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White Paper 1701:
Expansion Tanks for Geothermal Ground Loop Systems

Overview

This white paper specifically addresses bladder type expansion tanks used in geothermal systems with ground loop piping. Although this paper mentions traditional hydronic expansion tanks as they compare to ground loop systems, it is not meant to provide exhaustive coverage of expansion tanks. Traditional hydronic expansion tank application, sizing, and installation are well documented in existing HVAC literature.

History of Expansion Tanks in the Geothermal Heat Pump Industry

There is a lot of misunderstanding in the geothermal heat pump industry about expansion tank operation and even in the need for an expansion tank in the system. In the 1980s when the geothermal heat pump industry was in its infancy, many of the pumping systems, especially for residential installations, were built-up type flow centers, which consisted of “off the shelf” components found in hydronic applications.

Figure 1 shows a flow center from 1982. Many of the early systems had painted steel expansion tanks connected directly to the piping, allowing thermal transfer from the cold ground loop in the winter time. The expansion tank would condense, rust, and eventually need to be replaced, usually in a short amount of time.


Figure 1: Early flow center
(courtesy of WaterFurnace International)

In the late 1980s the industry switched from polybutylene piping to high density polyethylene (HDPE) for the ground loop portion of the system. HDPE was an improvement in many ways, and was lower in cost. Due to the high rate of thermal expansion of the HDPE pipe, the industry came to the conclusion that an expansion tank was no longer needed, especially for residential and light commercial applications. In fact, the ASHRAE diaphragm expansion tank sizing equation discussed later in this paper can yield a very small number, futhering this belief.

Comparison of Traditional (Hydronic) Expansion Tank Operation to Geothermal System Operation

It is important to recognize that the use of an expansion tank on the ground loop of a geothermal system serves a different function than expansion tanks used in other applications, and in other industries. For example, expansion tanks can be used to dampen water hammer, prevent over-pressurization in a hot water system due to thermal expansion of the fluid (water), and to prevent short-cycling of a pump. Most confusion in the geothermal industry seems to stem from comparison to traditional hydronic systems. In traditional hot water (boiler) systems, the expansion tank absorbs fluid as the fluid expands with increasing temperature. Without an expansion tank the system pressure would quickly rise to unsafe conditions since the fluid expands at a much faster rate than the rigid piping system. If the expansion tank is included but is too small, the pressure relief valve in the system will open, releasing fluid to limit the pressure.

The purpose of an expansion tank for a geothermal ground loop system is to provide additional system capacity to prevent the system pressure from dropping too low under worst-case conditions. In contrast to a traditional hot water system, *the ground loop pressure decreases as the fluid temperature increases*. Conversely, the loop pressure increases as the fluid temperature drops. Therefore, the loop pressure is highest during heating season (coolest loop temperature) and lowest during cooling season (highest loop temperature). This counter-intuitive pressure behavior is a result of the HPDE pipe expanding at a faster rate than the fluid as the temperature increases, and contracting at a faster rate than the fluid as it cools (see explanation on page 13, "Validation" section). Figure 2 illustrates expansion tank operation over the heating and cooling seasons, the opposite of boiler systems.

Since HPDE pipe expands and contracts, it behaves similar to an expansion tank. However, since the pipe expands more quickly than the fluid as temperatures increases, there is generally little concern about overpressurization. In addition, HDPE pipe is viscoelastic, which means that it will stretch but not return to its original shape. Unfortunately, these characteristics create a situation where the loop pressure can drop too low. This can be overcome by loop maintenance (i.e. periodically “bumping” the system pressure), installing an active pressure make-up device, or installing an expansion tank. The expansion tank is the simplest and least costly solution.

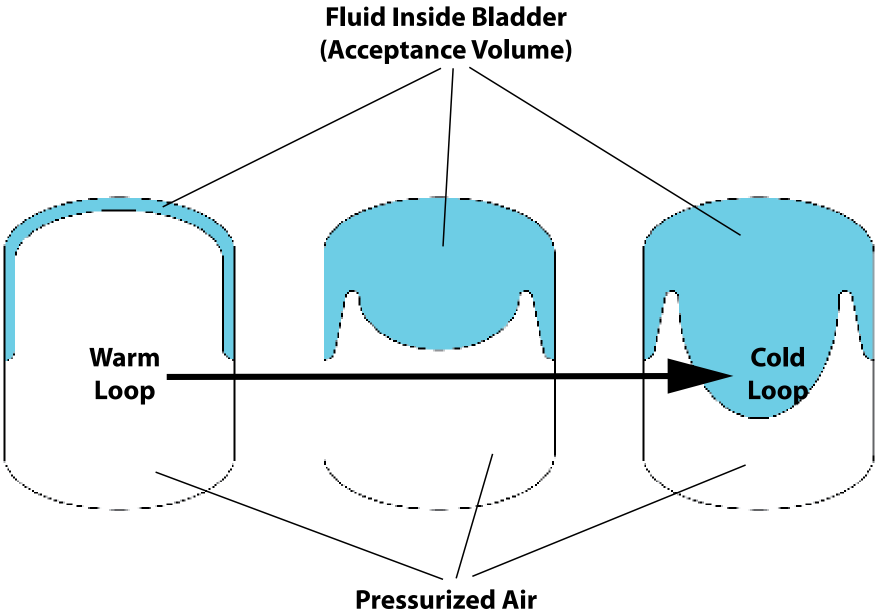
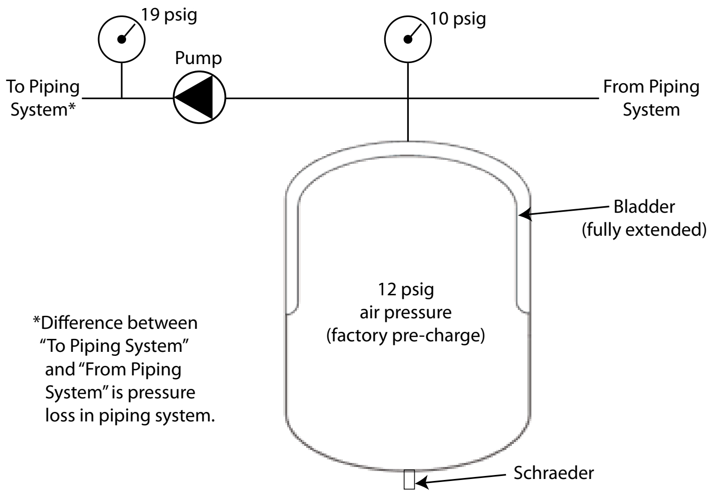


Figure 2: Seasonal Operation of an Expansion Tank in a Geothermal System

A diaphragm (or bladder) expansion tank in a geothermal ground loop system works well because the air trapped inside the tank expands and contracts at a much greater rate than the HPDE pipe. From practical experience in the industry, it is apparent that most ground loop systems benefit from an expansion tank. It should be clear that a properly sized and applied expansion tank will eliminate “flat loops” (i.e. zero pressure) due to the thermal expansion of the pipe. Flat loops can cause heat pumps to shut down due to low/no water flow, and premature pump failure. The biggest issue with decreasing loop pressure is that air bubbles that remain in the system after system startup (i.e. flushing/purging), or introduced when performing system maintenance (such as replacing a pump), expand to much larger air bubbles as the system pressure decreases. Large air bubbles circulating in the system have the potential to cause noise in the building, could air lock a loop circuit, and could air lock the circulating pump which could lead to both system shut down, and pump failure.

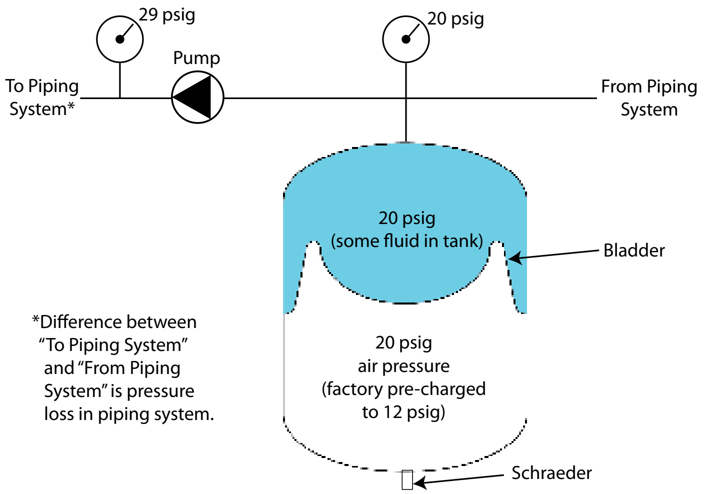
Expansion Tank Operation

Like expansion tank use and selection for geothermal heat pump systems, there is also quite a lot of confusion with regard to the operation of the expansion tank. In some cases, expansion tanks have been selected that have no benefit to the piping system. Figure 3 shows a diaphragm (bladder) expansion tank with a factory pre-charge of 12 psig air pressure. With the bladder fully extended, there is no fluid in the tank. Fluid can only enter the tank when the system pressure is higher than the initial air pressure. In Figure 4, some fluid is in the tank because the system pressure is higher than the initial (preset) air-side pressure. It is also important to note that the fluid side pressure will always be equal to the air side



*Difference between “To Piping System” and “From Piping System” is pressure loss in piping system.

Figure 3: Expansion tank, bladder fully extended



*Difference between “To Piping System” and “From Piping System” is pressure loss in piping system.

Figure 4: Expansion tank, some fluid in the tank

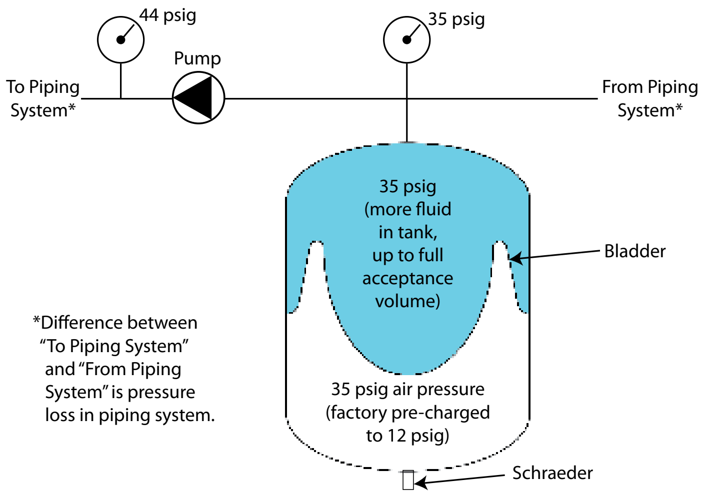


Figure 5: Expansion tank, more fluid in the tank

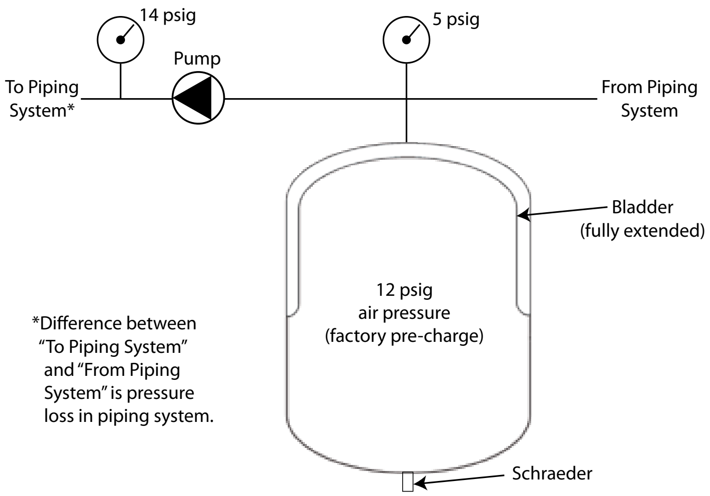


Figure 6: Expansion tank with air-side pressure greater than system pressure

pressure at every value above the initial air-side pressure setting (pre-charge). In Figure 5 there is even more fluid in the tank due to the increased system pressure. Figure 6 illustrates how the (pre-charge) air pressure affects the system operation. *In effect, the system in Figure 6 operates as if there is no expansion tank installed*. It is important to understand that the air pressure in the tank does not determine the minimum system pressure; the air pressure is the pressure at which the bladder is fully extended. Any pressure higher than the initial air pressure will allow fluid into the tank, and will help maintain system pressure. Later in the paper is a discussion on pre-charge settings.

Acceptance Volume

The acceptance volume of a bladder tank is the amount of fluid that it can hold at the maximum system pressure. Recall that the tank will not accept fluid until the system's pressure exceeds the pre-charge pressure. Since the air in the tank cannot compress to zero volume, the acceptance volume is always less than the size of the tank. For example, a 2 gallon tank with a pre-charge of 30 psig has an acceptance volume of 0.6 gallons at 50 psig and 1.2 gallons at 100 psig. Even if the pre-charge were 0 psig, the acceptance volume is less than 2 gallons. The acceptance volume in a traditional hot water system should be chosen to limit the pressure at the maximum expected fluid temperature.

The ASHRAE developed formula for sizing expansion tanks is widely accepted for traditional boiler systems. In geothermal systems, the acceptance volume should be large enough to prevent the system pressure from dropping below the required suction pressure of the circulation pumps to prevent cavitation. In addition, maintaining a higher pressure is advantageous since any air bubbles remaining in the system will remain relatively small. Therefore, a bladder expansion tank used in a geothermal system should be sized based on a minimum acceptance volume at the minimum allowable system pressure. An expansion tank acceptance volume exceeding the minimum allowable value is acceptable and will provide additional capacity, but at a higher initial cost.

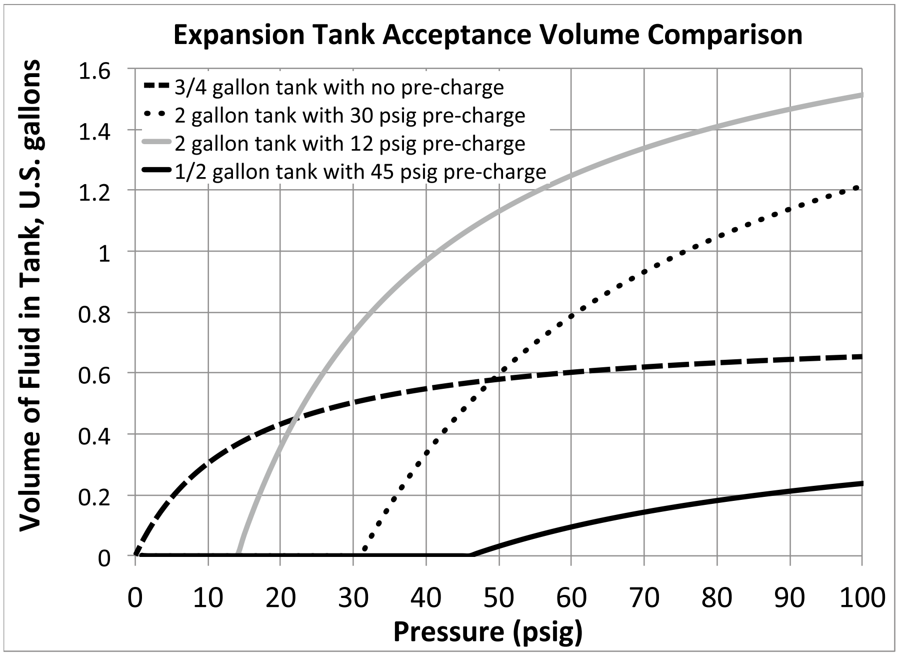


Figure 7: Acceptance Volume Comparison

Figure 7 is a graph of acceptance volume versus pressure of several representative expansion tanks used in the geothermal industry. Several important points can be illustrated by studying this graph. Before discussing these points it should be understood that the initial ground loop system pressure is determined by the method of introducing the pressure into the system. During initial start-up, the system is typically pressurized by a flush cart after all air and debris have been purged from the system. Most industry standard flush carts have a maximum pressure capability of around 50 psig. A "gooser" tool can be used to bump system pressure to equal the pressure available from the potable water source. This is typically 60 psig, but varies based on the geographic location and other factors. Returning to the graph, note that a 3/4 gallon tank with zero pre-charge has the same acceptance volume as the 2 gallon tank with a 30 psig pre-charge at a system pressure of 50 psig. Also note that the acceptance volume of the 1/2 gallon tank typically with a relatively high pre-charge is only 0.05 gallons (6.4 oz). It should be clear that this tank is insufficient for avoiding a "flat" loop. It will, however, help prevent system over-pressurization, but this is typically not a concern as discussed earlier.

Understanding Bladder Expansion Tank Pre-Charge

The pre-charge on the air side of the bladder in a traditional hydronic (boiler) system is based on the expected or desired system pressure. The pre-charge ensures that the bladder is expanded against the inside of the tank when the system is pressurized, but before the water heats up. Since the expansion tank will not absorb fluid until the system pressure exceeds the pre-charge value, the size of the expansion tank is minimized by using this method. A pre-charge on tanks in a geothermal ground loop system is not necessary. Recall that as soon as the system pressure drops below the pre-charge pressure on the expansion tank, the tank no longer contributes to providing make-up fluid to the loop system. Therefore, the pre-charge on the tank is in practice, the pressure at which the tank will stop working. If the pre-charge is 30 psig, for example, the loop will expand and contract as if no expansion tank were installed at any pressure below 30 psig.

There are three parameters that must be considered in determining the pre-charge air pressure in the tank. The first is the minimum air pressure required to maintain the bladder position (see Figures 3 and 6). The second is the maximum pressure allowed to avoid bursting the bladder (or the maximum specified tank pressure). Finally, the acceptance volume is the capacity of the tank when at the maximum system pressure. For example, if the maximum tank pressure is 35 psig, the acceptance volume would be the fluid shown in the tank (in gallons) as illustrated in Figure 5.

The minimum pressure allowed provides the most fluid capacity and therefore the most useful application of the expansion tank. For example, if the minimum air pressure required is 5 psig, fluid would enter into the tank if the system pressure is over 5 psig. This would allow the bladder to operate over a wider range, providing maximum stability in system pressure. However, commonly available residential bladder tanks are typically pressurized to around 12 psig for traditional hydronic/boiler systems. A higher pressure tank is not better. Domestic hot water expansion tanks are typically pressurized at 30 to 60 psig, and should be avoided, since most flush carts can only pressurize the system at startup to around 50 psig.

The amount of fluid and air in a diaphragm tank can be calculated using Boyle's Law. Boyle's Law states that the pressure and volume of an ideal gas is constant. The amount of air captured in the diaphragm tank follows this relationship. At a constant temperature, it can be expressed as:

$$P_1 V_1 = P_2 V_2$$

where:

P_1 =absolute pressure, initial (lbs/ft^2 or psia)
V_1= volume, initial (gallons)*
P_2= absolute pressure, final (lbs/ft^2 or psia)
V_2= volume, final (gallons)*

*Note that for unit consistency, the volume is usually expressed in ft^3. However, since conversion from ft^3 to gallons is a constant that cancels in the calculation, gallons is used here for simplicity.

Absolute pressure (psia) = gauge (or measured) pressure (psig) + atmospheric pressure at the specific location (generally around 14.7 psi).

Now, rearranging the formula,

$$V_2 = V_1 (P_1/P_2)$$

This version of the formula shows that the volume of air in the tank is inversely proportional to the change in pressure (i.e. the volume decrease as the pressure increases, and vice versa). It follows that as the volume of air in the tank decreases, the volume of water in the tank increases. This allows the calculation of both the volume of air and volume of water accepted into the tank at any pressure (i.e. acceptance volume).

Consider the following example:
A 2 gallon diaphragm expansion tank with a pre-charge of 12 psig is attached to a geothermal ground loop system that is flushed and pressurized to 30 psig. How much fluid is contained in the tank (i.e. the acceptance volume at 30 psig)?

P_1 = 26.7 psia (12 psig + 14.7)
V_1 = 2 gallons
P_2 = 44.7 psia (30 psig +14.7)
$V_2 = V_1 (P_1/P_2)$

Substituting,
$V_2 = (2) X (26.7/44.7)$
V_2 =1.2 gallons of air

This means the initial air volume was compressed from 2 gallons to 1.2 gallons when the pressure increased from 12 psig to 30 psig. Since the tank's air-side was initially pressurized to 12 psig, extending the bladder fully, the tank initially contained no fluid. Further, the tank will not begin to fill until the system pressure is greater than 12 psig. Therefore, the 2 gallon tank accepted 0.8 gallons of fluid as the loop was pressurized to 30 psig (and the air in the tank was pressurized from 12 psig to 30 psig). This is the amount of fluid that the tank can "give back" to the loop as it expands or relaxes as described earlier. Figure 7 (graph of acceptance volume) shows how the pre-charge of the expansion tank affects the amount of fluid in the tank. This should make it clear that a higher pre-charge bladder tank on the source side of the ground loop system is not useful, and may in fact provide no benefit.

Boyle's law also provides some insight on how loop pressure affects the size of air bubbles contained in a geothermal ground loop system, and shows an additional benefit of using an expansion tank. Current industry accepted practice dictates the use of a high-head, high flow pump (i.e. flush cart) to purge all air and flush debris from a system prior to startup. However, even with the best equipment and procedures, it is very difficult to remove all air from the geothermal equipment and loop system. Micro bubbles, and dissolved air (oxygen, gases) are difficult in the first case, and impossible in the second, to extract with standard flushing. Further, some mechanical equipment such as circulation pumps have closed rotor cans without vent screws that trap a small amount of air that is only displaced when the circulator starts. Finally, maintenance technicians (as opposed to the installation contractor) who are familiar with hydronic systems containing air separators and automatic air vents but not familiar with geothermal systems, can replace a system component such as a circulator pump and not re-flush the circuit. It can therefore be stated that all ground loops will contain air (gas, oxygen) at some point.

A small amount of air circulating around a loop system is only a problem if the air volume or bubble size is large enough to air-lock a loop circuit, air-lock or damage a pump, or cause unacceptable noise. With the exception of an air-locked circuit, the effect of a small amount of air on the ground loop heat exchanger is negligible. However, as Boyle's Law shows, a small air bubble at 50 psig becomes much larger as the pressure drops, which could pose problems sometime after startup or when service work has been completed. Although most residential systems are installed without a means of air separation, it is the authors' opinions that geothermal ground loop systems benefit from an air separation device as a preventative measure.

Consider the following example:
A professional geothermal ground loop company installs a 5 ton horizontal ground loop system up to the flow center in April, and flushes the system thoroughly. They pressurize the system to 50 psig, the maximum possible with the installer's flush cart. In May, the heat pump is installed and the interior piping and unit is filled with water up to the flow center. An expansion tank is not installed, and some very small bubbles remain in the system with a total volume of 2.2 cubic inches (about the size of a golf ball). Assuming the pressure drops to 10 psig, what is the volume of air**?

$V_2 = V_1 (P_1/P_2)$
$V_2 = 2.2 \text{ in}^3[(50+14.7)/(10+14.7)]$
$V_2 = 5.76 \text{ in}^3$, or 0.4 cups (about the size of a billiard ball)**

While a golf ball size of air distributed as small bubbles throughout the loop fluid may not be noticeable, if the bubbles group together and grow in size, issues such as the ones described above may result. Having an expansion tank installed in the system will greatly limit the system's static pressure loss as the loop expands, thereby retaining a higher static pressure and ensuring that if any air bubbles are present, they remain small.

> **An isothermal (constant temperature) pressure decrease is assumed to allow the use of Boyle's Law for simplicity and illustrative purposes only. In reality, the air bubble will also grow due to both the increase in temperature, and the release of dissolved oxygen as the fluid temperature goes from cool to warm. The actual solution to this problem can be found using established thermodynamic calculations, but is beyond the focus of this paper.

Expansion Tank Sizing / ASHRAE Formula

Bladder expansion tanks in traditional hot water hydronic (boiler) systems are sized based on the expected fluid expansion over the expected fluid temperatures and system pressure. Examination of the ASHRAE formula shows these variables. However, the formula assumes that the pressure at the lower temperature is lower than the pressure at the higher temperature which is always true in traditional boiler systems. As discussed above, this is not true in geothermal ground loop systems. Therefore, care must be exercised when applying the ASHRAE formula to ground loop systems.

$$V_t = V_s \frac{[(v_2/v_1) - 1] - 3\alpha\Delta T}{1 - (P_1/P_2)}$$

from: *2016 ASHRAE Handbook - HVAC Systems and Equipment*

where:
V_t = volume of expansion tank, gallons
V_s = volume of water in system, gallons
t_1 = lower temperature, °F
t_2 = higher temperature, °F
P_1 = pressure at lower temperature, psia
P_2 = pressure at higher temperature, psia
v_1 = specific volume of water at lower temperature, ft^3/lb
v_2 = specific volume of water at higher temperature, ft^3/lb
α = linear coefficient of thermal expansion, in/in • °F
    for steel piping, $\alpha = 6.6 \times 10^{-6}$
    for copper piping, $\alpha = 9.5 \times 10^{-6}$
    for HDPE piping, $\alpha = 67 \times 10^{-6}$
$\Delta t = (t_2 - t_1)$, °F

Consider the following example:
A system has 100 gallons of fluid and HDPE piping. The minimum desired system static pressure is 12 psig, and the maximum desired system static pressure is 50 psig. The ground loop is designed for a minimum/maximum entering water temperature (returning from the ground loop) of 35°F and 85°F. Based upon the information given, the following input data may be determined:

V_s = 100 gallons
t_1 = 35°F
t_2 = 85°F
v_1 = 0.01602 cu ft/lb
v_2 = 0.01609 cu ft/lb
$\alpha = 67 \times 10^{-6}$
Δt = 85 - 35 = 50°F
P_1 = 50 psig (psia = gauge pressure + 14.7 psi at sea level = 64.7 psia)
P_2 = 12 psig (psia = gauge pressure + 14.7 psi at sea level = 26.7 psia)

Using the above formula, $V_L = 100\frac{[(0.01609/0.01602) - 1] - [3(67 \times 10^{-6})(50)]}{1 - (64.7/26.7)} = 0.40$ gallons

Depending upon pre-charge air pressure and tank construction (maximum bladder expansion), a 0.4 gallon expansion tank typically has a very small acceptance volume. The small requirement has led some in the industry to conclude that an expansion tank is not needed due to the high linear coefficient of thermal expansion for HDPE piping.

From practical experience in the industry, it is apparent that ground loop systems benefit from an expansion tank to avoid “flat loops”, which can cause the heat pump to shutdown due to low/no water flow and premature pump failure. Based upon research and development conducted by Geo-Flo Products Corp. in the design of its Pressure Battery (HDPE bladder-type expansion tank -- Figure 8) for residential systems, an expansion tank calculator has been created on the Geo-Flo Calculators website (www.geo-flo.com, “Design Calculators” link). Calculations consider the percentage of HDPE pipe vs. the percentage of rigid piping (see the Calculator screen shot in Figure 10). For small systems (up to about 6 tons of equipment), the Pressure Battery is an easy solution. It is adequately sized for a small system, and avoids the issue of the tank rusting from low temperature operation. However, for larger systems, a higher volume tank will be required, which typically consists of a steel shell. Fortunately, there is a relatively simple solution to the condensation and eventual rusting problem associated with steel tanks. Providing a thermal break as shown in Figure 9 between the expansion tank and the piping system, helps reduce condensation on the tank. A short piece (typically 2 to 3 feet) of piping (typically rubber hose that is compatible with the antifreeze in the system) usually provides enough of a thermal break.

Figure 8: Pressure Battery™
(HDPE expansion tank)

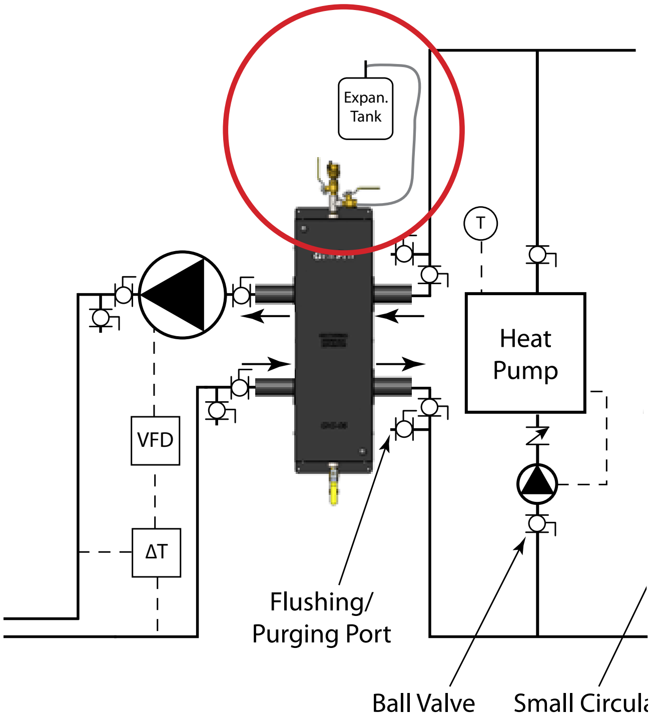


Figure 9: Partial Commercial System Diagram

Example Expansion Tank Selection for a Commercial or Large Residential Geothermal System

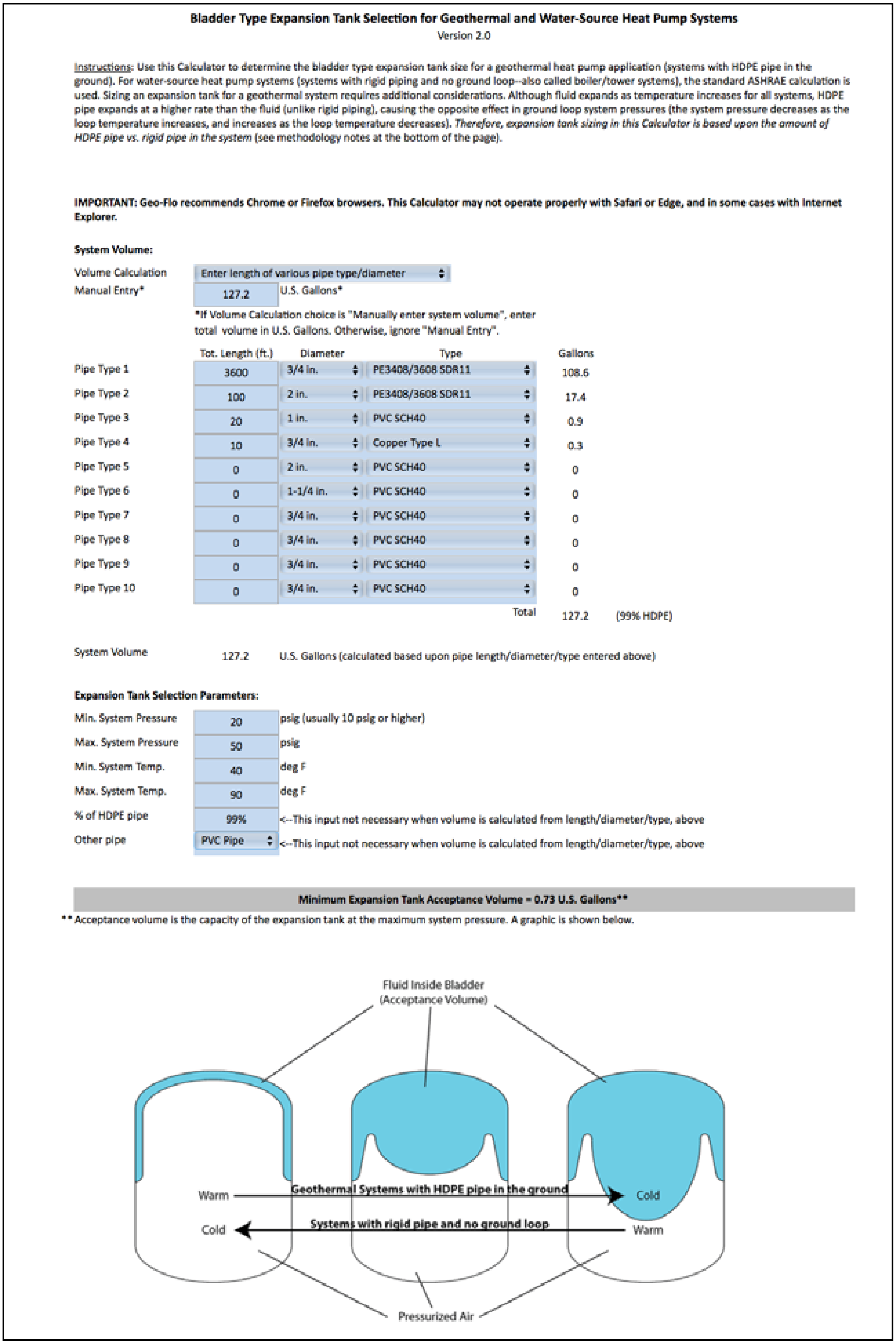
1. Calculate the total system gallons. For this example, use 400 gallons.
2. Find a tank designed for hydronic applications that is approved for the antifreeze used in the system, and one that has a pre-charge of 12 psig or less. Consult the manufacturer’s data. Table 1 includes data for a typical steel expansion tank. Note the asterisk in the Acceptance Volume column, indicating that this value is based upon a pre-charge air pressure of 12 psig. An expansion tank with a higher pre-charge pressure will require a larger tank, and should be avoided. Ensure that the tank is rated for the maximum expected loop pressure.
3. Use the Expansion Tank Calculator on the Geo-Flo website (www.geo-flo.com, “Design Calculators” link) to determine the tank needed (see Figure 10). In this example, a minimum acceptance volume of 6.8 gallons is needed.
4. Select a tank with at least the value calculated in step 3. In this example, choose model ABC-077 or larger.

Model Number	Tank Volume (Gallons)	Max. Acceptance Volume (Gallons)*	Diameter (inches)	Height (inches)	System Connection (NPT male)	Weight (lbs.)
ABC-020	2.0	1.0	8	13	1/2	5
ABC-040	4.0	2.5	11	15	1/2	9
ABC-077	7.7	5.6	11	23	1/2	14
ABC-140	14.0	11.3	15	21	1/2	23

*12 psig pre-charge, 30 psig system pressure

Table 1: Typical manufacturer’s data for a steel expansion tank

NOTE: The air volume simply follows Boyles Law ($PV = k$ pressure times volume = a constant when temperature is constant), or in this case for ease of calculation, $P_1V_1 = P_2V_2$ (inital pressure X initial volume = subsequent volume, V_2, under new pressure, P_2).



Bladder Type Expansion Tank Selection for Geothermal and Water-Source Heat Pump Systems

Version 2.0

Instructions: Use this Calculator to determine the bladder type expansion tank size for a geothermal heat pump application (systems with HDPE pipe in the ground). For water-source heat pump systems (systems with rigid piping and no ground loop--also called boiler/tower systems), the standard ASHRAE calculation is used. Sizing an expansion tank for a geothermal system requires additional considerations. Although fluid expands as temperature increases for all systems, HDPE pipe expands at a higher rate than the fluid (unlike rigid piping), causing the opposite effect in ground loop system pressures (the system pressure decreases as the loop temperature increases, and increases as the loop temperature decreases). *Therefore, expansion tank sizing in this Calculator is based upon the amount of HDPE pipe vs. rigid pipe in the system* (see methodology notes at the bottom of the page).

IMPORTANT: Geo-Flo recommends Chrome or Firefox browsers. This Calculator may not operate properly with Safari or Edge, and in some cases with Internet Explorer.

System Volume:

Volume Calculation: Enter length of various pipe type/diameter

Manual Entry*: 127.2 U.S. Gallons*

*If Volume Calculation choice is "Manually enter system volume", enter total volume in U.S. Gallons. Otherwise, ignore "Manual Entry".

	Tot. Length (ft.)	Diameter	Type	Gallons	
Pipe Type 1	3600	3/4 in.	PE3408/3608 SDR11	108.6	
Pipe Type 2	100	2 in.	PE3408/3608 SDR11	17.4	
Pipe Type 3	20	1 in.	PVC SCH40	0.9	
Pipe Type 4	10	3/4 in.	Copper Type L	0.3	
Pipe Type 5	0	2 in.	PVC SCH40	0	
Pipe Type 6	0	1-1/4 in.	PVC SCH40	0	
Pipe Type 7	0	3/4 in.	PVC SCH40	0	
Pipe Type 8	0	3/4 in.	PVC SCH40	0	
Pipe Type 9	0	3/4 in.	PVC SCH40	0	
Pipe Type 10	0	3/4 in.	PVC SCH40	0	
			Total	127.2	(99% HDPE)

System Volume 127.2 U.S. Gallons (calculated based upon pipe length/diameter/type entered above)

Expansion Tank Selection Parameters:

Min. System Pressure	20	psig (usually 10 psig or higher)
Max. System Pressure	50	psig
Min. System Temp.	40	deg F
Max. System Temp.	90	deg F
% of HDPE pipe	99%	<--This input not necessary when volume is calculated from length/diameter/type, above
Other pipe	PVC Pipe	<--This input not necessary when volume is calculated from length/diameter/type, above

Minimum Expansion Tank Acceptance Volume = 0.73 U.S. Gallons**

** Acceptance volume is the capacity of the expansion tank at the maximum system pressure. A graphic is shown below.

Figure 10: Screen shot of Geothermal Expansion Tank Calculator at www.geo-flo.com

Installation location

To avoid potential issues with low loop pressures (air bubble size increasing, pump cavitation, etc.) the expansion tank should be placed on the suction side of the loop's circulation pump. However, the reason for this recommendation has not always been well understood. The location (of the expansion tank) has been described in other texts (sources) as "the point of no pressure change", meaning that the pressure at the plumb-in point of the expansion tank is fixed. Others have suggested that the fluid contained in the expansion tank is fixed, and that fluid neither enters nor leaves the tank during operation. Both of these concepts are simplifications or generalizations of the reality of what occurs with the expansion tank. The "point of no pressure change" is an easy to remember phrase allowing teaching on a wide scale. Further adding to the confusion is the lack of understanding of how circulation pumps operate. Circulation pumps (or circulators for short) do not create pressure the way a piston pump does, but instead only overcome the frictional resistance (i.e. head) in the piping up to the point that the resistance matches the pump's capacity. To illustrate these concepts, consider the following:

Figure 11 is a simplified loop system. For illustrative purposes, imagine the entire loop were constructed of stainless steel piping and tubing. Once all the air is out of the loop, it should be obvious that injecting a very small amount of water rapidly increases the system pressure since the stainless steel pipe stretches or expands very little. For the sake of the example, say that one tablespoon of water is injected to increase the pressure from 0 to 30 psig, and that an additional 0.1 tablespoons can be added to further increase the pressure to 40 psig. This pressure is the static pressure on the loop. Keep in mind that if only a few drops of water escape the loop (through a leak or other means), the pressure will rapidly drop from 30 psig to nearly zero. When the circulator is energized, it overcomes the frictional resistance (head loss) in the pipe so that the pressure at the discharge of the pump is the highest, and the pressure decreases around the loop. Figure 12 illustrates this situation using a theoretical head loss of 10 psi, or about 23 Ft. of Head. When the pump is turned off, the loop pressure returns to the static state as shown in Figure 11.

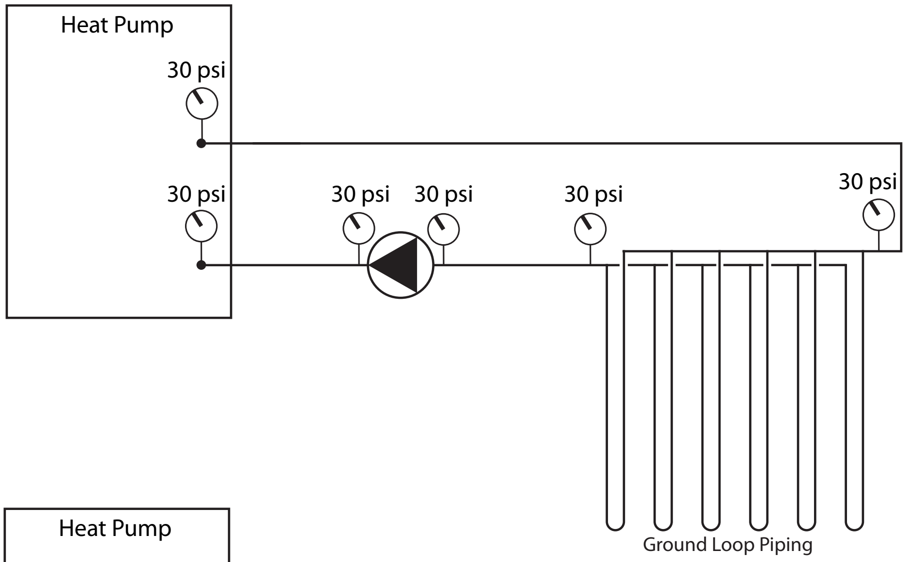


Figure 11: Loop static pressure (pump off)

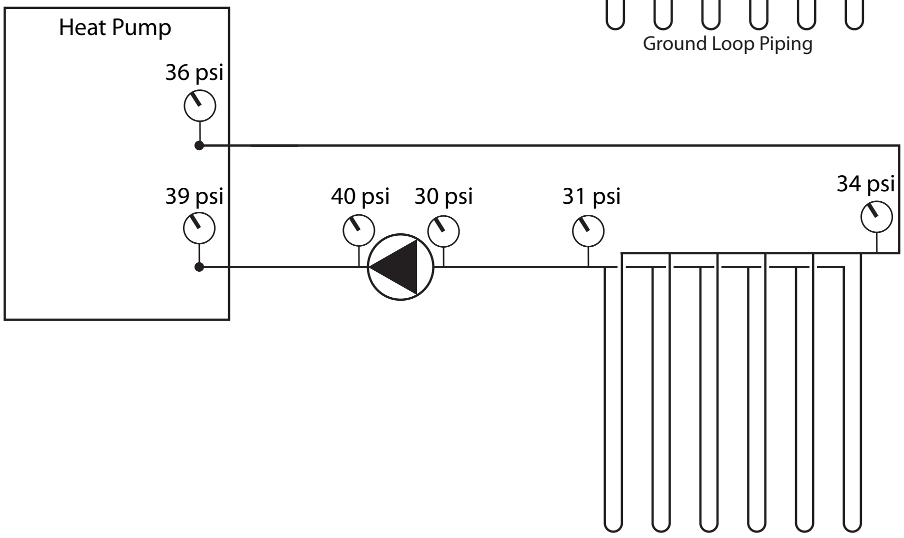


Figure 12: Loop dynamic pressure (pump energized) with 10 psi head loss (about 23 ft. of head)

Now, let's consider what happens if an expansion tank is installed in the loop system. Figure 13 shows a two gallon tank incorrectly installed on the discharge side of the pump with a ball valve between the connection point of the loop and the expansion tank. Again, the loop is flushed to remove all air and fluid is injected to increase the loop pressure to 30 psig. However, in this case, the amount of fluid injected is the original one tablespoon plus an additional 0.8 gallons since the tank will absorb fluid as the system is pressured (assuming the pre-charge is 12 psig in this case). As shown in Figure 13, the pressure on the air side of the expansion tank is equal to the pressure on the fluid side. This will always be the case at every pressure above the pre-charge pressure of the tank. Next, the ball valve isolating the tank from the system is closed and the circulator is again energized. Since the tank is isolated from the system, the pressure gauges will read exactly as they did previously (Figure 14) as the pump overcomes the head loss in the system. Note that the tank remains at 30 psig since the isolation valve is closed. Now, with the pump still running, open the isolation ball valve (Figure 15). What happens? Since the pressure on the fluid side is higher than the pressure in the tank, fluid will enter into the tank until the pressure on the fluid side (and loop system) is equal to the pressure on the air side of the tank.

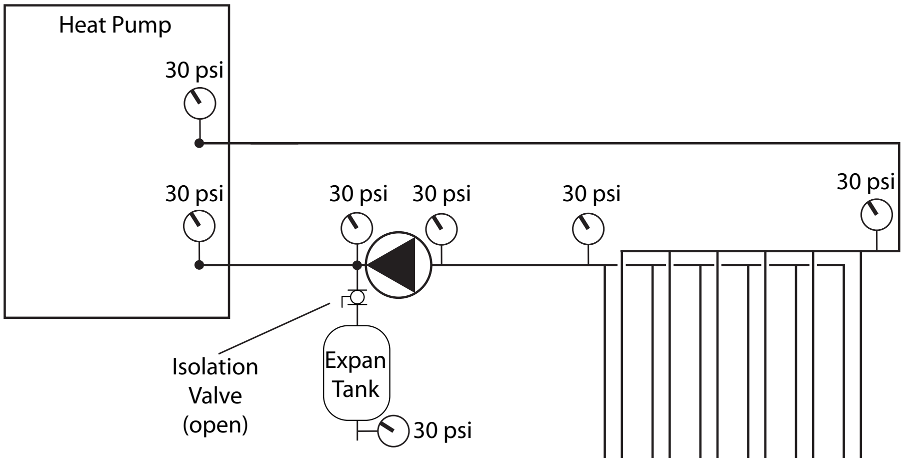


Figure 13: Expansion tank improperly installed, and system pressurized with isolation valve open

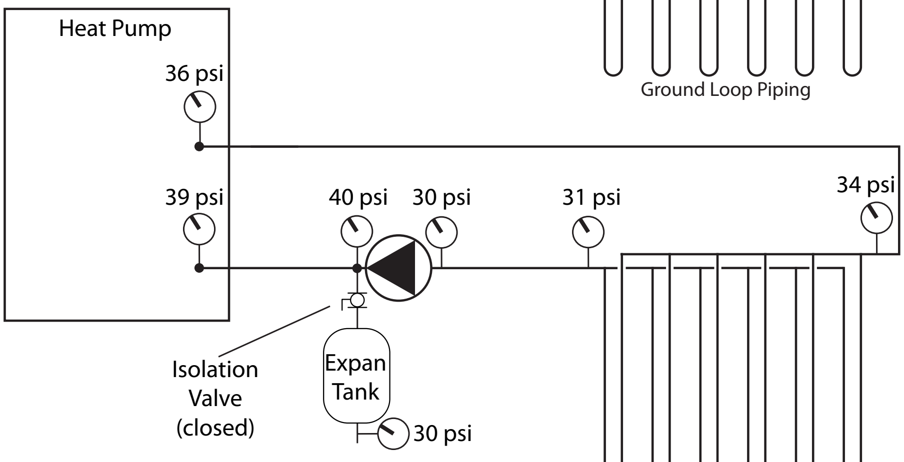


Figure 14: Isolation valve is closed, and then the pump is energized

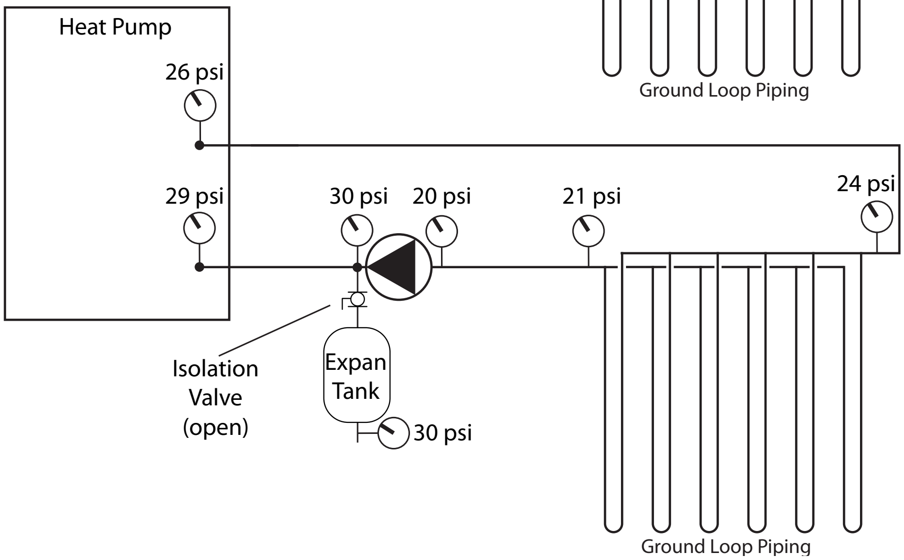


Figure 15: Isolation valve is opened with the pump running

The pressure in the tank will increase slightly from 30 psig as fluid is forced into the tank. Using Boyle's Law as described earlier, we can calculate this increase in pressure. Recall that the system pressure increased to 30 psig when injecting one tablespoon of water and an additional 0.1 tablespoon was required to bring the pressure to 40 psig. This small amount of additional fluid is the volume that will enter the expansion tank when the valve is opened. For simplicity, let's assume the entire 0.1 tablespoons goes into the tank and the air in the tank is compressed by this amount. The resulting pressure increase can be calculated as follows:

$P_2 = P_1(V_1/V_2)$
V_1 = Initial air volume, 1.2 gallons
V_2 =Final air volume, 1.2 gallons - 0.1 tablespoons = 1.2 - 0.0004 = 1.1996
$P_2 = [(30 + 14.7)(1.2000/1.1996)] - 14.7$
P_2 = 30.01 psig

Since this value is very near the initial pressure, for practical purposes it can be assumed to be the same. Hence, the plumb-in point of the tank can be considered "the point of no (or very little) pressure change". This is extremely important since the circulator still must overcome the 10 psi of head loss in the system. The dynamic pressure therefore decreases from the point of the expansion tank throughout the system when the tank is improperly installed on the discharge of the circulator. It follows that if the initial system (static) pressure is 12 psig, and the head loss in the system is 46 Ft-hd (20 psig), the system pressure will fall below atmospheric pressure (Figure 16). As discussed earlier, **this will** cause a host of problems including the additional issues of possibly drawing air into the system (since the pressure inside the pipes is less than atmospheric pressure) or collapsing flexible rubber hose attached to the suction side of the circulator. All of these issues can be avoided by maintaining a sufficient pressure on the suction side of the pumps, which is aided by installing the expansion tank in this location. Figure 17 shows the proper placement along with the pressures from the previous example. It should be recognized from the previous discussion that "the point of no pressure change" only applies if the tanks's pre-charge pressure is less than the static pressure plus the total head loss at the tank's plumb-in point. If the pre-charge is higher than this value, no fluid will enter the tank and the system will operate as if no expansion tank were installed.

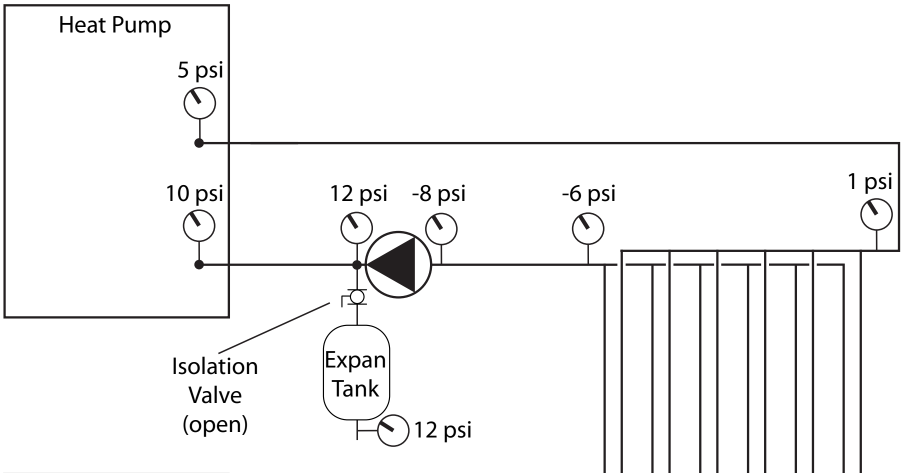


Figure 16: System (dynamic) pressure with a 12 psig static pressure and 20 psig head loss (about 46 ft. of head) with incorrect expansion tank location

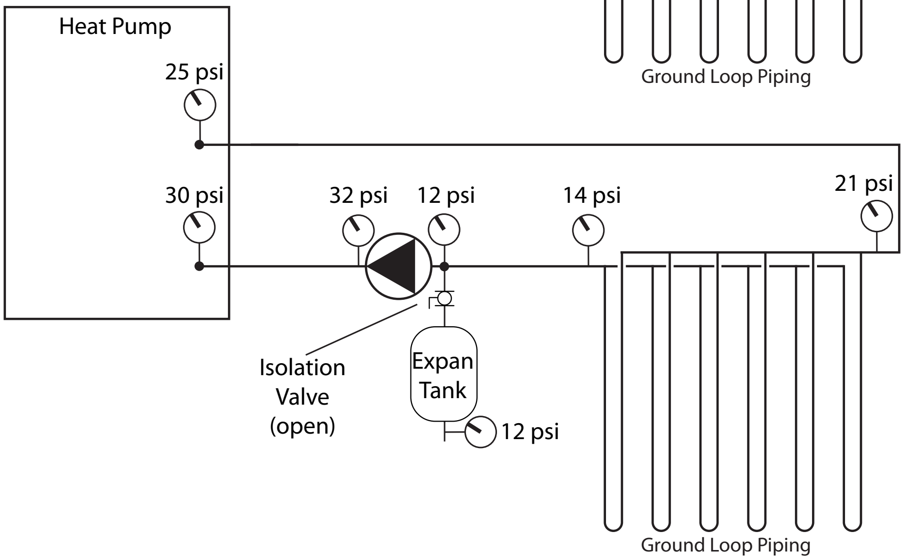


Figure 17: System (dynamic) pressure with a 12 psig static pressure and 20 psig head loss (about 46 ft. of head) with correct expansion tank placement

The installation location of an expansion tank in a residential system using an industry standard two pump pressurized flow center is a bit more complicated since the pumps are arranged in series in what some refer to as a "push-pull" configuration, but may be more properly considered "push-push" since each circulator overcomes the total system head loss equally (assuming both pumps in the flow center are the same) by creating differential pressure, not suction. Figure 18 shows an example of this application with the expansion tank located on the return side of the ground loop. In this example there is a total of 46 Ft-Hd loss total (20 psig), of which 7 psig of head loss is from the left circulator through the hose kit and heat pump, and the remaining 13 psig of loss is through the interior piping, header piping and ground loop circuits. The system's static pressure is 30 psig. The pressures throughout the system are shown to illustrate how the pressure profile changes along the loop system. Now consider the same system except that the expansion tank is located between the flow center and the heat pump just below the right side circulator. The pressure drop through the system is the same, but the pressure profile has changed slightly. In actual systems, the pressure drop through the ground loop is generally close to the pressure drop in the heat pump and piping to the flow center. Therefore, the expansion tank in systems that utilize a two-pump flow center should be located on the suction side of one of the circulators, preferably at the lowest pressure point in the system. This will be on the return side of the loop if the loop's head loss is greater than the heat pump's head loss (as shown in Figure 18) or on the leaving water side of the heat pump just before the circulator (as shown in Figure 19).

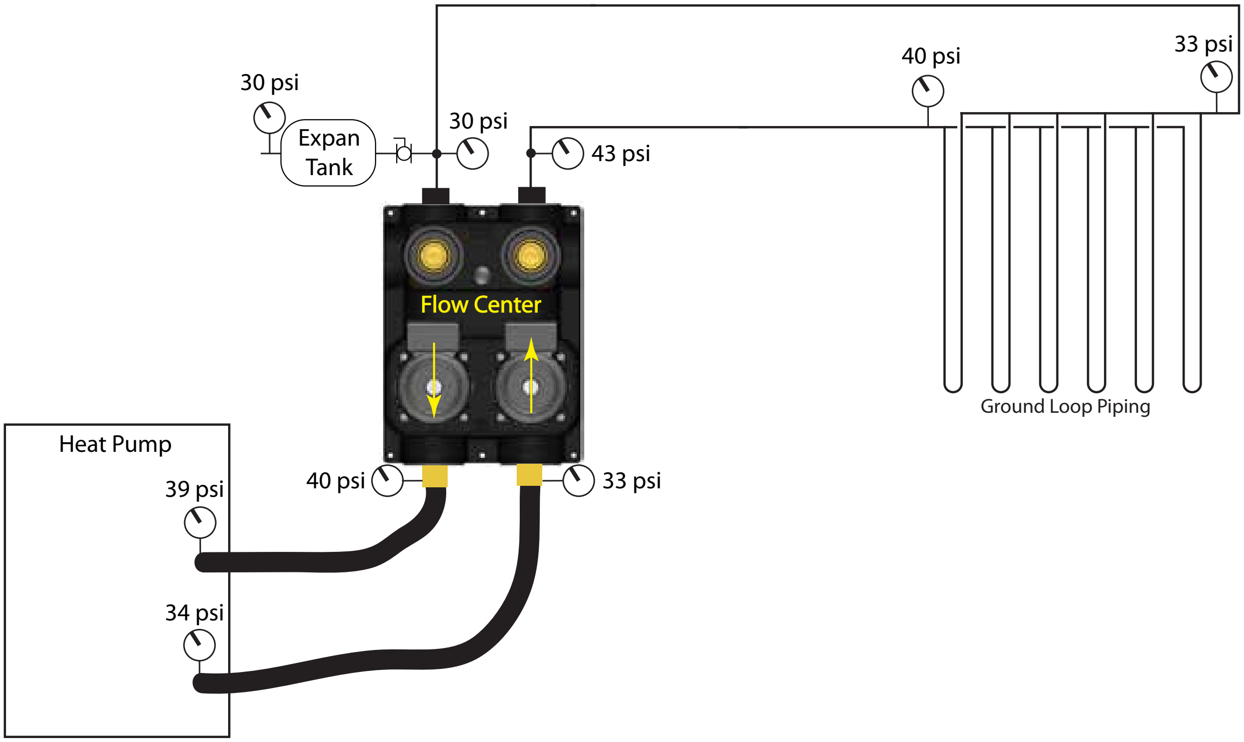


Figure 18: Expansion tank located on the return side of the ground loop (preferred location)

Finally, as discussed previously, the flexible HDPE ground loop pipe expands and contracts similar to an expansion tank, albeit much less, and therefore over-pressurization of the loop system is typically not a concern. An alternative, or an addition to a system with an expansion tank, is an active loop pressurization system (sometimes called a glycol feeder) with an integrated pressure switch that injects pre-mixed loop fluid if the pressure falls below the switch setting. This device has the additional benefit of preventing low loop pressures caused both by small leaks in the loop system and the standard expansion/relaxation of the loop. The installation of this device follows that of an expansion tank; that is, on the suction side of the circulator.

Additional Notes for Expansion Tank Selection

Some expansion tank manufacturers provide a "combination" package (sometimes called "boiler trim kit"), which includes an expansion tank, air scoop/air purger, automatic air vent, water make-up components (pressure reducing valve and back flow preventer -- Figure 20), and in some cases a pressure relief valve. Although a combination system can be a time saver for boiler systems, it is usually not appropriate for geothermal systems. The make-up water components could

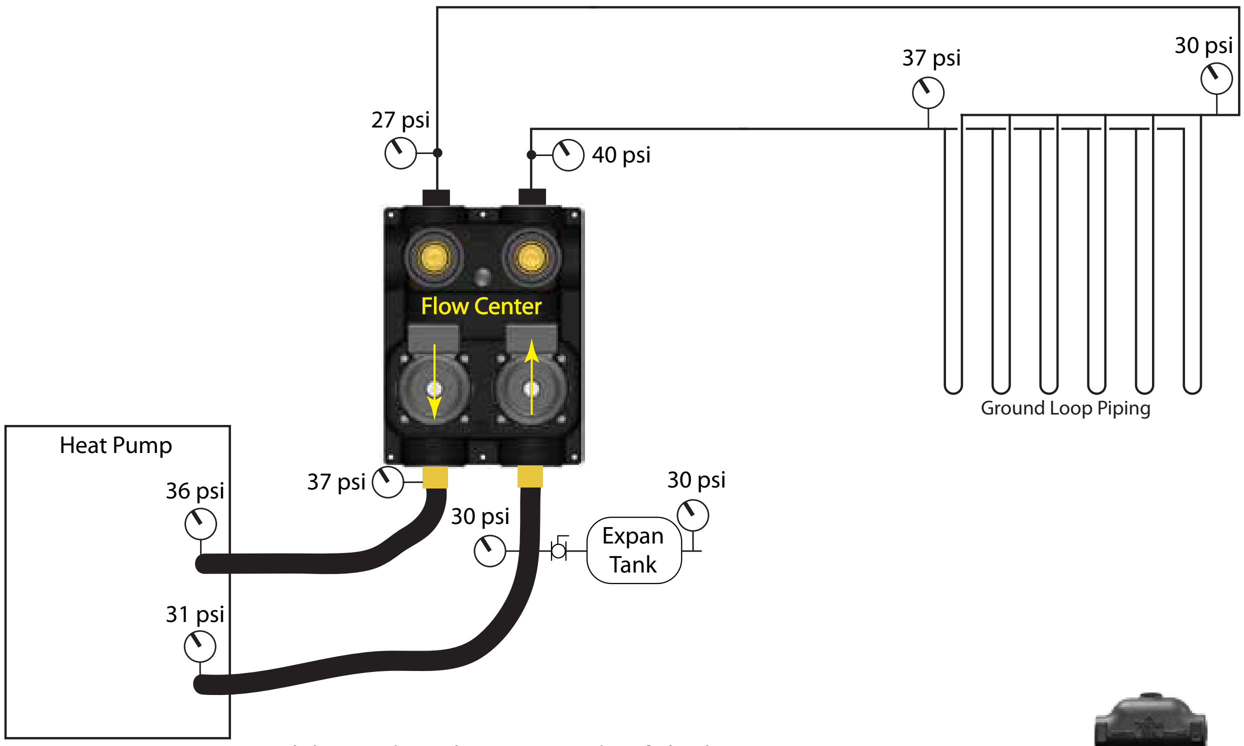


Figure 19: Expansion tank located on the return side of the heat pump (alternate location)

cause antifreeze dilution. An antifreeze or glycol feed system (like the Geo-Booster -- Figure 21) provides make-up fluid from a tank with a pre-mixed water/antifreeze solution. Also, most combination packages are designed with the expansion tank directly attached to the piping system, which could cause condensation on the tank at lower fluid temperatures (see discussion on page 7 and Figure 9).

Figure 20: Typical combination package

Figure 21: Geo-Booster

Validation of White Paper Concepts with Volumetric Calculations

There are a number of concepts discussed in this white paper that may be validated by considering the volumetric expansion of HDPE pipe versus the volumetric expansion of ground loop fluid over a typical temperature range. Assuming that the pipe expands at a faster rate than the loop fluid (as stated earlier in the paper), the volume increases may be calculated and compared to demonstrate the added fluid capacity needed for ground loop systems with HPDE pipe. To determine the volumetric increase in the piping system, several calculations are required, namely:

- Linear expansion of HPDE pipe (provides increase in length)
- Pipe diameter change (provides increase in diameter)
- PIpe volume change (calculation based upon increase in length and diameter)

$d_L = \alpha\, L\, \Delta T$ ***Linear expansion of HPDE pipe***

Where:
d_L = expansion (in.)
L = length of pipe (in.)
ΔT = temperature difference (°F)
α = linear expansion coefficient (in/in°F)
for HDPE pipe, $\alpha = 6.7 \times 10^{-5}$

$d_1 = d_0\,(\Delta T\, \alpha + 1)$ ***Pipe diameter change***
$\boldsymbol{\Delta d = d_1 - d_0}$

Where:
d_1 = final diameter (in.)

d_0 = initial diameter (in.)
ΔT = temperature difference (°F)
α = linear expansion coefficient (in/in°F)
for HDPE pipe, $\alpha = 6.7 \times 10^{-5}$
Δd = change in diameter (in.)

$V_0 = \pi r^2 L_0$ ***PIpe volume change***
$V_1 = \pi (r + \Delta r)^2 L_1$
$\mathbf{\Delta V_p = (V_1 - V_0) / 231}$

Where :
V_0 = initial volume (cu. in.)
V_1 = final volume (cu. in.)
r = radius of pipe I.D. (in.)
L_0 = initial length of pipe (in.)
L_1 = final length of pipe (in.)
Δr = change in pipe radius (in.)
ΔV_p = change in pipe volume (cu. in. -- converted to U.S. gallons with factor of 231)

Once the increase in pipe volume has been calculated with the above equations, the fluid volume increase may be calculated, and compared, using the equation below.

$\Delta V_f = 264.172\, V_0\, \beta\, \Delta T$ ***Fluid volume change***

Where:
ΔV_f = change in fluid volume (m^3 -- converted to U.S. gallons with factor of 264.172)
V_0 = initial volume (m^3)
β = volumetric temperature expansion coefficient (m^3/m^3 °C)
for water, β = 0.000207 1/°C
ΔT = temperature difference (°C)

Consider the following example:

A geothermal system with a vertical ground loop and the following parameters:

- 3,600 ft. of 3/4" DR11 HDPE piping (10 - 180 ft. vertical bores) -- 43,200 in. length, 1.05 in. O.D., 0.86 in. I.D.
- Temperature change of 50°F (40°F to 90°F)
- Fluid is water

1. Calculate the linear pipe expansion.
$d_L = \alpha L \Delta T$
$= (0.000067)(43{,}200)(50)$
$= 144.72$ in.

2. Calculate the pipe diameter change.
$d_1 = d_0 (\Delta T \alpha + 1)$
$= (1.05)((50)(0.000067) + 1)$
$= 1.0535$ in.
$\Delta d = 1.0535 - 1.05 = 0.0035$ in. (radius change, $\Delta r = 0.00175$ in.)

3. Calculate the pipe volume change.
$V_0 = \pi r^2 L_0$
$= (3.14)(0.43)^2(43{,}200))$
$= 25{,}081.32$ cu. in.
$V_1 = \pi (r + \Delta r)^2 L_1$
$= (3.14)(0.43 + 0.00176)^2(43{,}344.72))$
$= 25{,}370.59$ cu. in.
$\Delta V_p = (25{,}370.59 - 25{,}081.32) / 231 = 1.25$ U.S. gallons

4. Calculate fluid volume change.
$\Delta V_f = 264.172\, V_0\, \beta\, \Delta T$ ($V_0 = 25{,}081.32$ cu. in. $= 0.4158\ m^3$)
$= (264.172)(0.4158)(0.000207)(27.8)$ ($\Delta T = 50°F = 27.8°C$)
$= 0.63$ U.S. gallons

Although the fluid expands with temperature increase as expected (0.63 gallons), the expansion of the HDPE pipe is much greater (1.25 gallons). Based upon the above example, it can be determined that ground loop systems do indeed experience lower system pressure as the temperature increases, which is the opposite of systems with rigid piping. Therefore, an expansion tank must be sized to accommodate the difference between increased pipe volume at higher temperatures and increased fluid volume, rather than sized to limit maximum system pressure, typical of boiler systems.

Summary

In summary, all geothermal ground loop (pressurized) systems can benefit from an expansion tank or pressure make-up system (such as the Geo-Booster or other pressurization/feeder tank systems). Whether it be a Pressure Battery for residential applications, or a larger steel diaphragm expansion tank on a commercial application; the bladder tank helps maintain system pressure, and helps avoid equipment or pump service calls. Key concepts from this white paper include the following:

- Fluid expands as temperature increases.
- System pressure increases as temperature increases for rigid piping.
- HDPE pipe expands at a much faster rate than the fluid in the pipe.
- System pressure decreases as temperature increases for systems with HDPE pipe.
- Expansion tanks must be sized to limit maximum system pressure for systems with rigid piping to address safety and operational issues at higher pressures.
- Expansion tanks must be sized to provide additional fluid capacity at lower system pressures for ground loop systems with HPDE piping.
- Bladder type expansion tanks with a lower pre-charge provide more fluid capacity for ground loop systems. Pre-charge higher than 12 psig should generally be avoided. Note that the pre-charge may be higher for a multi-story structure to prevent the tank from filling when the system is filled. One could say that the pre-charge should equal the highest distance measured from the expansion tank to the top of the loop (i.e. equal to the water column pressure on the tank).
- The correct location of the expansion tank is crucial to long-term system reliability.
- A geothermal expansion tank Calculator is available at www.geo-flo.com ("Design Calculator" link).

Sources

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- *Modern Hydronic Heating* (3rd edition), Siegenthaler
- Research documents, Geo-Flo Product Corporation

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