The Evolution of Primary/ Secondary Pumping

How a simple concept became instrumental to hydronic system design.

BY BOB ARENTSEN, P.E., MEMBER ASHRAE; MIKE LICASTRO, ASSOCIATE MEMBER ASHRAE

The concept of primary/secondary pumping pioneered by Bell & Gossett has been around since the mid-1950s, when hydronic heating was in its infancy. Gil Carlson, a Bell & Gossett engineer, internationally recognized as one of the foremost authorities on hydronic heating systems, is largely credited with developing primary/secondary pumping. Since its advent, this hydronic heating technique has been significant in the design of pumping systems for commercial heating and chilled water cooling systems, and, more recently, residential and light industrial systems.

Although originally developed for large buildings with multiple zones and long loops of pipe, the primary/secondary pumping method is increasingly being used in a variety of modern hydronic system applications. Today, primary/secondary pumping is used in homes for radiant heating systems, including under-floor systems. Modern high-efficiency condensing boilers also benefit from primary/secondary pumping to protect them from thermal shock, low or no flow that can result in localized boiling and scaling, and excessive flow that can cause erosion.

Solving a Problem Job

Considered by many in the industry as one of the founding fathers of hydronic heating, Carlson earned his engineering degree from Purdue University. In 1946, he joined Bell & Gossett, working at the Morton Grove, Illinois facility until his retirement in 1988.

Carlson held seven United States patents and was an ASHRAE Fellow. He also served on the Industry Advisory Committee of Purdue's Herrick Laboratories for 32 years. During his tenure with Bell & Gossett, Carlson conceived heating products like the Red Ring Monoflo tee, the Triple Duty valve, the Circuit Setter balance valve and the Dyna-Disc Setter balance valve.[1]

Carlson was also essential in developing and promoting engineering principles and piping techniques as the hydronic industry developed. In fact, it was during a field call to troubleshoot a newly installed commercial hydronic system that Carlson came up with the concept of primary/secondary pumping.

According to industry lore, it was 1954 and Carlson and his colleague Jack Hanley, Bell & Gossett's eastern

Bob Arentsen, P.E., is an associate principal engineer and Licastro is manager of training and education–commercial building systems/HVAC at Xylem Bell & Gossett.

field representative, were called to consult on a hydronic system installed in a large garden-style apartment complex in Manhattan that was not delivering heat to the building's units. The system had been designed to operate as a Monoflo heating system, which relies on one primary circulator to pump hot water around the heating main. With a Monoflo system, there is only one main, and each riser's supply and return pipe is connected to that single main. Monoflo tees, which have a cone-shaped fitting inside that reduces the opening of the tee, are installed along the perimeter, causing pressure drop as water flows along the primary main. This pressure drop then causes a portion of the water to move off the main and into the radiation circuit. In the case of the cold apartment complex, water was flowing nice and hot along the main but not flowing up into the radiation loops.[2]

The problem became apparent when Carlson discovered that two different engineering firms had designed the heating system. One firm had significantly oversized the primary main piping, while the other firm had undersized the distribution and radiation piping.

To solve the issue, Carlson suggested raising the boiler temperature and installing a small, in-line booster pump on the supply riser of each building. The idea was to turn on the booster pumps every time the main circulator was running. By circulating the same flow at a higher temperature, the booster pumps could overcome the pressure drop of their own risers and radiation circuits. As a result, building residents had all the heat they needed—and a new, innovative method of pumping multiple circulators was born.[3]

Today, primary/secondary pumping is a standard technique employed every day by engineers, contractors and boiler manufacturers, who use the method to control multiple-boiler systems and radiation circuits in commercial buildings.

How Primary/Secondary Pumping Works

Primary/secondary pumping is simple in theory and practice. Its operation is based on this basic rule:

When two circuits are interconnected, flow in one will not cause flow in the other if the pressure drop in the piping common to both is eliminated.[4]

At its simplest, the primary/secondary pumping method calls for two (or more) "loops" of heating water—a primary loop that exits from and returns to the boiler and a secondary loop that takes water from the primary loop and moves it around a room or similar "zone." This arrangement needs two or more circulator pumps, but these can be small, energy-saving pumps.

In primary/secondary applications, the primary and secondary circuits are treated separately. Secondary circuit pump heads have no effect on the primary circuit pumping head requirements, and vice versa.

This singular fact permits the design of a large hydronic system as though it were a number of small systems. The function of the primary circuit simply becomes one of heat conveyance to or from the secondary, while the secondary circuit serves the terminal heat transfer units.[5]

Since the secondary circuits are energy-head-isolated from the large primary pumps, the control problem in the secondary circuits is minimized; pressure ratio increases across control valves, which can be set low because secondary pump heads are low. In effect, control isolation is achieved with a remarkable decrease in operating problems.[5]

As a result, primary/secondary pumping offers two important advantages:

- Less energy is required to move water through the entire system (rather than one large circulator, small energy-efficient circulators can be used to overcome the friction and inertia—or pressure drop—of their respective loops).
- More control can be taken over zones (and each zone can operate at its own optimum temperature).[6]

When it comes to designing primary/secondary pumping systems, there are a few fundamental rules:

The common pipe. The key to all primary/secondary applications is the use of a common pipe, which interconnects the primary and secondary circuits. The length of this pipe should be kept very short in order to keep the pressure drop low, and the supply and return tees to the secondary circuit should be a maximum of four pipe diameters apart. By keeping the pressure drop very low, water that is flowing in the primary loop will not flow into the secondary circuit until its circulator turns on.[6]

The secondary pump. A separate pump is installed in the secondary circuit to establish flow. This pump is sized to move the flow rate and to overcome the pressure drop of its circuit only. The pump should be located so it is pumping away from the "common piping" and discharging into the secondary circuit. This causes an increase in pressure in the secondary circuit rather than a reduction in pressure, which would occur if the pump were located on the return, pumping toward the common pipe.[6]

The "law of the tee." Primary/secondary pumping pioneer Carlson was fond of declaring: "Whatever goes into a tee, must come out of that tee."

This simple statement came to be known as the "law of the tee." And to fully understand primary/secondary pumping, it's important to understand this essential concept.

The "law of the tee" refers to what happens in the common piping. The flow rate and the direction of the flow rate that occurs in the common pipe needs to be discussed. Because one circuit is hydraulically isolated from the other, there can be different flow rates occurring in each circuit. These different flow rates will meet in the common piping. The law of the tee determines the flow rate and direction of flow that occurs in common piping. It is based on the relationship of the primary and secondary flow rates, and there are three possibilities to evaluate:

- The flow in the primary piping can be greater than the flow in the secondary circuit.
- The flow rates can be equal.
- The secondary flow rate may be greater than the primary.[6]

With different flow rates coming together in the common pipe, mixing of water temperatures is going to occur. Depending upon the flow rates of the primary circuit versus the secondary flow rate, supply water temperatures going to the secondary circuit can be mixed down. Conversely, the return water's temperature going back to the primary main can be elevated.

The possibilities are endless—which is one reason why a primary/secondary pumping system can achieve what other hydronic systems cannot.[3]

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The Basis of Modern Hydronic Systems

Since it was first conceived in 1954, the primary/secondary pumping method has stood the test of time and remains widely used today. As most modern large systems use some variation of the primary/secondary pumping technique, it's fair to say that primary/secondary pumping has become the baseline piping standard for most multi-load/multi-temperature hydronic systems.

The pumping arrangement was originally developed as a method of increasing allowable system temperature design drops, decreasing required pumping horsepower and increasing system control quality. However, many low-temperature and medium-temperature systems have been designed using temperature drops that correspond closely to those normally associated with high-temperature water systems.

Corresponding decrease in pumping horsepower as compared with conventional systems has also been proven. System control characteristics have been leveled out and smoothed because the high pressure rise characteristic across control valves as caused by a single high-head pump has been eliminated by primary/secondary breakdown of the system into a number of individually pumped low-energy head circuits. In addition, however, many other applications have been developed; anti-freeze design, chiller and boiler pumping and control arrangements, newer terminal equipment control arrangements, zone switchover methods, etc.[5]

Primary/secondary pumping systems are unique in their ability to keep the peace among several independently operating circulators, each delivering heat to its assigned load.

Simplifying the Piping Arrangement

As the primary/secondary pumping method proved to be successful for hydronic system design, Bell & Gossett sought to make the technique even simpler, introducing the first primary/secondary device—the B&G Primary-Secondary Fitting—in the late 1950s. The B&G Primary-Secondary Fitting provided a

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foolproof method for installing primary/secondary circuits.[7]

More than 60 years later, primary/secondary pumping continues to provide the same advantages, but at a higher rate when used with today's evolving equipment. The growing popularity of condensing and other modern boilers has made the use of primary/secondary piping more important. Ironically, these new-style high-efficiency boilers have a greater flow resistance than their predecessors. However, by hydraulically separating the flow in each circuit, the flow through the high-flow resistance boiler does not restrict the flow in the secondary circuits. This enables each leg of the circuit to be run at its optimal flow rate and temperature, raising the overall system efficiency.[7]

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To keep up with these modern systems and to simplify the piping arrangement, several manufacturers introduced a fixture known as the low-loss header, or hydraulic separator. The low-loss header simplifies the primary/secondary piping circuit and also eliminates a few other necessary components. It provides air separation, dirt collection and, most importantly, hydraulic separation from the boiler circuit to the distribution circuit. This results in cost savings since this single unit is less expensive and faster to install than all of the extra components.

A standard low-loss header device, like Bell & Gossett's Primary-Secondary Header (PSH), efficiently separates the primary and secondary circuits by acting as a closely spaced tee, which is normally seen in a traditional primary/secondary piping. Additionally, a low-loss header acts as an air and dirt separator, eliminating the need for any other central air separator in the system. The vessel is designed to create a low-velocity area, allowing air to rise to the top and sediment to sink to the bottom. Opening the purge valve at the bottom of the low-flow header allows the dirt to be flushed out of the system.[7]

Beyond Commercial Systems

While most of the applications for primary/secondary pumping have been in large commercial systems such as chilled water campus systems, dual temperature change-over systems and freeze protection for makeup air systems, hydronic system designers are increasingly discovering the value of primary/secondary pumping systems in residential and light industrial applications.

Residential hydronic systems today are often more sophisticated than those in large commercial buildings. Beyond space heating, these multi-load/multi-temperature systems may incorporate a range of loads, from domestic water heating, to radiant panel heating, to snow melting, to intermittent garage heating, to pool heating.

Primary/secondary pumping is particularly relevant for radiant heating systems, including underfloor systems. Typically, the design specifications for underfloor heating loops require much lower water temperatures than are supplied by the boiler; however, boiler return temperatures must be kept above their minimum. Water might be exiting a secondary radiant loop at 90°F, but the minimum return temperature of a domestic boiler might be 140°F. In a primary/secondary system, cooler water exiting the secondary mixes with hotter primary loop water, ensuring that water returning to the boiler is warmer than the minimum.[8]

Other Methods Emerge

Although valued for their simplicity and flexibility, primary/secondary pumping systems may not be appropriate for all projects. While the design typically has low first costs, has flexibility and reduces the complexity of the chiller or boiler staging and control by eliminating on/off valves and minimum/maximum flow requirements, efficiency is limited because the zone nearest to the primary loop is susceptible to over-pressurization.

In the last decade, manufacturers have developed more sophisticated HVAC equipment. Today's chillers and boilers are equipped with their own variable frequency drives (VFDs), enabling a significant range of flow so equipment can be under-flowed or over-flowed and still function optimally. The advances in controls, chiller and pump technologies ultimately led to the development of the variable primary pumping method. This technique, which features staged pumps and chillers, relies on variable speed secondary pumps and uses two-way valves.

In a primary/secondary system, a chiller and its primary pump typically operate in tandem. In contrast, the variable primary flow system can separate pump control from chiller sequencing.

The variable primary system design is relatively simple, with only one set of pumps creating flow for the entire system. There is still a common pipe between the chiller or boiler pumps and the system distribution, but there are no secondary pumps. A control valve is installed in the common pipe. Throttling this valve creates a pressure drop through the common pipe, which forces more water into the distribution piping. The control valve is the only means of regulation in this type of system.[9]

Like the secondary pump in a primary/secondary system, the pumps in a standard variable primary flow system operate to maintain a target differential pressure at a specific point in the system. This pressure difference tends to decrease when the air-handler control valves open in response to increasing loads. To restore differential pressure across the system, the pump controller increases the speed of the pump. Conversely, when the air-handler control valves close in response to decreased coil loads, the pump controller slows the pump speed to maintain the target differential pressure.[10]

A major benefit of the variable primary flow system is that low Delta *T* can be managed by controlling the pump flow rate, and neither a neutral bridge nor three-way valves are required. Using variable speed pumps, chiller flow is adjustable to match system Delta *T*, and the number of operating pumps does not need to match the number of chillers.

Variable primary flow designs use fewer pumps and piping connections than primary/secondary systems, which means fewer electrical lines and a smaller footprint for the plant. These factors may reduce the initial cost of the chilled water system. Since fewer pumps are needed with this method, the capital investment is less, energy costs are lower and less space is required.[11]

Although the variable primary flow method can be an ideal solution for new chiller plants, the pumping technique can be difficult for retrofit projects, as it requires properly sized valves and controls as well as a building automation system (BAS) that is able to monitor the optimal pressure throughout the building.

The setup of the controls system for variable primary flow system pumping systems is key to its success. If not configured properly, the variable-only pumps will provide little operational benefit for the building.

A Lasting Legacy

Today there are many ways modern hydronic systems can be pumped, and each method has its own distinct advantages and disadvantages. That does not diminish the lasting importance the primary/secondary pumping method has had on the hydronic industry.

The development of primary/secondary pumping was essential to removing the barriers to using hydronic systems for large commercial building projects. And now, more than 60 years later, there continues to be new discoveries of how the primary/secondary pumping method can be applied in various applications—from large commercial, to light industrial, to residential.

Despite the advent of newer hydronic pumping methods like variable primary flow, the primary/secondary pumping method has proven itself as a versatile piping method that is increasingly being used as the backbone of modern multi-load/multi-temperature hydronic systems.

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