A 10 million litre chilled water thermal storage tank

Chilled Water Thermal Storage

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Introduction

Technological development to cater to human needs is fuelling the consumption of electrical power, increasing the gap between its demand and generation. There is a need for reducing power consumption by using energy efficient products and reducing wasteful consumption. Governments have brought in legislation to encourage the use of energy efficient products and systems. The industry has also been working on developing energy efficient products such as variable frequency drives for motors, energy efficient IE3 and IE4 motors, etc.

Another method being adopted to minimise power consumption during peak hours is using chillers to produce chilled water during off-peak period. Since energy consumption varies during the day, some state governments have introduced policies to encourage the use of energy efficient systems by reducing the tariff during off-peak hours at night.

About the Author

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Ice Thermal Energy Storage System

A thermal energy storage (TES) system utilises off-peak electricity, which is usually cheaper than peak time electricity, to chill or freeze water. The system stores cooling energy in an ice or chilled water storage tank and discharges the stored energy for air conditioning during peak time. Such a scheme of operation reduces peak energy consumption and total operation cost. A TES system reduces peak consumption to the extent of 30 to 35% of designed building load.

There are two types of TES systems using water, namely Ice Thermal Storage and Chilled Water Thermal Storage. In the chilled water thermal storage system, the separation of warm and chilled water takes place by means of gravitational stratification. This kind of system is recommended for air conditioning of buildings, as it can be retrofitted easily into an existing chilled water system without the need for additional chillers. This system reduces the overall capacity of the refrigeration plant as well as peak demand load, thereby saving on initial capital cost of the project.

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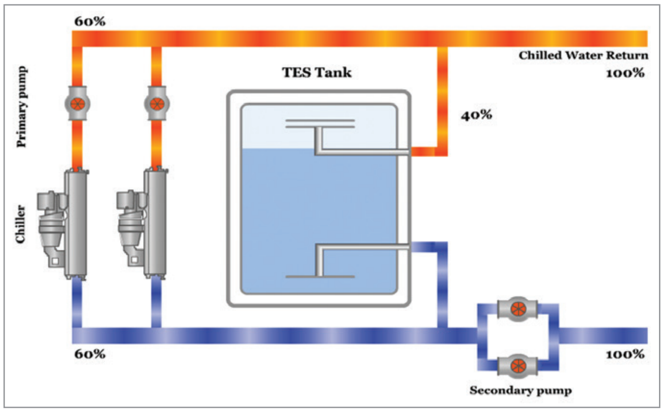

Figure 1: Chilled water thermal storage system schematic

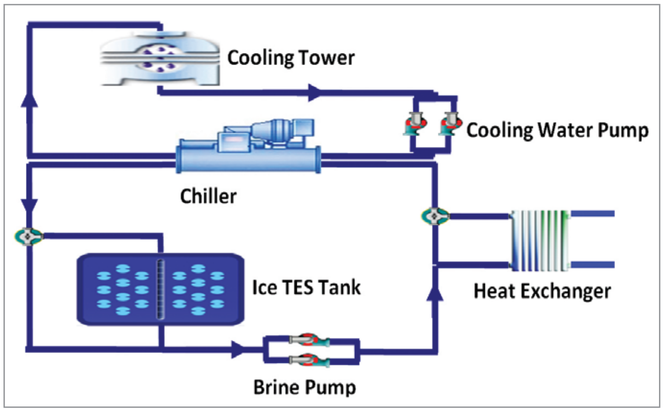

Figure 2: Ice thermal storage system schematic

Chilled Water Thermal Energy Storage

The advantage of chilled water storage is its compatibility with conventional water chillers and instant distribution to the load. The storage system can be worked out and added with minimum modification of existing equipment, thereby ensuring net reduction in energy use that can often be easily achieved. On the other hand, the relatively large storage tank that is required for the system may not be feasible due to space limitations. *This article will focus on chilled water TES.*

In a chilled water TES, the warmer, less dense returning water floats on top of the stored chilled water. The water from storage is supplied and withdrawn at low velocity, in an essentially horizontal flow, so that buoyancy forces dominate inertial effects. Pure water is most dense at 4°C; therefore, it cannot be stratified below this temperature. When the stratified storage tank is charged with chilled supply water, it enters through the diffuser at the bottom of the tank, and return water exits to the chiller through the diffuser at the top of the tank. The incoming water mixes with water in the tank to form a 0.3 to 0.9 m thick thermocline, which is a region with vertical temperature and density gradients. The thermocline prevents further mixing of the water above it with that below it. The thermocline rises as recharging continues and subsequently falls while discharging. It thickens somewhat while charging and discharging due to heat conduction through the water and heat transfer to and from the walls of the tank. The storage tank may have any cross-section, but the walls are usually vertical. Horizontal cylindrical tanks are generally not good candidates for stratified storage.

When chilled water systems are designed for large capacity requiring larger volume of chilled water storage, such stratified chilled water storage systems are located outdoors (such as in industrial plants or suburban campus locations). A tall tank is desirable for stratification, but a buried tank may be required for architectural or zoning reasons. Tanks are traditionally constructed of steel or prestressed concrete. A supplier who assumes full responsibility for the complete performance often constructs the tank at the site and installs the entire distribution system.

Natural Stratification

A thermal energy storage tank integrates seamlessly into any chilled water cooling system. Because of its specially designed internal diffuser system, the chilled water remains stratified within the tank throughout the charging and discharging process. The performance of a stratified storage depends upon the ability to store warm and chilled water with little incursion of temperatures during its storage. The thickness of the interfacial zone between the warm and chilled water in the storage tank with a large temperature gradient, i.e. the thermocline, should be as small as possible.

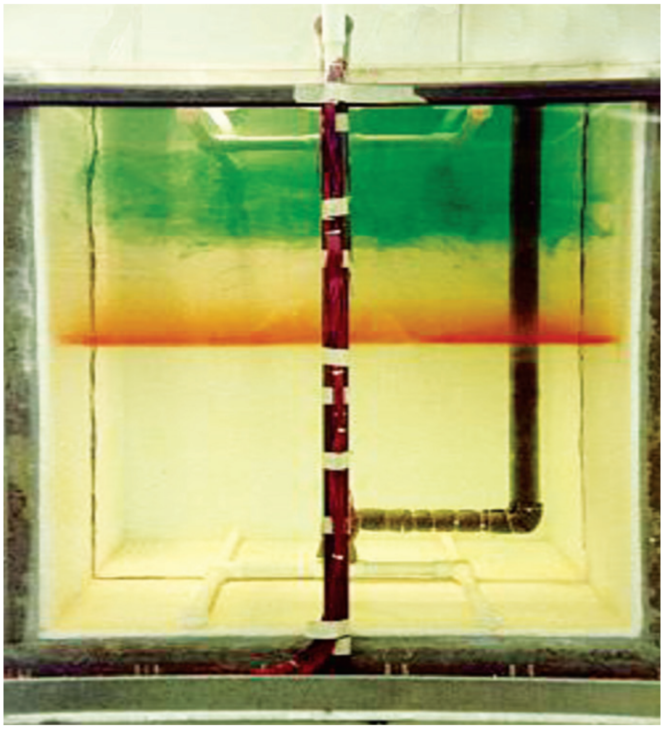

Figure 3: Natural stratification in storage tank

The stratification of chilled water can be performed by utilizing the difference in water density at varying water temperature. (The density of water is highest at 4^{o}C.)

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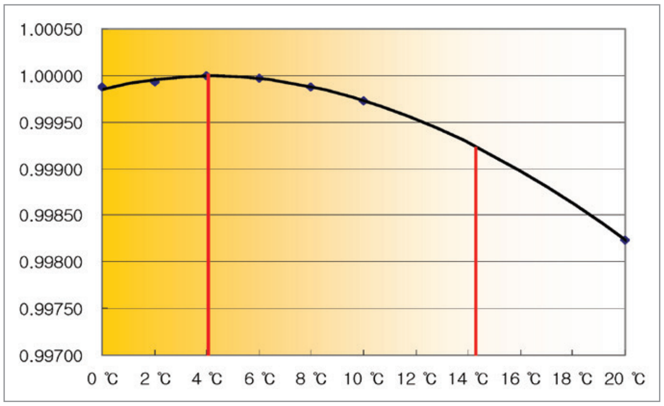

Figure 4: Water density variation with temperature

The stratified chilled water storage tank utilizes natural stratification of water within the tank. This system allows the TES tank to be 'charged' and 'discharged' of chilled water on a daily basis. See *Figure 5* to *8*.

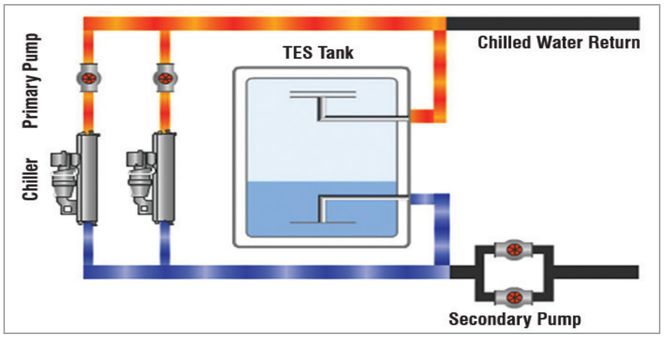

Figure 5: TES discharging without load

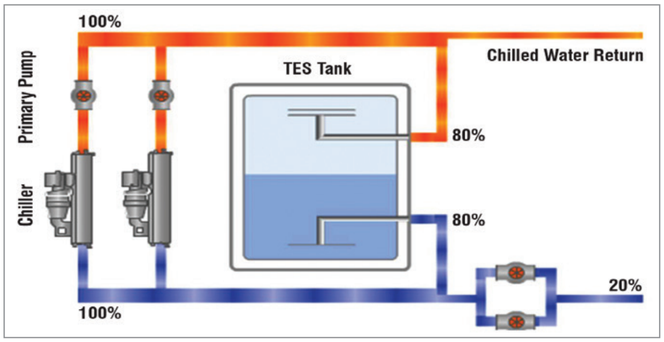

Figure 6: TES discharging with load

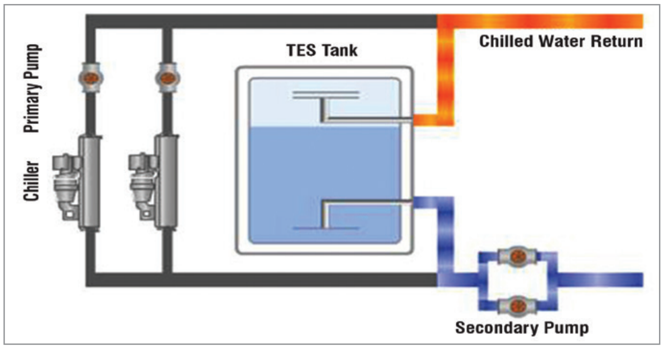

Figure 7: Discharging with chiller

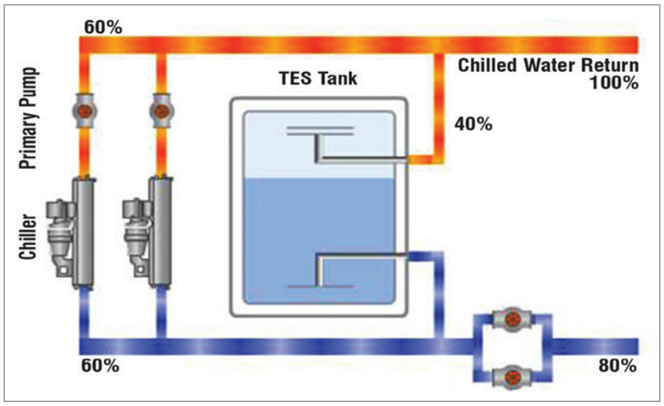

Figure 8: Discharging without chiller

The key technology of CHW storage system is the diffuser design which ensures thermal stratification of chilled water and warm water by density difference.

Charge Cycle

Chilled water at the desired temperature is charged through the bottom diffuser into the tank at the same rate at which the warm water is displaced through the top of the storage tank. A 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 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. Hydrodynamic disturbances caused by the high jet velocity of the inlet stream cause mixing of warm and chilled water. The thermal degradation due to mixing reduces with decreasing charge flow rate. Therefore, at very low charge flow rates, the thermal degradation is mainly a result of a combination of heat gain from ambient, thermal diffusion and axial wall conduction.

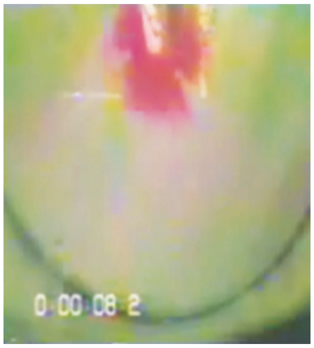

Figure 9: Gravity current with linear diffuser

Figure 10: Gravity current with radial diffuser

Discharge Cycle

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 passed through the load. The thermocline forms at the top initially and slowly moves down to the bottom at the end of a discharge cycle.

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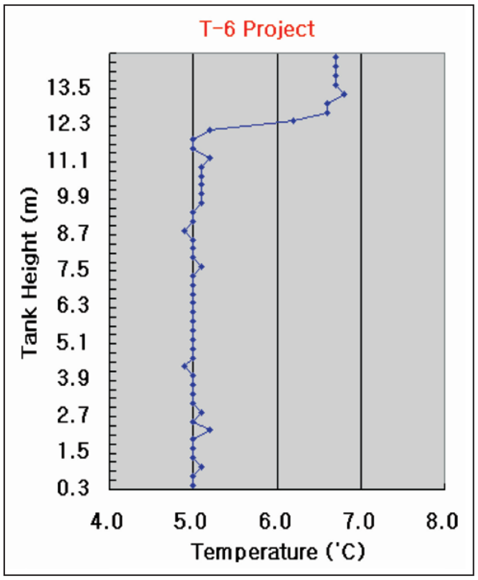

Figure 11: Temperatures during chiller test run

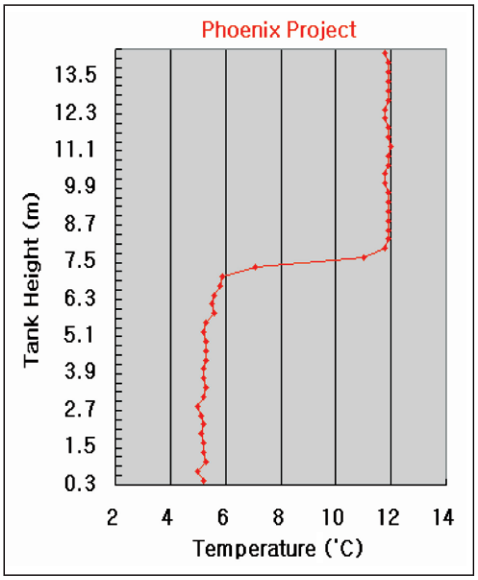

Figure 12: Temperatures during charging mode in normal operation

(Temperature difference is only 2°C, and density difference is much less than 0.1%. The temperatures are measured during Chiller Test Run, with the water inside. The tank has started to be cooled down from 30°C.)

(Temperature difference is 7°C.)

Conclusion

The key features of chilled water thermal storage are:

- Low initial investment.
- 30% energy saving by utilising conventional chillers with higher efficiency than low temperature chillers.
- Simple system with easy control without additional heat exchangers , using lesser equipment.
- High efficiency of discharging cooling.
- Easy to convert conventional system into chilled water TES system by adding only chilled water storage tank.
- Adaptable to heating process.
- Environmentally friendly system free from brine.
- Storage water can be utilised for fire fighting in emergency.