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Avoiding Stratified Chilled Water TES Problems

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Thermal energy storage (TES) is an effective means of shifting cooling electrical load from peak to off-peak electrical rates or load-leveling combined heat and power plants to provide energy cost savings. Chilled water is the most common form of TES for large facilities, using concrete or steel tanks to store chilled water. During discharge, cold water is pumped from the bottom of the tank, while an equal amount of warm return water is returned to the top of the tank. Due to the increased density of colder water, a stable stratification of layers of water can be obtained.

The author has witnessed many installations under operation that have dramatically hindered the system's ability to provide full capacity and minimize energy costs. This month, I will discuss some of the common problems and means for achieving optimum performance.

Stratified TES Tank Operation

Water is a good medium for cold sensible energy storage. The principle of stratified TES tank operation is based on thermal stratification. In atmospheric stratified thermal storage tanks, warmer, less dense return water floats on top of the denser chilled water. The distribution headers in the tank are designed to use horizontal low velocity so buoyancy forces dominate inertia movement in the water. Pure water is most dense at 39.2°F (4°C); it is less dense both above and below this temperature as shown in *Figure 1*. Most stratified chilled water storage systems are designed with a chilled water supply temperature of 39°F to 42°F (4°C to 6°C).

The performance of a stratified storage tank depends upon the ability to store warm and chilled water with little mixing of temperatures during its storage. The interface zone between the chilled and warm water in the storage tank, where there is a steep temperature gradient, is called the thermocline, and its thickness should be as small as possible. Stratification in a storage tank depends mainly on the water density difference of the inlet and outlet and the inlet and outlet diffuser design. A larger density difference between the cold water and warm water in the storage tank will result in a thinner thermocline allowing a higher figure of merit (FOM), which is used as a measure of the amount of cooling available from the storage tank. The FOM is the ratio of actual discharge capacity to the ideal capacity that could have been withdrawn in the absence of mixing and losses to the environment.

The chilled water is charged through the bottom diffuser into the tank at the same rate as the warm water is displaced through the top of the storage tank. The thermocline forms at the bottom and slowly moves up to the top as charging is continued. During charging, the available cooling capacity of the charged water degrades slightly due to mixing of the charge with the stored water. This is in addition to the thermal diffusion, axial wall conduction and heat gains from the ambient. *Figure 2* shows a typical temperature profile in a stratified TES tank.

In a discharge cycle, the storage tank initially filled with chilled water is discharged through the bottom diffuser and returned to the tank through the diffuser at the top, after it is supplied to the load (e.g., cooling coils). The thermocline forms at the top initially and slowly moves

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FIGURE 1 Temperature effect on water density.

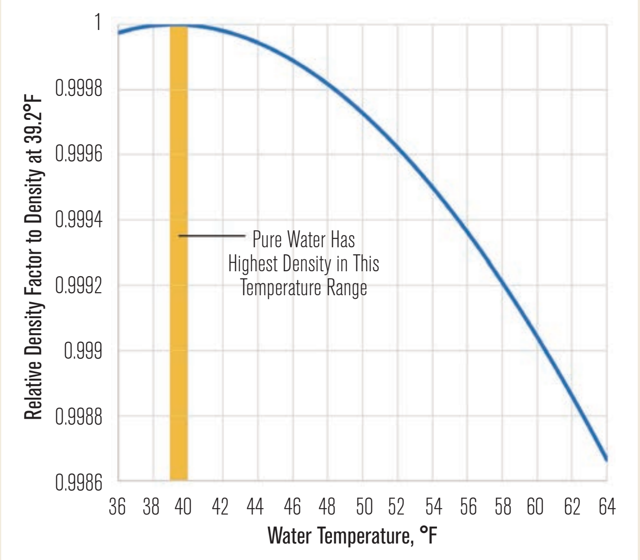
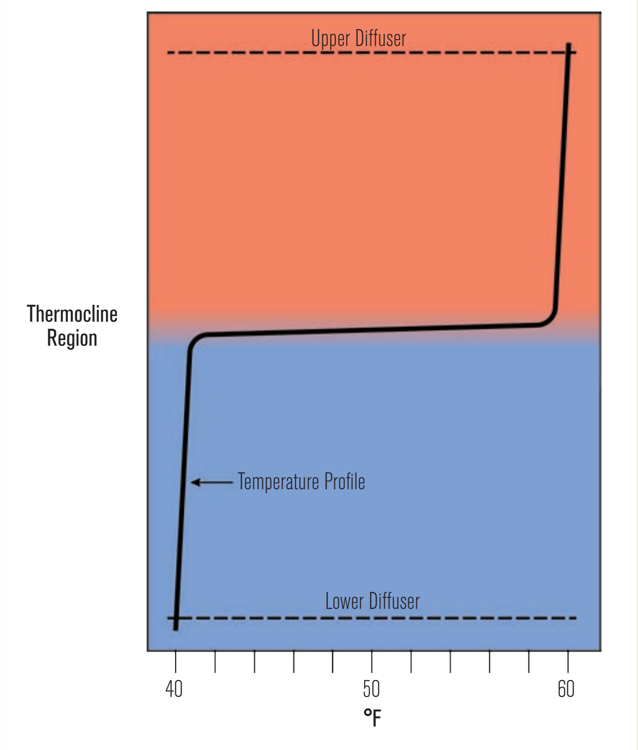


FIGURE 2 Temperature profile in stratified TES tank.



down to the bottom at the end of a discharge cycle. The higher the temperature difference (ΔT) between the chilled water supply and return, the more cooling capacity per unit of water delivered from the tank. Maintaining the ΔT as large as possible is important in achieving the intended beneficial performance of the system.

Design and Operational Issues

TES Tank Pumping

Most atmospheric chilled water TES tanks are hydraulically connected to the chilled water system by installing the TES tank(s) next to the chiller plant, using the plant's primary and secondary pumping to charge and discharge the tank. A common mistake is to believe separate TES tank pumps are required to charge or discharge the TES tank when it is located next to the chiller plant. The author has seen several installations where the TES tank pumping system was mistakenly designed to overcome the water column in the atmospheric TES tank. Since the chilled water supply and return reference the same column of water in the TES tank, this is not a factor in calculating required pump head.

Refer to a previous column[1] for additional information on chilled water TES hydraulic considerations.

Need for Chilled Water Coils to be Sized Correctly

Coils determine the ΔT. It cannot be created by designing the plant for a high ΔT. So often designers are not aware of the importance of high ΔT coils when connecting new chilled water coils to the system. Facility standards must be created and strictly enforced, especially when chilled water thermal storage is implemented. Refer to Taylor[2] for additional information on chilled water coil sizing.

TES Tank Charging Temperature Increased

Most chilled water TES tanks are designed with a specific chilled water supply charging temperature. The designer determines what the expected chilled water return temperature will be based on the performance of the connected coiling coils at design conditions. This ΔT is directly proportional to the thermal storage capacity of the TES tank. The author has found many plant operators increasing the charging temperature from design conditions due to either implementing chilled water reset or believing that most cooling coils in the facility were not selected to operate at the lower design temperature.

It is true that chillers are more efficient for a given load when lift (as indicated by the difference between leaving condenser water temperature and leaving evaporator water temperature) is reduced. As a general rule, centrifugal chillers use roughly 1.5% less energy per °F of reduced lift. This reduction in lift could be accomplished with a higher chilled water supply temperature

FIGURE 3 Impact on LWT from varying EWT for an original 45°F EWT/55°F LWT chilled water coil while maintaining the same airside conditions. Assumes constant load.

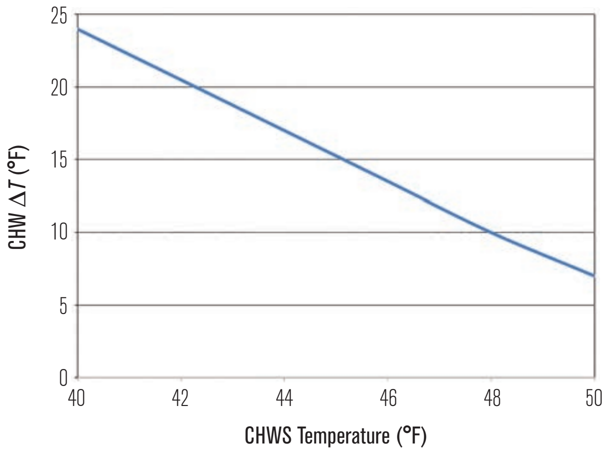
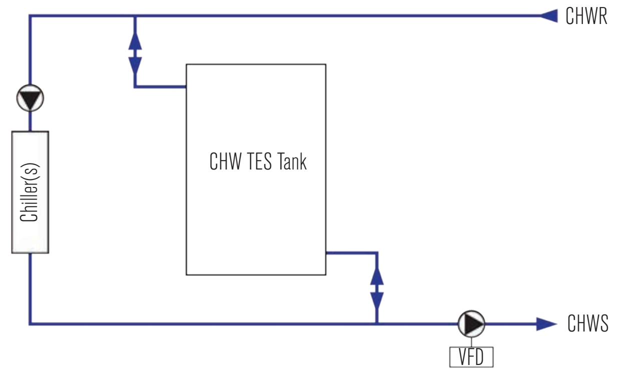


FIGURE 4 Primary-secondary chilled water TES configuration.



setpoint or a lower condenser water supply temperature setpoint. It is important to remember that chiller efficiency is only one part of overall system efficiency. A high-level view would take into account overall chilled water system efficiency and its ability to operate at the lowest annual cost/ton-hour delivered. Overall chilled water system efficiency should include all energy to produce and deliver the chilled water to the loads (chillers, cooling towers, condenser water pumps, and all chilled water pumps in the plant and distribution system). It is also critical for the TES tank to deliver the design ton-hours shift during peak electrical periods in order to avoid turning on additional chillers.

At the system cooling coils, increasing the chilled water supply temperature will always increase pump energy and (perhaps counter-intuitively) decreases return water temperature as shown in *Figure 3* and thus decreases overall plant and TES tank Δ*T*. For a given cooling coil and load, raising the entering water temperature will require more chilled water flow, resulting in lowering the leaving water temperature. For a given cooling coil and load, a lower entering water temperature will result in a higher chilled water Δ*T*.

The lower system Δ*T* has a direct negative impact on the storage capacity of the TES tank. It is not uncommon for a system with cooling coils designed to operate at 40°F to 60°F (4.4°C to 15.6°C) to see 45°F to 55°F (7.2°C12.8°C) operation when the supply water temperature setpoint is increased to 45°F (7.2°C). This reduces the TES tank ton-hour cooling capacity to 50% of its design capacity. This increase in supply water temperature would require double the design chilled water flow rate to meet the same cooling load condition.

Chilled water TES tank systems should be operated near their original design chilled water supply temperatures during the peak cooling season to be able to utilize the design ton-hour storage capacity. The author has seen successful chilled water reset strategies implemented. These chilled water supply temperature reset strategies usually limit the reset between 39°F to 42°F (4°C to 5.6°C) during the heating season.

Primary CHW Pumps

Another common problem encountered is when the primary chilled water pumps are sized for design chilled water ΔT. *Figure 4* shows a common piping configuration when the TES tank is located near the chiller plant. The tank is located in the common leg of the primary/secondary loops, which allows the tank to be charged, discharged, or both at the same time without any added pumps or valves. The plant operator will encounter lower chilled water Δ*T* at non-peak load conditions. If the pump providing flow through the chiller evaporator is limited to the flow corresponding to high Δ*T*, the chiller will not be able to reach full load at lower Δ*T* conditions. This can be a problem if the tank needs to be fully charged during a limited period of time. This problem can easily be avoided by selecting pumps that can provide the flow corresponding to the low chilled water differential expected in the winter months allowing the chiller(s) to reach full load at the lower system Δ*T* during the TES tank charging period. It is also important to remember that the peak pump TDH in primary-variable flow systems would be calculated at peak Δ*T* flow condition since it normally occurs at peak load conditions.

The primary chilled water pumps should be variable speed so that if the chilled water return temperature is higher than design, as might be encountered on a hot day, the chiller will not overload and cause the chilled water supply temperature to increase above design.

Concluding Remarks

Chilled water thermal storage can provide many energy cost benefits when implemented or operated correctly in chilled water systems. It is important for designers and operators to understand operational ramifications on the entire chilled water system throughout the year. Operations should focus on achieving the chilled water system Δ*T* in order to get the most benefit from the chilled water TES system.

References

1. Peterson, K. 2015. "Chilled water TES hydraulics." Engineer's Notebook. *ASHRAE Journal* 57(2).

2. Taylor, S. 2011. "Optimizing design & control of chilled water plants." Engineer's Notebook. *ASHRAE Journal* 53(12). ■