Primary/Secondary Piping: Back By Popular Demand

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The concept of primary/secondary (P/S) piping has been around since the mid 1950s. Until the last decade, it was used mostly for larger commercial heating and chilled water cooling systems. But renewed interest in radiant floor heating, combined with increasingly sophisticated expectations placed on residential and light commercial systems, prompted designers to look for a piping method more flexible and forgiving than the standard 2-pipe system. It turns out their predecessors had already made most the fundamental discoveries. During the last few years many of these principles have been "redeployed" and successfully integrated with modern controls. The result is an extremely versatile piping method that's increasingly being used as the backbone of modern multi-load/multi-temperature hydronic systems.

Inseparable

The fundamental concept of a P/S system is to "uncouple" the pressure differential established by any given circulator, from those established by other circulators in the same system. P/S piping allows any pump in the system to operate with virtually no tendency to induce flow, or even disturb flow, in circuits other than it's own. It's about as forgiving as hydronics can get.

There are at least a couple other conceivable ways to isolate the flow dynamics of one circuit from those of another circuit in the same system. One uses a hot water reservoir tank to serve as a common pressure reference point for each of several circuits piped to it. Another isolates each circuit from the others using heat exchangers. Both of these pale in comparison to the simple elegance of the P/S approach, which makes the piping common to both circuits as short as possible. A pair of closely-spaced tees performs the desired task at a fraction of the complexity and cost of other methods (see **Fig. 1**).

Since the pressure drop between the closely-spaced tees in the primary circuit is almost zero, there's virtually no tendency for flow in the primary circuit to induce flow in the secondary circuit. When the secondary circulator operates it establishes its own pressure distribution in the secondary loop. The primary loop simply becomes the source of hot water (as opposed to a direct connection to the boiler or a holding tank).

The primary loop also becomes the pressure reference point for the secondary circuit. In effect it acts like an expansion tank for the secondary circuit. Because of this, it's important that each secondary circulator pumps into its circuit, (i.e., away from the expansion tank reference point). This allows the pressure in the secondary circuit to increase when its circulator operates.

P/S to the Rescue:

Consider the hydronic system shown in **Fig. 2**. Two circulators share common header piping with a heat source having a high flow resistance (a heat exchanger coil for example). Either pump operating by itself produces flow in its own circuit. However, if both circulators operate simultaneously the head loss across the heat source caused by the larger circulator is greater than the shut-off head of the small circulator. There will not be any flow in the circuit served by the smaller pump. In fact, the check valve in this circuit will be back-seated whenever the larger circulator is running. This is flow interference in the extreme, and I've witnessed it first hand. It's relatively easy to create inadvertent situations likes this when combining large and small circulators in a common parallel piping arrangement. Especially if there's a component common to the circuits that has a high flow resistance. It's a problem that simply can't happen using P/S piping.

NOTICE! Gravity Is Still In Effect:

Years ago, I had a physics professor who, after correcting some tests, pointed out that someone in my class had begun a mechanics problem with the convenient statement, "Assuming gravity can be ignored...." The student then proceeded through the math in a futile attempt at finding the correct answer. While still in denial over that student's blatantly inept assumption, the professor pointed out that most things in physics would be a lot simpler if we could just "ignore gravity."

Because we rely almost exclusively on circulators to propel water through our modern piping systems it's easy to forget that hot water still "wants" to go up and cool water "wants" to descend--an effect sometimes referred to as "gravity flow." Our predecessors discovered this and even learned to wield it to their advantage. They also discovered that certain piping arrangements, including some found in P/S systems, had to be protected against undesirable heat migration.

In P/S systems there are two primary causes of hot water migrating to places it isn't desired:

1. The natural thermosiphoning tendency of hot water in a piping loop installed above a heat source (e.g. "gravity flow").

2. The pressure drop between the closely-spaced tees at the P/S piping interface is still not zero. Without a device to block it, some hot water will still migrate from the primary circuit into an inactive secondary circuit.

Every secondary circuit in a P/S system must include detailing to prevent heat migration when its circulator is off. One method is to install flow-check valves (which have a weighted plug) on both supply and return risers of the secondary circuit. The opening pressure of these valves is about 1/4 psi. Sufficient to prevent buoyancy forces from sneaking any hot water into the secondary circuit when the pump is off. A spring-loaded check valve is an acceptable alternative to a flow-check in these locations.

Two other options exist for the return riser. One is an underslung piping loop which forms a thermal trap (see **Fig. 3**). The other is a swing check. However, neither of these will prevent forward flow caused by buoyancy forces, hence neither should be used on the supply side of the secondary circuit.

Purging Provisions

The closely-spaced tees connecting a secondary circuit to the primary circuit are counter-productive to the desired effect when the system is being purged of air. A strong purging flow in the primary circuit will not induce a similar flow in a secondary circuit. The solution is to install a means of independently purging each secondary circuit. One approach is to install ball valve and hose bib near the end of each secondary return riser (**Fig. 3**).

During purging, the ball valve is closed forcing pressurized make-up water in the desired direction through the secondary circuit as air is blown out through the open hose bib. On larger systems the hose bib may be too restrictive during purging. In this case use a larger ball valve with barbed hose connection as the outlet. Some manufacturers have combined the function of these two valves into a single specially valve. They're available in pipe sizes up to 1-1/4 inches.

Sizing the Primary Circulator

Every circulator in a P/S system functions as if it were installed in an isolated circuit. The primary circulator does not assist in moving flow through any of the secondary circuits, or vice versa. The function of the primary loop is simply to convey the output of the heat source to the secondary circuits while operating at a selected temperature drop.

The flow rate necessary to deliver the output of the heat source using a specific temperature drop is found using **Formula 1:**

$$f_{primary} = Q \div 490 \text{ x } gT$$

Where: $f_{primary}$ **= flow rate in the primary circuit (gpm)**

Q = heat output rate of the heat source (Btu / hr)

gT = intended temperature drop of the primary circuit (F)

490 = a constant for water at an average temperature of 140 F, (use 470 for 30% glycol, 450 for 50% glycol).

For example: A primary circuit is connected to a boiler having an output rating of 250,000 Btu/hr. It will supply a primary piping loop that is intended to operate with a temperature drop of 15 F. What is the necessary primary loop flow rate? **Solution:**

$$F_{primary} = Q \div 490 \text{ x } gT$$

$$= 250{,}000 \div 490 \text{ x } 15$$

$$= 34 \text{ gpm}$$

The designer now chooses a piping size and estimates the head loss of the primary loop based on this flow rate. A circulator capable of providing this head at the calculated flow rate is then selected.

Selecting a high gT for the primary circuit results in lower flow rates, and often reduces primary pipe size. It may also reduce the size of the primary circulator. However, A larger gT also implies lower supply water temperature to secondary circuits located downstream on the primary loop. This is fine for systems using both high temperature and lower temperature heat emitters provided the higher temperature secondary circuits are located near the beginning of the primary circuit, while those with lower water temperature requirements are located near the end.

Secondary Circuits in Series

When secondary circuit are connected in series along a common primary loop the designer must account for the temperature drop associated with each operating secondary circuit. Use **Formula 2:**

$$gT = Q_{secondary} \div 490 \text{ x } f_{primary}$$

Where: $gT_{primary}$ **= temperature drop in primary loop due to an operating secondary load (F)**

$Q_{secondary}$ **= design heating load of secondary circuit (Btu/hr)**

$F_{primary}$ **= flow rate in primary loop (gpm)**

490 = a constant for water, (use 470 for 30% glycol, 450 for 50% glycol).

The heat emitters in the various secondary circuits need to be sized based on the water temperature available to them based on the location of the secondary circuit along the primary circuit, as well their individual location within a given secondary circuit.

If a conventional boiler is used, be sure to check that the water temperature at the end of the primary loop (when all loads are operating) is above the dew point of the boiler's exhaust gases. Minimum return temperatures of 130 F for gas-fired boilers, and 150 F for oil-fired boilers are often suggested.

Secondary Circuits in Parallel

When the same water temperature needs to be supplied to each of several secondary circuits, the primary circuit can be split into several parallel "rungs" as shown in **Fig. 4**. Each rung should be equipped with a flow balancing valve such that flow rates can be proportioned to the load each rung serves. The pipe sizes of the rungs can even be different if the branch loads vary considerably. The split primary loop approach is especially helpful when several of the secondary circuits need to operate within a fairly narrow water temperature range.

Secondary Creativity

The design of secondary circuits is not limited to a series loop of heat emitters. In fact any piping design that could be connected to a boiler can in effect be connected to the closely-spaced tees at the P/S interface. Some examples are shown in **Fig. 5**.

The secondary risers can be treated as headers from which two or more independently controlled zone circuits can begin and end, or the secondary circuit could form a two pipe direct- or reverse-return subcircuit. Another possibility is to install a pumped manifold station as the secondary circuit connected to circuits of flexible PEX or PEX-AL-PEX tubing which run out to individual heat emitters. The latter is known as a "homerun" distribution system.

Several mixing strategies used in conjunction with low temperature distribution systems (such as radiant floor heating) use the higher temperature primary circuit to create a second mix point that boosts water temperature before it returns to the boiler thus preventing sustained flue gas condensation. There are lots of piping possibilities. Just think of the closely-spaced tees as equivalent to a boiler, and design as appropriate from that point out.

Summary of P/S Design Practices

Here's a summary of the basic principles to keep in mind when designing a P/S system:

- The center-to-center spacing between the side ports of the tees at the P/S interface should not exceed 4 times the diameter of the primary piping.
- To minimize turbulence install a minimum of eight pipe diameters of straight pipe upstream of the first tee (of a closely-spaced pair), and four pipe diameters of straight pipe downstream of the second tee.
- Pump into the secondary circuit so that circuit pressure increases when operating.
- To minimize turbulence specify a minimum of 10 pipe diameters of straight pipe upstream of the inlet of any inline circulator.
- Always install measures to prevent heat migration into inactive secondary loops.
- In a series P/S system account for the decrease in water temperature from one secondary circuit to the next (using **Formula 2**). Size heat emitters accordingly.
- In a series P/S system install loads requiring higher water temperature near the beginning of the loop, and those capable of operating at lower water temperatures near the end of the loop.
- Size each circulator as if it's in a stand-alone piping system.

  Stick to these basics and you'll be pleased with the performance primary / secondary piping consistently delivers.

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