to the energy expended in the operation of the condenser water pump. Because of this, manipulation of one or both of these power consuming aspects will have an effect on the cooling tower's energy requirement.

Let us compare two common cooling tower design configurations in order to illustrate this fact. Two common cooling tower configurations are shown below in figures 1 and 2.

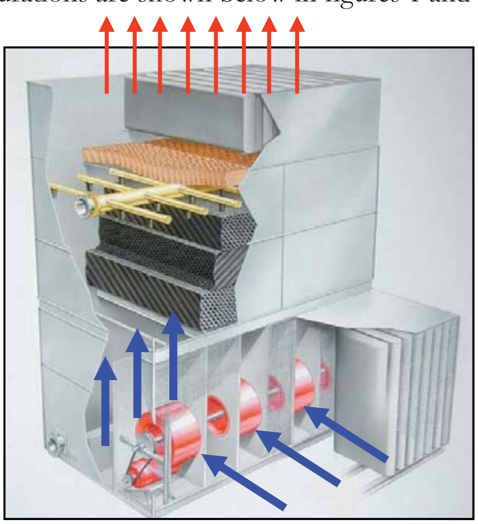

Figure 1 - Forced Draft, Counter-Flow Tower
Marley MCW Product Shown

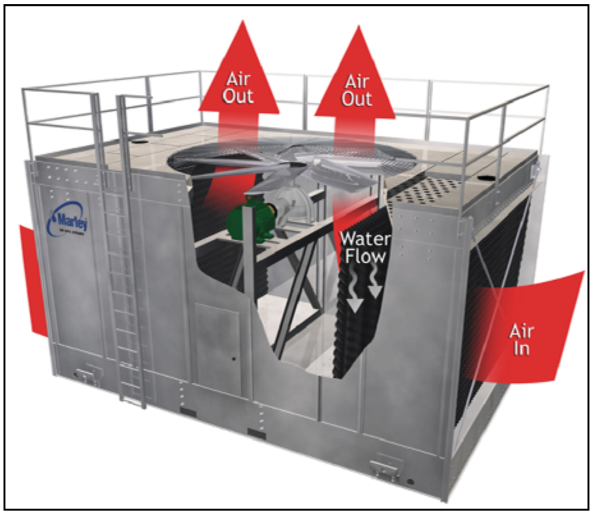

Figure 2 - Induced Draft, Cross-Flow Tower
Marley NC Class Product Shown

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Figure 1 illustrates a counter-flow, forced draft cooling tower. A **forced draft** tower uses a fan located in the ambient airstream entering the cooling tower. The fans ***force*** air through the fill media and out the top of the tower enclosure. Forced draft towers are characterized by high air entrance velocities and low exit velocities. Accordingly, they are extremely susceptible to recirculation and because the fans are located in the cold entering ambient air stream, forced draft fans can become subject to severe icing during operation in winter months.

Usually, forced draft towers are equipped with centrifugal blower type fans which, although requiring considerably more horsepower than propeller type fans, have the advantage of being able to operate against the high static pressures associated with ductwork. Therefore, they can either be installed indoors (space permitting), or within a specially designed enclosure that provides significant separation between intake and discharge locations to minimize recirculation.

In **counter-flow** towers, air moves vertically upward through the fill, counter to the downward fall of water. Because of the need for extended intake and discharge plenums, the use of high-pressure spray systems, and the typically higher air pressure losses, some of the smaller counter-flow towers are physically taller, require more pump head, and utilize more fan power than their cross-flow counterparts. See ***Figure 3*** to the right.

Figure 3 - Counter-Flow Water Distribution

Figure #2 depicts an induced draft cooling tower**. Induced draft** towers have a fan or fans located on the air ***exiting*** side of the cooling tower, and they draw air through the tower rather than force the air through it. These towers have an air discharge velocity of from 3 to 4 times higher than their air entrance velocity, with the entrance velocity approximating that of a 5 mph wind. Therefore, there is little or no tendency for a reduced pressure zone to be created at the air inlets by the action of the fan alone. The potential for recirculation on an induced draft tower is not self-initiating and, therefore, can be more easily quantified purely on the basis of ambient wind conditions. Location of the fan within the warm air stream provides excellent protection against the formation of ice on the mechanical components. Widespread acceptance of induced draft towers is evidenced by their existence on installations as small as 15 gpm and as large as 700,000 gpm.

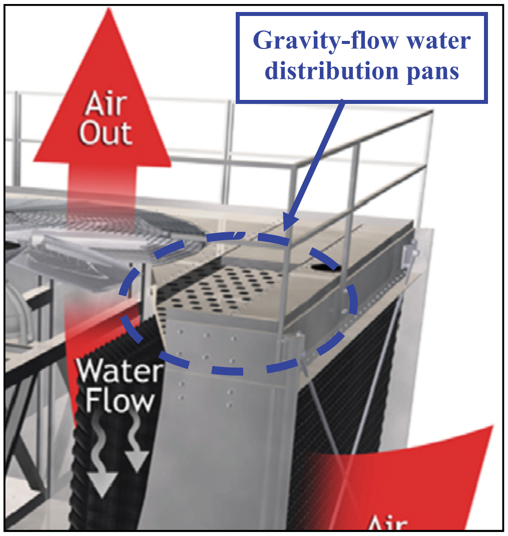

Figure 4 - Cross-Flow Water Distribution

Cross-flow towers have a fill configuration through which the air flows horizontally, across the downward fall of water. Water to be cooled is delivered to hot water inlet basins located atop the fill areas, and is distributed to the fill by gravity through metering orifices in the floor of those basins. This eliminates the need for a pressure-spray distribution system, and places the resultant gravity system in full view for ease of maintenance. By the proper utilization of flow control valves, routine cleaning and maintenance of a cross-flow tower's distribution system can be accomplished sectionally, while the tower continues to operate. See ***Figure 4*** to the left.

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To begin the energy utilization comparison between these two tower arrangements, let us first consider the fan energy requirements of each tower. For a forced-draft tower, both blower fans and propeller fans can be used. This impacts the energy utilization significantly, as blower fans characteristically require twice the horsepower of propeller fans. So the first factor to consider is what type of tower arrangement is being utilized and what fan technology does it incorporate? Also, how many fans are needed, and what is the resulting total horsepower requirement to meet the project conditions?

Take the following comparison of a two, 200-ton cooling towers with a 600gpm flow rate, 95˚F hot water, 85˚F cold water, and 78˚F wet bulb:

For a counter-flow, forced-draft cooling tower utilizing blower type fans, the horsepower requirement would be 25HP total. Based on seasonal operation of approximately 2,000 hours with a VFD controlled fan, the tower fan motor would consume 33,288.3 kWh and the system pump energy consumption would be approximately 4,000 kWh.

For a cross-flow, induced-draft cooling tower, utilizing a propeller type fan, the horsepower requirement would be 7.5HP total. Based on seasonal operation of approximately 2,000 hours with a VFD controlled fan, the tower fan motor would consume 11, 297.7 kWh and the system pump energy consumption would be approximately 3,416 kWh.

Under identical design conditions for a ***seasonal*** cooling tower application, a counter-flow, forced draft cooling tower will consume ***well over twice the energy*** as a comparable capacity cross-flow, induced draft cooling tower. At $0.08 per kWh, a comparison of energy costs shows the following:

- **200 Ton Counter-flow, Forced-draft** cooling tower operating seasonally (95˚HW—85˚CW—78˚WB)
  - Fan Energy Consumption with VFD: 33,288.2 kWh
  - Pump Energy Consumption: 4,000.8 kWh
  - **Total Energy Cost at $0.08 per kWh: $2,983.00**

- **200 Ton Cross-flow, Induced-draft** cooling tower operating seasonally (95˚HW—85˚CW—78˚WB)
  - Fan Energy Consumption with VFD: 11,297.7 kWh
  - Pump Energy Consumption: 3,416.1 kWh
  - **Total Energy Cost at $0.08 per kWh: $1,177.00**

The Cross-Flow, Induced-draft tower offers an annual energy cost savings of $1,806.00 over the Counter-flow, Forced-draft tower. So there are significant on going cost reductions available for this technology, just based on energy efficiency alone. On top of this, a comparably equipped Cross-Flow, Induced Draft tower at the 200 ton capacity level is **<u>only $1,200.00 more costly</u>** than the Counter-flow, Forced-draft tower. The return on the investment of the additional $1,200.00 up front is accomplished within the first 8 months of operation. From that point on, the energy savings are pure operational cost reduction.

Let's look at the same cooling tower technology comparison, only moving up to a 400 ton design. Here are the results:

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For a 400 ton counter-flow, forced-draft cooling tower utilizing blower type fans, the horsepower requirement would be 60HP total. Based on seasonal operation of approximately 2,000 hours with a VFD controlled fan, the tower fan motor would consume 88,747.1 kWh and the system pump energy consumption would be approximately 9,940.5 kWh.

For a 400 ton cross-flow, induced-draft cooling tower, utilizing a propeller type fan, the horsepower requirement would be 20HP total. Based on seasonal operation of approximately 2,000 hours with a VFD controlled fan, the tower fan motor would consume 30,275.5 kWh and the system pump energy consumption would be approximately 7,974.6 kWh.

Again, under identical design conditions for a ***seasonal*** cooling tower application, a counter-flow, forced draft cooling tower will consume ***well over twice the energy*** as a comparable capacity cross-flow, induced draft cooling tower. At $0.08 per kWh, a comparison of energy costs shows the following:

- **400 Ton Counter-flow, Forced-draft** cooling tower operating seasonally (95˚HW—85˚CW—78˚WB)
  - Fan Energy Consumption with VFD: 88,747.1 kWh
  - Pump Energy Consumption: 9,940.5 kWh
  - **Total Energy Cost at $0.08 per kWh: $7,895.00**

- **400 Ton Cross-flow, Induced-draft** cooling tower operating seasonally (95˚HW—85˚CW—78˚WB)
  - Fan Energy Consumption with VFD: 30,275.5 kWh
  - Pump Energy Consumption: 7,974.6 kWh
  - **Total Energy Cost at $0.08 per kWh: $3,060.00**

This comparison adds a twist to the story. At the 400 ton capacity level, the Cross-flow, Induced-draft tower is actually ***LESS*** costly up front. Not only are the energy savings double, the price tag is less as well. This trend would continue as larger capacity cooling towers are considered in this same type of comparison.

It can be clearly seen that the induced draft, cross-flow cooling tower is vastly superior in operational energy efficiency. Because of this fact, manufacturers of counter-flow, forced-draft cooling towers have in some cases resorted to utilizing propeller fans in lieu of blower fans, in order to lessen some of their excessive energy consumption. This makes an improvement in energy efficiency. However, the nature of the counter-flow, forced-draft tower design still necessitates higher horsepower requirements to accomplish the same duty as a comparable capacity cross-flow, induced-draft cooling tower.

For example, a 200 ton counter-flow, forced draft tower with propeller fans might employ three (3) 3HP fan motors in contrast to the cross-flow, induced-draft tower's (1) 7.5HP motor. This still results in superior energy conservation on the part of the cross-flow, induced draft tower. To counter this fact, it is sometimes proposed by counter-flow, forced draft cooling tower manufacturers that during certain conditions where capacity requirements are reduced or the wet bulb temperature is much lower than the design condition, that they can modulate off a fan motor and achieve better energy efficiency with (2) 3HP fan motors running at a given rpm as compared with (1) 7.5 HP fan motor running at a lower rpm. This argument is not well-founded, as it depends not only on circumstantial conditions, but also proving that at higher rpm of the (2) 3HP fan motors, they can achieve better energy efficiency than the (1) 7.5 HP fan motor running at a lower RPM. In considering this, it is important to recall that

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on fan loads, the horsepower requirement varies as the cube of the speed, so the slower the fan speed, the less energy required. A fan running at 80% speed will consume only 50% of the power of a fan running at full speed. At 50% fan speed, power consumption is only 16%.

In conclusion, energy efficiency is a major concern for all facility managers. There is a clear solution to increasing energy efficiency of a cooling tower by simply considering the technology that is specified for use on the application. A cross-flow, induced draft cooling tower offers many benefits to an end user, and one of them is superior energy efficiency.

Resources:

"*Cooling Tower Energy and Its Management*", SPX Cooling Technologies, Technical Report, 1982