Hydronics 101

BY JEFF BOLDT, P.E., HBDP, MEMBER ASHRAE; JULIA KEEN, PH.D., P.E., HBDP, BEAP, MEMBER ASHRAE

Authors' note: This article focuses solely on the basics related to configuration, layout, and major system components of hot water and chilled water systems as an introduction to hydronics for those new to the design industry.

The first documented hydronic cooling systems were connected to the Roman aqueducts, in which water was routed through brick walls of homes of the affluent. Hydronic heating became prevalent in buildings as the source of hot water expanded. The first commercial hot water boilers became available in the 1700s. Gravity hot water or steam heating systems were the norm in buildings until the mid-1900s.

The operation and design of these systems were greatly advanced with the introduction of water pumps early in the 20th century. Post-World War II, hydronic systems experienced significant competition with the development of forced air systems. Today, hydronic heating and cooling coils are frequently used in conjunction with forced air systems. More recently there has been a resurgence of hydronic applications at the zone level as a result of the increased emphasis on energy conservation.

Definition of Hydronics

This article uses the definitions of hydronics, open system, and closed system from ASHRAE Terminology on ASHRAE.org, which defines hydronics as "science of heating and cooling with water." Open systems are open to the atmosphere in at least one location. Systems that employ cooling towers as their heat rejection method are one of the most common examples of open hydronic systems. Closed systems, on the other hand, are not open to the atmosphere, except possibly at an expansion/compression tank.

Advantages of Hydronic Systems

Hydronic systems have several advantages:

- They require little space when compared to air systems. A 3 in. diameter pipe is needed to convey 1,000,000 Btu/h of heating or cooling energy when a 70 in. × 46 in. duct would be necessary to accomplish the same task with air.

(Assume a ΔT = 20°F and friction loss of 0.08 in./100 ft length for air and 4 ft/100 ft length for pipe.

Jeff Boldt, P.E., is a principal and director of engineering at KJWW Engineering in Monona, Wis. He is a member of standards committees 90.1, 189.1 and 215. Julia Keen, Ph.D., P.E., is an associate professor at Kansas State University in Manhattan, Kan. She is past chair of TC 6.1, Hydronic and Steam Equipment and Systems.

100 gpm = 1,000,000 Btu/h/[500(20°F)] and 46,000 cfm = 1,000,000 Btu/h/[1.086(20°F)].)

- Energy loss due to pipe leakage is almost nonexistent.
- Transport energy is very low. For example, transporting 1,000,000 Btu/h of cooling in a ducted air system may require 100 hp of fans, whereas a typical hydronic system would require about a 2 hp pump.

1,000,000 Btu/h/(20°F × 1.086) = 46,000 cfm × 90.1 limit + allowances ≅ 60 to 120 bhp.

1,000,000 Btu/h/(20°F × 500)= 100 gpm × 50 ft of head × 0.0002525/70% pump efficiency = 1.8 bhp.

- Noise complaints are less common than in air systems, as long as established pipe sizing principles are followed.

How Many Pipes?

Closed hydronic systems commonly are referenced based on the number of pipes within the system: one-, two-, three-, and four-pipe. One-pipe systems have one supply pipe and return from each coil connected back into that same pipe. The advantage of one-pipe systems is reduced piping cost. The disadvantage is a loss of exergy because of blending of temperatures in the supply main. One-pipe systems are rare, but sometimes seen in geothermal heat pump systems or individual floors of buildings with heating water systems.

A two-pipe system is depicted in *Figure 1*. It has one supply pipe and one return pipe. This type of system can heat, or it can cool, but it cannot do both simultaneously because it is using the same distribution piping but opening and closing valves to isolate the heat source (i.e., boiler) or heat sink (i.e., chiller). This is the main disadvantage of a two-pipe changeover system. A building must be fully in cooling or fully in heating, which is unlikely to make all occupants comfortable, especially during moderate climatic conditions. Deciding when to change from heating to cooling can be a major issue with two-pipe systems.

Three-pipe systems have a separate supply pipe for hot water and chilled water but a common return pipe for both. This system allows for simultaneous heating and cooling with reduced length of installed piping but at the sacrifice of energy. Therefore, three-pipe systems are not permitted by modern energy codes. The energy consumption of three-pipe systems is very high because the mixing of chilled and heated return water creates

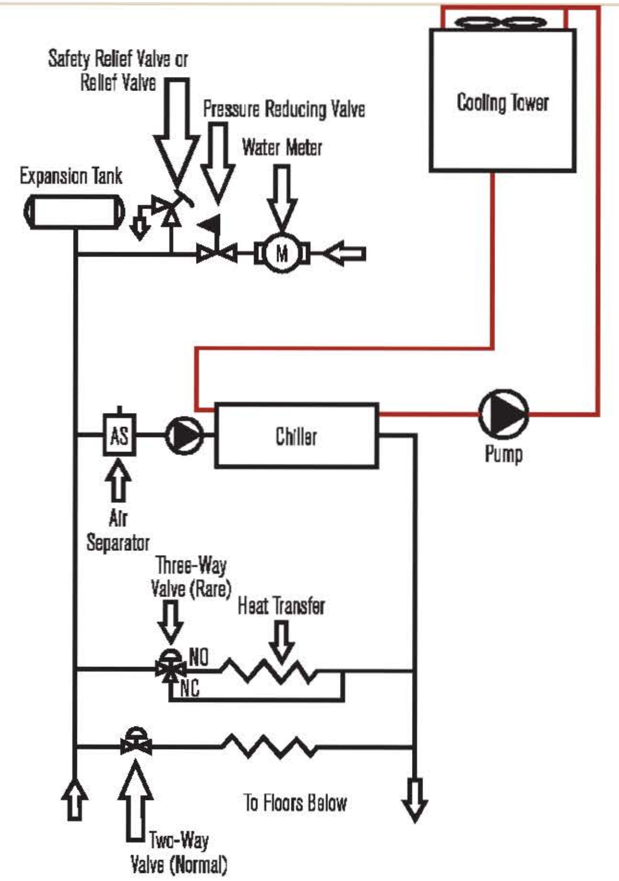

FIGURE 1 Chilled water closed system with cooling tower open system. Feed water components are not shown for the cooling tower (condenser) loop.

a much greater temperature differential at the heat source or sink, requiring more work.

Four-pipe systems as depicted in *Figure 2* have separate supply and return pipes for hot water and chilled water. Four-pipe systems can provide heating to some coils while simultaneously routing cooling to other coils. This makes them very versatile and provides for much greater occupant comfort, but the first cost of the piping is higher than that for the other piping system arrangements.

Direct vs. Reverse Return

In addition to the number of pipes used in a system, the piping configuration must also be considered. There are two configurations: direct and reverse return. Direct return systems use less piping and are depicted in *Figure 1*. Reverse return systems require more return piping, but simplify the balancing of systems, because the pipe length to each coil is approximately the same (*Figure 3*). A single piping system can combine direct and reverse

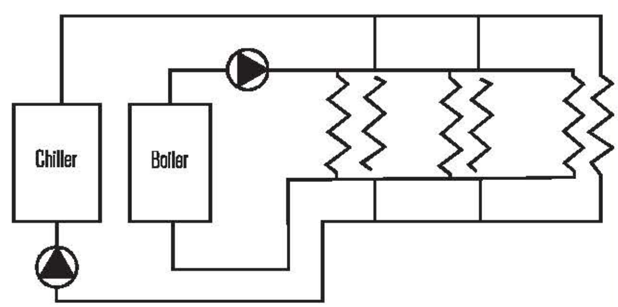

FIGURE 2 Four-pipe systems have a separate supply and return pipe for hot water and chilled water.

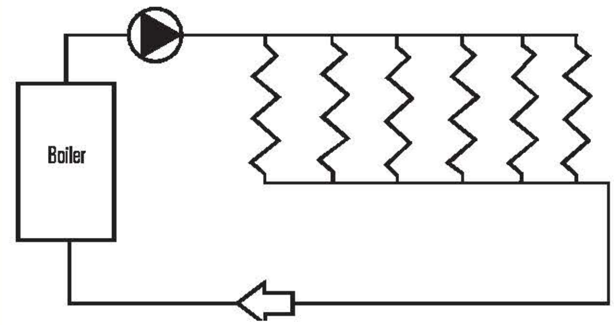

FIGURE 3 Two-pipe reverse return systems require more return piping, but simplify the balancing of systems.

return. Combining the configurations is commonly done to reduce the first cost of the system while reaping most of the benefits of a reverse return system. In a large multi-story building, direct return may be used to minimize the large piping (such as the main supply and return risers), but to make balancing easier reverse return may be used to serve small coils located on each floor. (A complete analysis of direct and reverse return can be found in Reference 1.)

Hydronic Components

Both hot water and chilled water systems have common components that serve similar purposes. The components that are common include: piping, pumps, air separators, expansion tanks, fill accessories, valves, and accessories. The following section will discuss each of these components and the purpose they serve in the system. This will be followed by a discussion of the differences between hot water and chilled water system component layouts.

Piping and pump selection, sizing, and layout are critical to the proper design of a hydronic system. The piping will have a direct impact on pump selection because it will influence the pump head and energy required to move the water through the system. There are many different factors to consider when designing and laying out the piping as well as when selecting the pump to apply to a hydronic system. Piping design must consider the pipe material, flow rate, water velocity, fittings, and friction loss. The flow rate depends on the load and temperature differential selected for the pumped fluid. The pump type (inline, base mounted, etc.), pump arrangement (primary, primary-secondary, etc.), and pump controls must all be decided and will have a significant impact on the energy consumed over the life of the building. (These topics require far more discussion and detail than can be contained in this article; therefore it is encouraged that the *ASHRAE Handbook*, Chapters 13, 44 and 47, be consulted when beginning design.)

Air separators remove entrained air from hydronic systems. If this is not done, corrosion rates may be high and noise may become prevalent when air is lodged in equipment near occupied areas. Air separators should be located where air is least soluble in water—this depends on two factors the hottest water temperature and the lowest system pressure. Curves are available to describe the exact relationship between pressure, temperature, and solubility. (See *2012 ASHRAE Handbook—HVAC Systems and Equipment*, Chapter 13, Figure 3.) Centrifugal separators are very common, but competing designs are making inroads.

Expansion tanks control the system pressure and absorb the expansion/contraction of water as the temperature changes. Today, most expansion tanks include a bladder or diaphragm, allowing the water to be totally separated from atmospheric air, minimizing the introduction of oxygen that contributes to corrosion. Expansion tanks are sized based on the total volume of the system, maximum temperature variation, and maximum and minimum pressures that are acceptable at the tank location.

Fill accessories include water meters, pressure reducing valves, backflow preventers, and safety relief valves (SRVs), and pressure relief valves (modulating relief valves, as opposed to "popping" safety valves). Water meters measure the amount of makeup water. Tracking the amount of makeup water is important because it reveals how many gallons of fresh water, including fresh oxygen, were added to the system. Makeup water is needed regularly to keep the piping full in closed systems because water is drained in the blowing down of strainers, draining of coils in the winter, improperly operating automatic air vents, and system leaks. Minimizing makeup water maximizes system life because it limits the introduction of oxygen to the system.

Pressure reducing valves are included to reduce the water pressure entering the system from the building potable water system, which is often higher than that of the hydronic system. Plumbing codes require backflow preventers to prevent backflow of chemicals, biological growth, etc., from hydronic systems to potable water systems. The pressure reducing valve is normally selected to maintain 5 psig (34 kPa) of positive pressure at the lowest pressure portion of the system (normally the return side of the system on the top floor). A rule of thumb is 5 psig plus 5 psig (34 kPa plus 34 kPa) per floor of building height. A small SRV is often located downstream of the pressure reducing valve. The purpose of the SRV is to relieve excess pressure from the system when outside the desired conditions. This very small SRV located at the system fill location is added to avoid operation of the much larger SRVs at each major boiler or heat source.

Valves are used to control water flow. Many different valve types are used in hydronic piping applications. The decision as to the type of valve depends on its size and use. Ball valves are probably the most common form of on-off or modulating two-way valve used today.

Advances in elastomer technology have made ball valves economical and reliable. Butterfly valves dominate the market in applications larger than 2.5 in. (64 mm) because ball valves become more expensive in large sizes. Once common, gate and globe valves have had much reduced market share in recent decades because ball (smaller size) and butterfly (larger size) valves are less expensive. Three-way valves are another valve type commonly used in the past. These have become less popular as technology has allowed system water flow to be variable, rather than constant, which results in reduced energy use (encouraged by energy codes). Three-way valves are sometimes necessary in systems that use equipment that requires a minimum water flow rate. Check valves are installed to prevent reverse water flow.

Multi-function or triple-duty valves are ubiquitous on pump discharge piping. They provide the functions of a balancing valve, shutoff valve, and check valve at a low cost and in a compact configuration. The disadvantage of the triple-duty valve relates to its balancing function. In variable speed pump applications often used today, the balancing function is not desired at the pump and can waste significant pumping energy if discharge valves are throttled. In addition to not needing all the functions, the pressure drop for a triple-duty valve is higher than for most combinations of check valve, flow measuring device, and shutoff valve. Therefore, in some applications it may be more appropriate to use a separate check valve, shutoff valve, and flow measuring device in lieu of a triple-duty valve.

Besides the many necessary pieces of a hydronic system for operation and control, there are a number of accessories that are typically installed to more easily monitor the system and troubleshoot when there is a problem. Pressure gauges often wear out far sooner than expected. All manufacturers recommend closing the shutoff valves when readings are not being taken to reduce wear on the movement mechanism, which is usually a bourdon tube with a rack and pinion assembly. However, most operators leave the valves open continuously. Therefore, snubbers are recommended on all gauges.

Snubbers dampen pressure changes so that gauges read a steady average pressure instead of bouncing wildly. Where gauges aren't needed continuously but occasional readings of pressure or temperature are needed, test plugs or pressure/temperature plugs are installed. These plugs allow for instruments to be installed as needed without having to interrupt the system operation. It is helpful to locate a plug near all DDC pressure or temperature sensors to aid in calibration.

Hydronic Heating System Layout and Components

Many common components exist between chilled water and hot water systems, but the position of the components within the piping system is different. *Figure 4* depicts the normal location for boilers in hydronic systems. Boilers are commonly the heat source in a heating hot water system. The two classifications of boilers used in commercial hydronic systems are fire-tube and water tube. (A discussion comparing the different boiler types and their application is too extensive to be included in this article, and it is recommended that the information be obtained from the *ASHRAE Handbook*, Chapter 32.)

Most hydronic components are rated for at least 125 psi (862 kPa) of differential pressure between the interior pressure and the exterior (atmospheric) pressure. Cast iron flanges and fittings are generally rated at 125 psi (862 kPa). Steel flanges and fittings are rated at 150 psi (1034 kPa). Often, the boiler is the lowest pressure-rated item in the system, with 15 psi (103 kPa) steam/30 psi (207 kPa) water matching the ASME definition of a low-pressure system. Because of this, the boiler is generally placed immediately upstream of the expansion tank, which controls system pressure and is the point where pressure remains relatively constant. It is also directly upstream of the air separator because the water leaving the boiler is the hottest water in the system and, therefore, can hold the lowest concentration of entrained air. Water pressure also affects air separation. Therefore, when the boiler is in a basement, it may be preferable to have the air separator at the top floor.

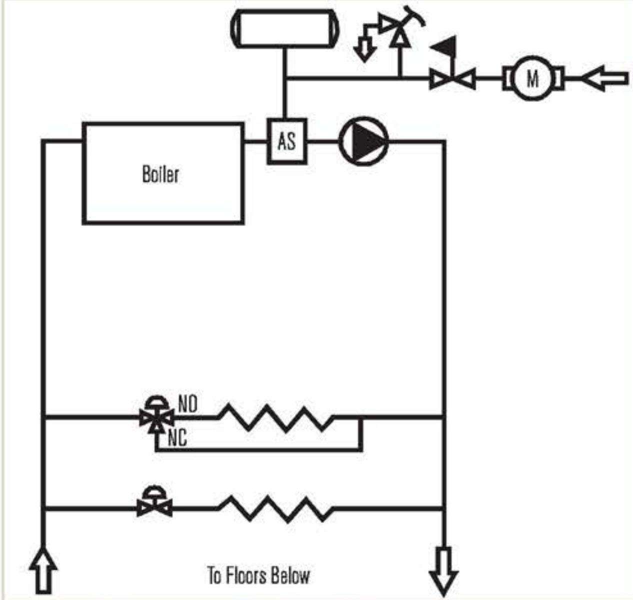

FIGURE 4 Hydronic system with a boiler in the typical location.

Hydronic Cooling System Layout and Components

The obvious difference between a hydronic heating and cooling system is the production of hot or chilled water. In lieu of a boiler, in a hydronic cooling system a chiller is used. There are many types of chillers;

reciprocating, scroll, helical rotary, centrifugal, and variations that recover heat from one process to transfer to another. (A discussion comparing the different chiller types and their application is too extensive to be included in this article, and it is recommended that the information be obtained from the *ASHRAE Handbook*, Chapters 42 and 43.)

There are some differences between the system layout of heating and cooling hydronic systems. Cooling hydronic systems have expansion tanks, but they can be much smaller than in heating systems because of the much lower temperature difference between the maximum and minimum fluid temperatures.

Theoretically, the fill water is warmer than the normal chilled water temperature, resulting in makeup water being added to the system to fill the piping when the chilled water is brought down to operational temperature. Some designers delete air separators in cooling hydronic systems, although this is not recommended. Heating systems, on the other hand, need much larger expansion tanks and air separation is a more critical design concern because air more easily separates from heated water (watch bubbles form when you heat a pan filled with water).

Summary

Hydronic systems are a staple of our industry. They provide large amounts of heat transfer with low first costs and energy costs for transporting energy. This article provides only a basic overview and introduction to hydronic system design, layout, and components. For more information, on the topic of hydronic systems, the *ASHRAE Handbook* is an excellent reference.

We plan to cover many other hydronic topics: condensing boilers, valve-coil-heat transfer, pressure independent control valves, etc., in future articles.

References

1. Taylor, S., J. Stein. "Balancing variable flow hydronic systems." *ASHRAE Journal* 8.

2. *2012 ASHRAE Handbook—HVAC Systems and Equipment*, Chapters 32, 36, 43, and 44. ■