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Avoiding Common Chilled Water Distribution Problems

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The design decisions made in selecting and sizing chilled water distribution system components have a direct impact on the performance of the overall chilled water system. Attention to fundamentals can also help improve system performance.

This month, I intend to point out some common problems that must be addressed in chilled water distribution systems. These problems can impede the system's ability to perform reliably and efficiently. These are all real examples from actual facilities that I have designed, peer reviews I performed of designs by others, or retrofits of systems designed by others.

Distribution System Objectives

It is important to begin with some key objectives of the chilled water distribution system. These objectives should be viewed on an annual basis and not simply at design conditions. The system should:

- Deliver the amount of chilled water required to satisfy the loads;
- Operate reliably;
- Minimize pumping energy;
- Minimize excessive pressure differential across the supply-return distribution system; and
- Optimize life-cycle costs of distribution system components.

Distribution System Fundamentals

While it appears that pump sizing should be an easy exercise, it is the author's experience that this is where some designers fail to properly evaluate the expected operating conditions. The first step in sizing pumps and chillers is to understand the anticipated load diversity, load profile and ΔT for the system. Chilled water load diversity can be defined as:

$$\text{CHW Load Diversity} = \frac{(\text{Plant Maximum Actual Load})}{(\text{Sum of Connected Block Loads})} \quad (1)$$

Chilled water system load diversity varies and is dependent on size of facility, occupancy schedules and internal loads. Large multibuilding facilities and campuses can have chilled water load diversities as low as 50% to 70%. Load modeling programs commonly overestimate the actual combined chilled water loads for multiple buildings. This knowledge usually comes from experience with similar systems by evaluating measured peak loads and dividing by the area of the total connected load served.

The anticipated load profile tries to predict how many hours the system will operate at various loads. Most of the time, the author has found it effective to consider 10% load increment bins, or how many annual hours the plant will operate from 0–10%, 11–20%, etc. Many large systems will operate with a minimum base load at night. The chillers and pumping system should be able to operate reliably and efficiently at all load conditions.

Pump total dynamic head (TDH) is calculated by adding the pressure losses from the pump outlet through piping and components of the system and back to the pump. Large looped distribution systems are best evaluated using modeling software since the designer does not always intuitively know the most hydraulically remote path. There are many effective modeling tools available today to model both simple and complex distribution piping systems, and visualize how the complete system operates under various conditions.

In selecting pumps, there are some fundamental principles to remember:

- Determine the system curve potential operating conditions;

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- The system curve should intersect the pump curve(s) over the range of operation;
- Avoid operating on the flat portion of the pump curve since performance is unpredictable;
- The best operating conditions for the pump are near the pump best efficiency point (BEP);
- Pumps in parallel add flow at the same TDH condition and must operate at similar discharge pressures; and
- Pumps in series add TDH at a given flow condition.

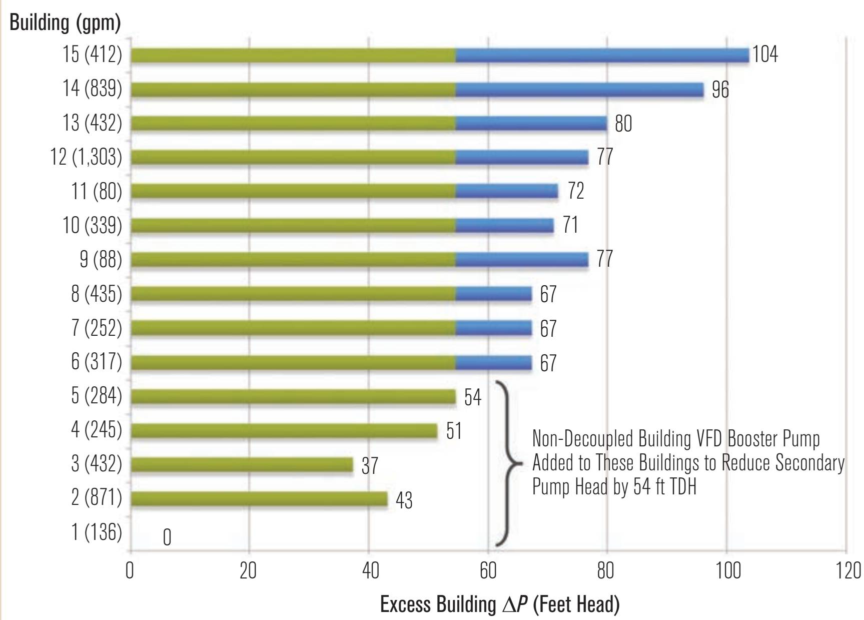

FIGURE 1 Example of multibuilding CHW system ΔP requirement valuation.

Avoiding Common Problems

The following are common problems the author has found in chilled water distribution systems. These problems and solutions are presented to assist readers to avoid these same problems.

Chillers Not Loading at Low ΔT

Chilled water ΔT will vary throughout the year as cooling coil entering air temperature varies. It is important to size the pumping system to operate at the anticipated range of chilled water ΔT. Even a well-designed and controlled chilled water system will experience low ΔT in mild weather due to low ambient air temperature entering cooling coils that have outdoor air economizers or are 100% outdoor air. The chillers should be able to reach individual peak capacity at low ΔT conditions by sizing the peak evaporator flows based on the lowest anticipated ΔT. Peak loads will likely occur at near-peak ΔT when the system is operating properly.

One common problem is chilled water pumps sized for chiller evaporator flow at anticipated peak ΔT. If the pump providing flow through the chiller evaporator is limited to the flow corresponding to high ΔT, the chiller will not be able to reach full load at low ΔT. 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, allowing the chiller(s) to reach full load at the lower system ΔT. It is also important to remember that the peak pump TDH in primary-variable flow systems would be calculated at peak ΔT flow condition since it normally occurs at peak load conditions.

Excessive Differential Pressure

Chilled water system performance can be impacted by the ability of the connected loads to control the chilled water flow and to maximize the chilled water ΔT as designed. Operating at higher ΔP requires control valves to be able to provide unnecessary pressure drop, wasting energy and adding additional cooling load to the system as friction pressure drop. This unnecessary pressure drop results in wasted pumping and cooling energy.

A good starting point to avoid this problem is to select the proper distribution system and use life-cycle cost chilled water pipe sizing as described by Taylor.[1] Most large underground chilled water distribution systems will last at least 50 years. Based on the author's experience, chilled water systems generally perform better with higher ΔT when operating at reduced system pressure differentials, ≤100 ft (300 kPa) head. Generally, systems that require low main distribution piping pressure drop perform better than systems with high main distribution piping pressure drop. This allows most of the buildings to operate at similar chilled water differential pressures.

Water at 60°F (15.5°C) has a density of 62.3 lb/ft^3 (998 kg/m^3), so pump energy is directly proportional to flow and head as shown in the following equations:

$$Pump\ HP = \frac{gpm \times head}{3,960 \times \eta_{pump}} \quad (2)$$

$$Pump\ kW = \frac{\text{L/s} \times kPa}{1,000 \times \eta_{pump}} \quad (3)$$

Distribution pumping energy can be reduced in existing systems by evaluating connected load ΔP to determine if building non-decoupled variable speed booster pumps can reduce total pumping energy. *Figure 1* (Page 51) shows a university campus hydraulic modeling example where the existing central chiller plant used secondary chilled water pumps to pump through all the connected buildings.

The graph represents the excess head throttled at the buildings from the secondary pumps to circulate design flow through each building. As seen in the results, Building 1 is hydraulically remote and drives the TDH requirement for the secondary pumps. Building 15 is required to throttle 104 feet (311 kPa) head of excessive pressure at peak design flow. The modeling determined that adding building non-decoupled VFD booster pumps to Buildings 1 through 5 would result in reducing the TDH on the main distribution pumps by roughly 54 feet (161 kPa) head to save pumping energy and reduce system differential pressure. This type of analysis is useful to identify outlier requirements that drive the system TDH requirements. In some cases, simple piping or valve changes can reduce building pump requirements by 10 to 15 ft (30 to 45 kPa) TDH. The conversion to building booster pumps on Buildings 1 through 5 would save the green-colored TDH in the Figure and reduce overall peak pumping demand by 119 bhp (89 kW). Secondary benefits that are realized

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include lower distribution pressures, the ability for many of the buildings to operate better since they are not required to throttle the original excessive differential pressure and added secondary pump capacity/redundancy.

Distributed building non-decoupled variable speed booster pumping is a good strategy for reducing distribution pumping energy in large systems with large pressure gradients while potentially improving chilled water ΔT.[2]

Oversized Pumps

System flow and TDH requirements can be visualized graphically with a system curve. The pump manufacturer normally describes the pump characteristics graphically with pump performance curves. The pump curve describes the relationship between flow rate and head for the actual pump. Pump fundamentals indicate that the system curve must intersect with the pump curve. Pumps are typically sized to run as close as possible to its best efficiency point (BEP). This not only makes the pump more efficient but also improves the reliability of the pump. System curves in large variable flow distribution systems can be difficult to predict without using hydraulic modeling software. Even then, the system curve will typically vary depending on varying load conditions throughout the system.

The majority of existing systems with high TDH pumps evaluated by the author never operate close to the nameplate head of the chilled water distribution pumps. The excessive TDH pump selections are typically due to not properly understanding load diversity or not calculating the TDH requirement and assuming the variable speed drive will allow the high TDH pump to find the system curve.

In evaluating systems, it is not unusual to find chilled water distribution pumps in large systems sized for 200 to 260 ft (600 to 780 kPa) TDH operating at less than 50% of the nameplate TDH. *Figure 2* shows an example of when pumps selected with too high TDH have difficulty intersecting the actual system curve. The system curves assume differential pressure reset strategy is implemented. The only way to get the actual system curve to intersect the pump curve in this circumstance is to create additional system pressure drop, wasting pumping energy. Contrary to what some believe, variable frequency drives do not always solve these problems. As the pump speed decreases, the pump curve moves down and to the left, resulting in less flow and head. Even if the variable speed drive can solve these large differences, the pump would operate inefficiently.

Gone are the days of letting the pump be oversized and run back on its curve at a low efficiency, low reliability operating point. It is vital to model hydraulic system performance in large distribution systems to understand the potential system curve for proper pump selection.

Ineffective Pumping Strategies

Some pumping strategies result in more than just poor efficiency; the system does not operate properly. Most ineffective pumping strategies are a result of not following the chilled water distribution system key objectives and pump selection fundamental principles. Some common pumping strategies to avoid include:

- Constant speed non-decoupled building pumps;
- Pumps operating on the flat part of the pump curve; and
- Pumps in parallel that do not have similar discharge pressures.

It is common to find systems where a constant speed booster pump has been added to improve chilled water flow to a building with high-pressure drop. This can have an adverse effect on the distribution return pressure by raising the return pressure near the building connection and in turn causing flow problems in adjacent buildings. These flow problems tend to manifest during peak load conditions when control valves are open. Building non-decoupled booster pumps should always be variable speed.

Pumps selected on the flat part of the pump curve can result in unpredictable performance. Pump head curves with very flat head flow characteristics can make the pump difficult to control. Small changes in system resistance can create large changes in the pump's flow rate. This makes the control of the pump difficult in situations that also have a flat system loss curve. The problem is exacerbated when variable-frequency drives are used to control the pump operating point. This can be avoided by selecting pumps to operate as close as possible to the best efficiency point and avoid the flat portion of the pump curve.

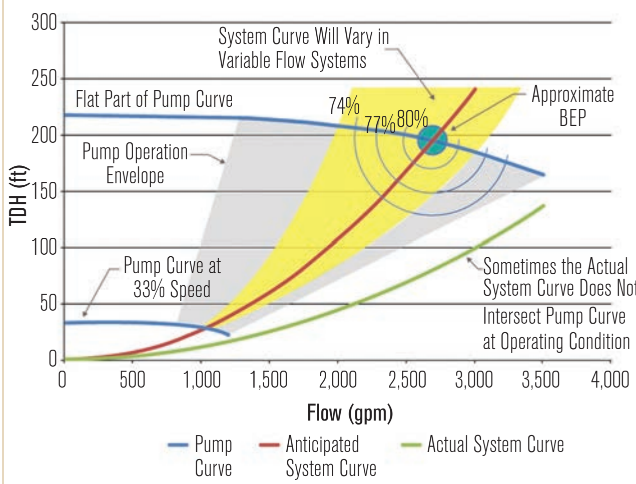

FIGURE 2 Pump and system curves.

It is common to have multiple pumps in parallel in large systems. Pumps operating in parallel are required to have the same TDH at the operating flow rate. The author has seen multiple chiller plants with variable frequency drives on only one to two pumps where more than three pumps are in parallel. This typically results in inefficient pump operation since the constant speed pump needs to run to the right of the best efficiency point (BEP) on the pump curve to match the VFD pump head. The parallel pump operating on VFDs can match speed to stay closer to the BEP on the curve. A similar mistake is selecting a parallel pump for low nighttime loads and using it throughout the pump staging sequence. If this pump is selected for low flow and low head, it can only be used as the first stage and not used in staging with the system pumps after the larger pumps are required to operate.

Summary

The benefits of understanding chilled water distribution system key objectives and pumping fundamentals are substantial. While it is often more memorable to experience problems in the field, it is cheaper and much less painful to learn from others! Hopefully, these tips can help designers and owners avoid the common problems in designing their next chilled water system.

References

1. Taylor, S., M. McGuire. 2008. "Sizing pipe using life-cycle-costs." *ASHRAE Journal* 50(8).
2. Peterson, K. 2014. "Improving performance of large chilled water plants." *ASHRAE Journal* 56(1). ■