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System Pressure in Typical Hydronic Systems

What's the Pressure...?

It's a simple question. The answer, of course, is that the pressure is the number you read on a system pressure gauge. It's usually measured in "pounds per square inch, gauge (psig)" if it's greater than atmospheric pressure, or in "inches of mercury vacuum" if it's less than atmospheric pressure. Pressure gauges are the most commonly used instruments for observing the status of the hydronic system. In small systems, there's probably only a single pressure gauge, and it's usually located down in the basement on the boiler. Larger systems should have gauges, or at least taps to measure pressure, at several places in the system; e.g., at air-handling coils, chiller evaporators, pumps, etc.

It would seem to be pretty obvious what those gauges are telling us, but many times their information is misunderstood or even downright puzzling. This article will take a closer look at the system pressure in a typical hydronic system.

The system pressure in hydronic systems is not constant; it varies during normal operation, but it always represents the sum of several factors acting at that measuring point at that time. These factors include:

1. The initial or "cold fill" pressure that we establish when the system is filled with water.

2. The rise in pressure that occurs as the system water temperature increases and the water expands in volume.

3, The pressure effect of the pump

First Factor

The first of these factors is the initial pressure that must be established when the system is filled or re-filled after repair or modification.

We'll start by assuming that the system is full of air at atmospheric pressure, so all the gauges are reading zero psig. We can use a pressure-reducing valve (PRV) connected to the cold-water supply to fill the system and set the initial pressure. These valves often come factory-set to reduce the city supply pressure to 12 psig, so some installers have come to think that 12 psig fill pressure applies to all systems. That's just not true. This valve can be set to establish any pressure within its range by a simple adjustment at the top with a screwdriver. Typical adjustment ranges include 10 to 25 psig or 25 to 60 psig at the valve outlet. That setting is the system initial pressure. (Larger-capacity PRVs commonly found in plumbing applications are normally set at 50 psig.)

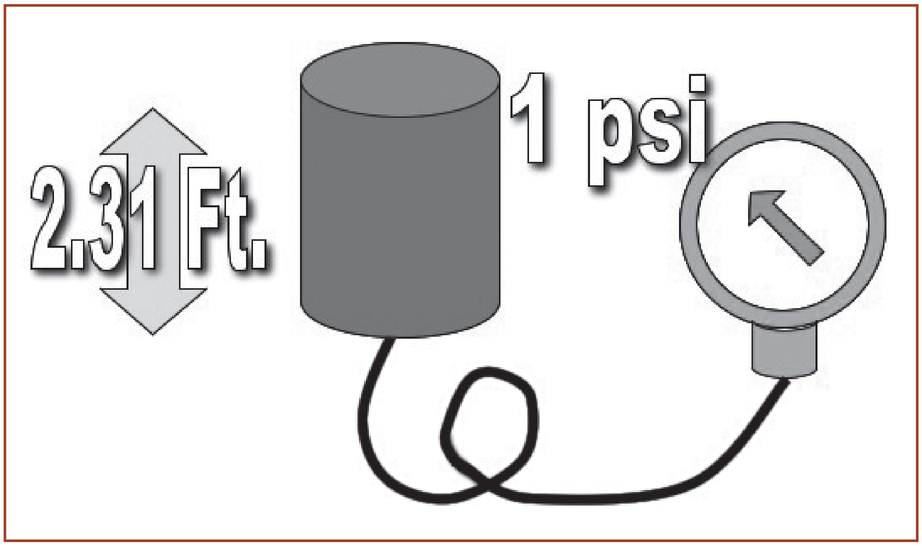

Figure 1. Pressure Gauge Reading and Equivalence of Elevation Head

Suppose the hydronic system (not the building itself) is 18.5 feet high, and the pressure-reducing valve and gauge are located near the boiler at the bottom of the system. Filling the system completely to the top would require at least 8 psig at the boiler since each foot of water will exert a pressure of 0.43 psig or 2.31 ft. of water will exert 1 psig (See Figure 1). Remember that we're filling the system with cold water, near standard density, so a column of water one foot high exerts 0.43psi.

Thus, 18.5 feet x 0.43 psi/foot = 8 psi (pounds per square inch)

Is that good enough? Probably not, because the water at the top of the system would be at zero psig, and if the design temperature is greater than 212° F, we'll have boiling, noise, and complaints during normal operation. Also, we may use automatic air vents to get rid of air bubbles at the top of the system. If the system pressure up there is only zero, there would be no differential pressure

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across the air vent to allow it to work. Finally, 8 psig at the bottom of the system might not be adequate to provide a system NPSHA (Net Positive Suction Head Available) great enough to exceed the pump's NPSHR (Net Positive Suction Head Required), and the pump would cavitate.

Common practice is to set the pressure-reducing valve a little bit higher to establish 4 psig at the top of the system. This setting keeps the water from boiling, allows the vents to work, and adds to NPSHA. With that additional 4 psig at the top, we'll read 12 psig at the bottom of the system. That's the reasoning behind that traditional 12 psig set point for the pressure-reducing valves used in hydronic systems. Many single-family homes have systems that are about 18 feet high, water temperatures that are low enough so 4 psig will be well above saturation pressure, and pumps that don't need much NPSHA as calculated at design temperature.

On the other hand, 12 psig at the bottom could be way too low for a taller system using hotter water. Perhaps the pump has a high NPSHR at design flow, or maybe it's installed at the top of the system where it doesn't see the system static pressure. In any of these situations, the pressure-reducing valve would have to be set to some higher pressure.

If the pressure-reducing valve is installed at the top of the system, then 12 psig might be higher than we need, and we would see excessive pressures at the bottom, possibly causing problems at the relief valve and compression tank.

So what's the "cold fill pressure?" It's the setting that you need at the pressure-reducing valve after you consider system height valve location, design, water temperature, and pump NPSHR.

Second Factor

The second variable is increased system pressure that occurs as water heats up. Most things expand as their temperature rises, and water is no exception. Because the typical hydronic system is closed to the atmosphere, water expansion as it heats up will clearly have the effect of raising pressure throughout the system.

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How High Can We Allow That Pressure to Rise?

Obviously the system relief valve is set at the upper pressure limit because the relief will open and discharge water to a drain when the system pressure exceeds the valve's set point. It is useful to think about the system operating pressure as a band. The lower limit of the band is the PRV setting; the upper limit is the relief valve setting. It doesn't make much difference what the pressure might be at any given moment as long as it's higher than the initial cold fill pressure but lower than the relief valve setting. We can't count on the relief valve to control the system pressure because that would result in frequent loss of water, which would have to be "made up" by adding new water with its dissolved oxygen and scale forming elements. Frequent addition of make up water can cause damage to pump seals and piping due to accelerated corrosion or scaling of heat transfer surfaces. Also, frequent operation of the relief valve may cause it to fill with scale and rust, or in some other way make it useless as a safety limit on the system pressure.

Earlier I used the term "cold fill" pressure, but didn't define what I meant by "cold." Most authorities have used 40° F as a starting point for discussions like this because water is at maximum density at that temperature. So I guess "cold" means 40° F. Does that mean that we're going to wait until the city water temperature drops to 40° F before we can start filling the system? Of course not! In Miami, we would never see the city water temperature drop that low. The temperature of the city water isn't under our control anyway, so we'll fill the system with water at whatever temperature is available. More importantly, it really doesn't make much difference as long as it's "cool."

Water doesn't expand at a uniform rate. In the neighborhood of 40° F, each degree rise in temperature results in only a slight increase in volume. So if we fill the entire system with cool water, it will hold about the same number of pounds of water give or take a little depending on the actual temperature and density. At higher temperatures, each degree results in a greater increase in volume. A closed heating system that holds 100% of cool water will see an expansion of perhaps 5% as the water temperature rises to the design value. The higher the design temperature, the greater the amount of expansion.

Five percent may not sound like a lot, but consider that most engineers describe water as "incompressible" meaning that a volume of water has to be placed under enormous pressure to achieve a tiny reduction in volume. That change in volume is so small, and the pressure required in getting it is so large, that we simply say water can't be compressed.

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With that in mind, you can see that a 5% increase in volume will exert huge pressures on the piping system, certainly large enough to cause the relief valve to discharge.

Net Expansion

As the water heats and expands, so does the pipe. Knowing the coefficient of expansion for the pipe material and the range of temperature change, we can calculate the small increase in piping system volume as it heats up, too. Subtracting the pipe expansion from the water expansion, we may see a "net expansion" on the order of 4.5%, but that's still going to exert a large pressure and open the relief valve unless we can absorb the additional 4.5% of water somewhere. That "somewhere" will be the gas cushion of the compression tank.

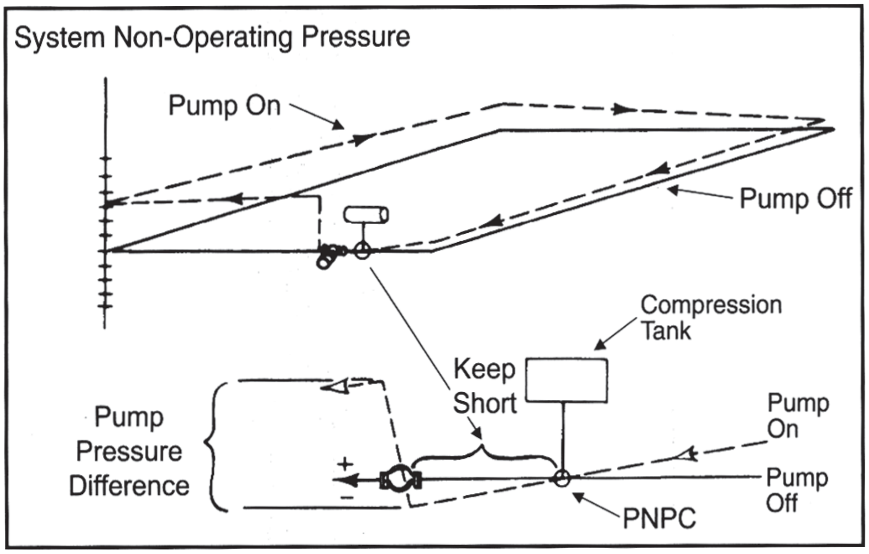

Figure 2. Flow Diagram – Point of No Pressure Change

The initial volume and pressure of the gas cushion in the compression tank as that "net expansion" occurs determine the actual rise in system pressure. Therefore, from a design point of view, the volume of the compression tank is selected so that the pressure rise will remain within the band between the PRV and relief valve settings. The most complete discussion of the factors that determine the volume required in hydronic system compression tanks was published in the ASHRAE Journal Section of heating Piping & Air Conditioning magazine in April, 1953 by H.A. Lockhart and Gil F. Carison from Bell & Gossett. Today, most designers calculate the size of the compression tank using software based on that or similar analyses. The important data required as input to these applications include:

- System volume in gallons
- Design temperature and design temperature drop
- Relief valve setting. (Some designers discount the setting in recognition of allowable operating limits and weakening of the relief valve spring with age).
- Initial pressure
- Relative height of tank, relief valve, pump, fill point, and top of the system.

For a given temperature change, glycol and water solutions expand much more than water alone, so that's an important additional fact to include.

Chilled Water Systems

What about a chilled water system? If the water volume doesn't change much from 40° F to 50° F, do we have to worry about an increase in volume and pressure? In these systems, we don't size the compression tank for the small increase in water volume that occurs during normal operation. We size it for the more substantial increase in volume and pressure that could occur if the system is turned off during a hot period, and the whole system warms up to ambient temperature. Remember, we still don't want to depend on that relief valve because it's not an operating control, it's a safety limit. For a chilled water system, use the highest ambient temperature the system is likely to see during a shutdown period.

Heating systems are filled with cool water, then heated up to operating conditions, resulting in a rise in pressure. It's not hard to find systems that work just the opposite way. Consider a hydronic system designed to provide cooling to the freezer cases in a supermarket. The "secondary refrigerant" is usually some kind of brine (or water plus some chemical) to prevent freezing at the low temperature required for the freezer case. Here, the pressure established in the system during the initial fill of the system has to be high enough so that the system will still be filled to the top and have adequate NPSHA and so on when the system cools to operating temperature and contracts. The second component of pressure is therefore subtracted from the initial fill pressure.

Third Factor

The remaining component of pressure is due to the action of the pump. We often hear the observation that "pumps create pressure." That's not a very useful way of thinking about what the pump does in a typical hydronic system. Centrifugal pumps have an impeller that applies 'work' to the fluid, thus increasing the total fluid head. In pumps that have equal sized suction and discharge nozzles, that transference of energy creates an application of work that moves a pound of low pressure water from the pump suction and discharges it as a pound of higher pressure water at the discharge nozzle. Therefore, it's more useful to think about the pump as a machine that establishes and maintains a pressure difference. Since water is essentially incompressible, the difference in pressure maintained by the pump causes flow.

In **Figure 2** the system is shown as a horizontal loop to simplify the drawing. In an actual system with elevation differences, the following analysis would still apply. With the pump off, the pressure everywhere in that horizontal loop would

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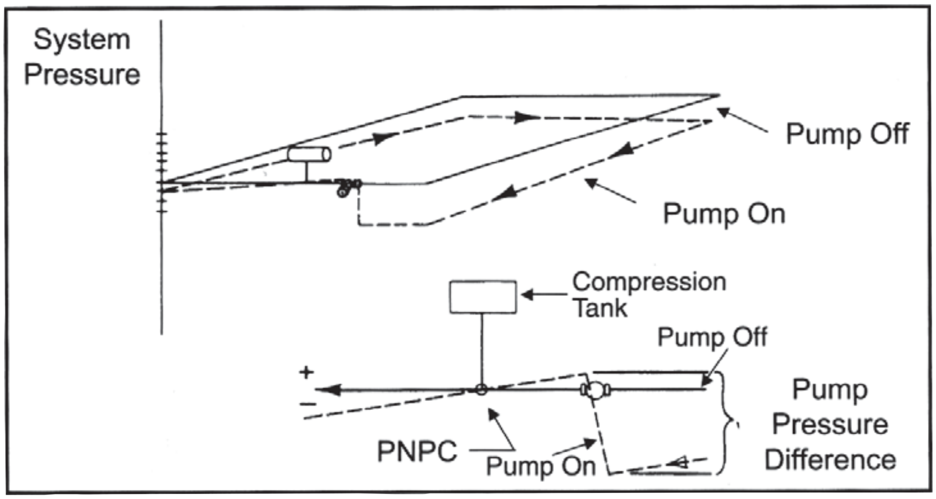

Figure 3. Flow Diagram – Tank Installed on Discharge Side of Pump

be the same, so there would be no flow. In the drawing, that pressure is shown as the "nonoperating pressure." We could consider it to be the sum of the initial pressure plus any pressure rise due to heating and expansion. When the pump is turned on, it develops head according to its head capacity curve. The pump head is represented as a vertical line. The difference in pressure across the pump now causes flow, and as the water starts to move, friction causes a pressure drop or head loss as predicted by the Darcy Weisbach relationship.

$$h_{friction} = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

where:

$h_{friction}$ = feet of head loss due to friction

f = friction factor (no units)

L = length (feet)

D = diameter (feet)

V = average velocity of liquid (feet per second)

g = acceleration due to gravity (feet per second^2)

Point of No Pressure Change (PNPC)

In **Figure 2** the PNPC is identified as the point where the compression tank connects to the system. But just exactly what does "no pressure change" mean? It's an important question because the pressure at that point can be changed. For example, adding more water to, or draining some from, the system could easily change the pressure at that point. Either action would change the volume of water in the system, which would change the volume of air in the compression tank and change the pressure. Similarly, venting air out of the tank or compressing more air into the tank will change the pressure at the PNPC.

We've already discussed the effect of changing the average system temperature, and how that changes the pressure. What then do we mean by "no pressure change?" We mean that (a) the pump can't change the pressure at that point because the pump certainly can't change the amount of water or air in the system, and (b) the amount of heat that it adds is usually quite small compared to the heat added by other components.

Notice in **Figure 2** that when the tank is located at the pump suction, the pressure effect of the pump results in an increase in pressures everywhere in the system. The increase is greatest at the pump discharge, there's no effect at the PNPC, and there's a small decrease in pressure in the piping between the tank and the pump suction. Therefore, the distance between the tank connection and the pump suction should be kept as short as possible to minimize the pressure drop. This is also one reason why high pressure drop devices like control valves or strainers using fine mesh should not be installed on the suction side of the pump.

In **Figure 3** the tank has been incorrectly installed on the discharge side of the pump. The action of the pump now decreases the pressure below the non operating pressure of the system everywhere except in the small section between the pump and the tank. In systems where the non operating pressure of the system is low compared to the pump head, the large reduction in pressure when the pump comes on could cause boiling in hot water systems, draw air in through automatic vents, or even result in pump cavitation. When the pump is located in this way, it also can cause a great deal of confusion. I've had telephone calls from technicians who asked why the pressure gauge reading decreased whenever the pump started. It really seems to defy common sense until you understand the PNPC, and the implications that flow from it.

So... What's the Pressure?

The answer to this simple question really depends on several factors:

- Where is the gauge located? Is it at the top or closer to the bottom of the system?
- What's the system temperature? Has that net expansion happened or not?
- Is the pump on or off?
- If the pump is on, how far away from the discharge is the gauge located?
- Is the pump correctly located with respect to the tank?

Knowing these answers will allow us to use pressure gauge readings to analyze and troubleshoot the system much more readily.

This article was written by Bell & Gossett engineers and was originally published as a three part series in 2004 issues of *Plumbing Systems & Design* magazine. Reprinted with permission.