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Chilled Water TES Hydraulics

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Thermal energy storage (TES) is an effective means of shifting cooling electrical load from peak to off-peak electrical rates. Chilled water is the most common form of TES, using concrete or steel tanks to store chilled water at 39°F (4°C), which is the temperature at which water density is highest, encouraging stratification within the tank. Under normal conditions, a chilled water TES tank is always filled with 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.

Placing an open chilled water thermal energy storage tank in a chilled water system has several ramifications on the hydraulic performance of the system. This month, I intend to point out engineering issues that must be addressed under various scenarios. These are all real examples from actual facilities that I have designed, peer reviews I performed of designs by others, or retrofits of designs by others.

System Considerations

TES tanks are seldom ASME-rated pressure vessels due to the high cost, so they must be vented to atmosphere. This establishes the reference pressure for the system; essentially the TES tank is serving as a vented expansion tank. Heat exchangers could be used to physically isolate the TES tank from the distribution system, but this is typically not preferred since chilled water ΔT will suffer with heat exchangers and additional pumps would be required. This column will focus on how to control for pressure in chilled water systems with atmospheric TES tanks without heat exchangers.

A chilled water system with an atmospheric TES tank must always maintain a positive gauge pressure in all parts of the system to prevent air from leaking into the system. Ideally, the TES tank would be located at a vertical high point in the system or constructed tall enough that the system's static pressure requirements are met by the tank water height. If the water level in the TES tank is lower than parts of the chilled water piping system, some means of sustaining positive pressure when the system is operating will be required in the system design. This means of control will create an additional pressure drop in the chilled water return system to maintain positive pressure at the highest points of the chilled water system. Even a small air leak when the chilled water system is off can lead to the atmospheric TES tank overflowing when the tank is located below the highest point in the piping system.

Chilled water systems with multiple TES tanks pose additional considerations since flow can be motivated by the static head differences between the open tanks. A very small difference in static head pressure would result in water removed from one tank possibly overflowing to the other tank if both tanks are open to the system at the same time.[1] This month's column will focus on single atmospheric TES tanks.

Location of Chilled Water TES Tank

The locations of chilled water TES tanks are sometimes located based solely on aesthetic considerations without understanding the engineering ramifications of the tank location. Chilled water TES tanks in large chilled water systems are often located at or near the central chiller plant or at or near one or more satellite chiller plants. However, in some cases it is not practical to locate the TES tank at or near the plant and will need to be located near the chilled water distribution network preferably near the highest point.

Once a TES tank location has been sited within a plot plan of a chilled water distribution network, there is still the choice of locating the tank above ground or below

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ground. *Table 1* compares various considerations for both aboveground and belowground TES tanks.[2]

TABLE 1 TES tank location considerations.

CONSIDERATION	BELOWGROUND TES	ABOVEGROUND TES
Site Space Use	Can Be Preferable	Can Be Less Preferable
Site Aesthetics	Out of Site Out of Mind	Visible
Sensitivity to Site Soil Conditions	Very sensitive	Less Sensitive
TES Tank Inspection	More difficult	Less Difficult
TES Tank Costs	Higher	Lower
TES to CHW System Hydraulic Differential	Higher	Lower
TES Tank Pumping Energy	Higher	Lower

Hydraulic Integration of TES Tanks

Atmospheric CHW TES tanks are typically hydraulically interconnected to chilled water systems by one of the following common methods:

- Integrating the TES tank within the chiller plant, using the plant's primary-secondary CHW pumping, or
- Siting the TES tank remotely from the chiller plant while using dedicated TES pumps

When the TES tank can be located next to the chiller plant, it can be connected between the plant's primary and secondary chilled water loops without adding additional TES pumps as shown in *Figure 1.* The TES tank's upper region of warm water connects with the CHWR header while the lower region of cold water connects with the CHWS header. Whenever the plant's primary CHW flow exceeds the secondary CHW flow, the TES tank is charging. When the plant's secondary CHW flow exceeds the primary CHW flow, the TES tank is discharging. This method of connection is typically the simplest and least expensive means of connecting the chilled water TES tank because it allows for charging and discharging, separately or simultaneously, without the use of automatic control valves to reroute flow.

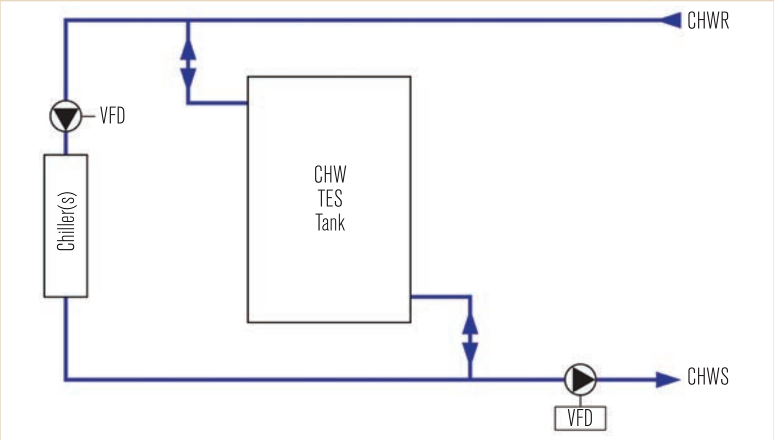

FIGURE 1 Local TES tank.

When the TES tank needs to be remotely located from chiller plant(s), a TES pumping station would be required to pump both in/out of the TES tank. The TES tank connects to the CHWS and CHWR headers similar to above; however, the water must always be pumped from the atmospheric pressure of the TES tank into higher-pressure chilled water headers. During discharge, the cold water is pumped from the lower region of the tank into the CHWS header. During TES charging, the warm water is pumped from the upper region of the tank into the CHWR header. The same set of TES pumps are generally used for both charging and discharging, with interconnecting cross-over piping with automatic valves used to select operating mode as shown in *Figure 2*. This allows the remotely sited TES tank to act as a load when charging and act like a chilled water source when discharging. Control valves, CV-1 through CV-4 are normally two-position valves. CV-5 and CV-6 would be two-position if the TES tank is highest point in the chilled water system. If the tank is located lower than the chilled water system piping, CV-5 and CV-6 could modulate to control back pressure.

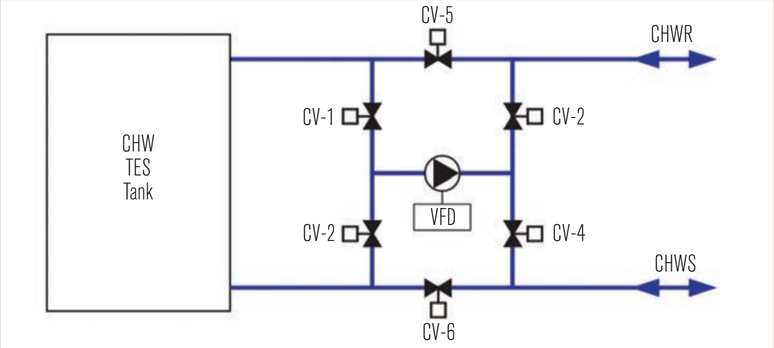

FIGURE 2 Remote TES tank pumping.

The objectives of the TES tank pumping system during TES tank charging are:

- Pump the proper amount of chilled water to load the chiller plant(s);

- Maintain positive gauge pressure at the highest point in the chilled water system; and
- Maintain positive differential pressure between the CHWS and CHWR headers.

The objectives of the TES tank pumping system during TES tank discharge are:

- Pump the proper amount of chilled water to supply the building loads; and
- Maintain positive gauge pressure at the highest point in the chilled water system.

Maintaining Positive Pressure

One commonly overlooked engineering criterion when using atmospheric TES tanks is maintaining positive gauge pressure (a pressure above atmospheric pressure) within the entire chilled water system while maintaining the top of the vented tank at atmospheric pressure. This is required to prevent the pressurized water from draining into the atmospheric TES tank, which could not only overflow the tank but also create a vacuum and draw air into the piping at its highest elevations. There are various methods to maintain positive pressure when the TES tank water level is below higher parts of the chilled water system, each with varying pumping energy penalties.

One means of control is to use self-contained pressure sustaining valves (PSV). These are typically pilot-operated devices with manually adjusted setpoints. Because the setpoint is manual, it is set to create enough back pressure to pressurize the highest point in the chilled water system. For example, if the highest point in the system is 120 ft (36.6 m) above the TES tank water level, the back-pressure setpoint required to maintain 5 psig at the highest point would be 57 psid or 132 ft (40.2 m) head:

$$\text{Back-Pressure Setpoint} = 5\text{ psig} + \frac{120\text{ ft}}{2.31\text{ ft/psi}}$$

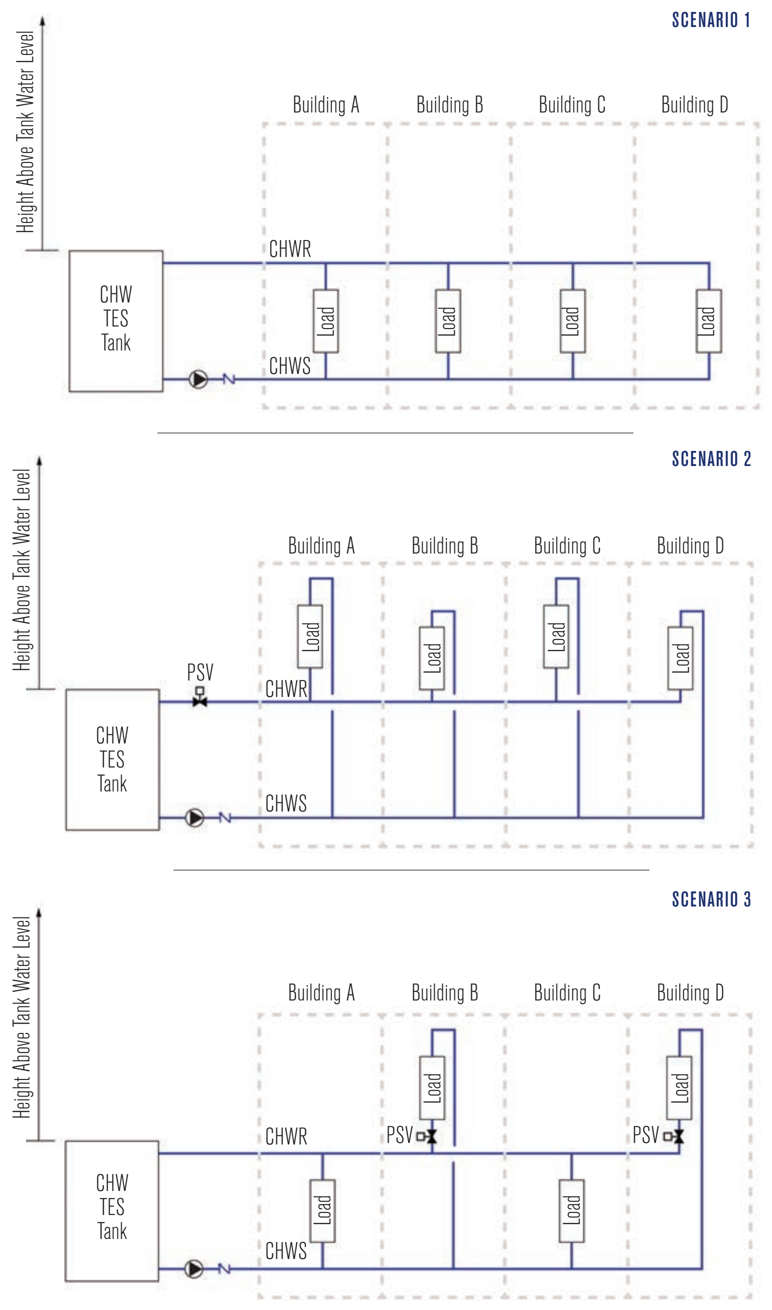

FIGURE 3 TES tank elevation scenarios. Scenario 1: All connected loads below TES tank water level. Scenario 2: All connected loads above TES tank water level. Scenario 3: Some connected loads above TES tank water level.

Another means of control is using a control valve or parallel control valve arrangement. Note that the flow range will typically vary substantially from low load to peak load and the back-pressure control valve arrangement would be required to operate over the entire range. The pressure on the inlet of the valve assembly should be measured and set to allow positive gauge pressure at the highest point in the system being controlled. The type of control valves can vary based on the flow and back pressure required.

When most of the chilled water system is above the TES tank water level, the pumping energy required for the back-pressure control can be substantial. A hydro turbine assembly used in lieu of the PSV could be used to recover a majority of the additional pumping energy. This allows the potential energy from the hydraulic back pressure to drive a reaction turbine, which, in turn, can assist in driving the main distribution pumps. This technology should be considered when the back-pressure head is greater than 50 ft (16 m).

Figure 3 shows various elevation scenarios that can be encountered when connecting atmospheric TES tanks in chilled water distribution networks. Scenario 1 shows that when the chilled water TES tank water level is above the entire chilled water piping system, no additional back-pressure control is required since the atmospheric pressure on the TES tank is pressurizing the piping system.

Scenario 2 illustrates when all or most of the chilled water piping system is above the TES tank water level. This can happen when the TES tank is below grade or the central plant and TES tank are located at a lower elevation than the buildings served. Under this scenario, it is typically preferred to control back pressure at a single location near the TES tank. The pressure drop from this back-pressure device will result in additional pumping head anytime the system is operating and must be taken into account when calculating pump head.

Scenario 3 is the most energy efficient when only some of the connected chilled water distribution system is higher than the TES tank water level. It is optimal to only control back pressure in those buildings where the piping is higher than the TES tank water level, thus reducing the total system pumping energy required to control back pressure.

Summary

Chilled water thermal storage can provide many energy cost benefits when implemented in chilled water systems. Placing an atmospheric chilled water thermal energy storage tank in a chilled water system will have several engineering ramifications on the hydraulic performance of the system. Understanding these hydraulic implications and designing the optimum solutions for addressing these implications will improve both control and energy performance.

References

1. Hyman, L. 2011. *Sustainable Thermal Storage Systems: Planning, Design, and Operation*. New York: McGraw Hill.
2. ASHRAE. 2013. *District Cooling Guide*. ■