EXPANSION TANKS IN GEOTHERMAL SYSTEMS

A DETAILED PRESENTATION ON DIAPHRAGM TANKS IN CLOSED LOOP GEOTHERMAL SYSTEMS

IGSHPA DIG DEEPER SERIES

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Goals For Training

- Understand the purpose of expansion tanks in closed loop geothermal systems
- Recognize differences between expansion tanks in boiler versus geothermal systems
- Explain how an expansion tank works in a geothermal system
- Define and understand the importance of acceptance volume
- Determine tank pre-charge
- Perform expansion tank sizing
- Discuss installation considerations
- Provide sources for independent investigation of this topic

References

1. ASHRAE Handbooks
2. ANSI/CSA/IGSHPA C448 standard
3. The Handbook of Polyethylene Pipe, Plastic Pipe Institute
4. Modern Hydronic Heating (3rd edition), Siegenthaler
5. Understanding Expansion Tanks, ASHREA Journal March 2003, Taylor
6. White paper: Expansion Tanks for Geothermal Ground Loop Systems, Geo-Flo Corporation (see https://www.geo-flo.com/presentations-and-tech-documents/)
7. Geo-Flo Calculators; https://geo-flo.com/calculators/

Why use an expansion tank in a geothermal system?

- Experienced installers know that a typical system will have the highest pressure in the winter and lowest in summer
- HPDE pipe expands and contracts at a faster rate than the loop fluid (see following example)
- The HPDE pipe in used closed loop systems is viscoelastic and experiences stress relaxation
- These conditions lead to a decrease in system pressure over time
- Low system pressure can lead to issues including:
  - Pump cavitation leading to failure and system shut-down
  - Air lock of the pump leading to failure and system shut-down
    - Small air bubbles trapped in the system will become larger with decreasing system pressure
  - System noise due to larger air bubbles in piping
  - Negative system pressure leading to collapsed hoses or drawing air into system
- An expansion tank in a ground loop system helps prevent critically low system pressures

HDPE Pipe Expansion Versus Fluid Expansion

- Volumetric change in the pipe can be determined from the change of pipe length and diameter over the expected temperature range
  - This assumes an unrestrained pipe, which leads to a conservative estimate

Linear expansion of HPDE pipe, dL

$d_L = \alpha L_0 \Delta T$

Where:

d_L= expansion (in.)

L_0 = length of pipe (in.)

ΔT = temperature difference (°F)

α = linear expansion coefficient (in/in°F), for HDPE pipe, $\alpha = 6.7 \times 10^{-5}$ ((This value is reported to be in the range of 67 to 100 $\times 10^{-6}$)

Pipe diameter change,

Δd = change in diameter (in.)

$\Delta d = d_1 - d_0$

$d_1 = d_0(\Delta T\, \alpha + 1)$

Where:

d_1= final diameter (in.)

d_0= initial diameter (in.)

ΔT = temperature difference (°F)

α = linear expansion coefficient

Pipe volume change

ΔVp = (V1 - V0) / 231

$V_1 = \pi (r + \Delta r)^2 L_1$

$V_0 = \pi r^2 L_0$

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)

HDPE Pipe Expansion Versus Fluid Expansion

- Volumetric change in fluid

Fluid volume change

$\Delta V_f = 264.172\ V_0 \beta\ \Delta T$

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)

- Once the volume changes in the pipe and fluid are calculated, they can be compared

HDPE Pipe Expansion Versus Fluid Expansion

- Example 1: Expansion of fluid versus HPDE pipe
- A geothermal system with a surface water (pond/lake) heat exchanger and the following parameters:
  - 3,600 ft. of 3/4" DR11 HDPE piping (12 x 300 ft. spaced coils) -- 43,200 in. length, 1.05 in. O.D., 0.86 in. I.D.
  - Expected temperatures are 40°F (4.4 °C) to 90°F (32.2°C)
  - Fluid is water

- Solution:

1. Calculate the linear pipe expansion.

$$d_L = \alpha\, L\, \Delta T$$
$$= (0.000067)(43{,}200)(50)$$
$$= 144.72 \text{ in.}$$

2. Calculate the pipe diameter change.

$$d_1 = d_0\,(\Delta T\, \alpha + 1)$$
$$= (1.05)((50)(0.000067) + 1)$$
$$= 1.0535 \text{ in.}$$
$$\Delta_d = 1.0535 - 1.05 = 0.0035 \text{ in. (radius change, } \Delta r = 0.00175 \text{ in.)}$$

HDPE Pipe Expansion Versus Fluid Expansion

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. (~110 gallons)

$V_1 = \pi (r + \Delta r)^2 L_1$
$= (3.14)(0.43 + 0.00176)2(43,344.72))$
$= 25,370.59$ 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 m3]; [ΔT = 50°F = 27.8°C]

$= (264.172)(0.4158)(0.000207)(27.8)$
$= 0.63$ U.S. gallons

- Expansion of HDPE pipe (1.25 gallons) > Expansion of fluid (0.63 gallons)
- Expansion tank should be sized to “give back” the difference (1.25-.63=.62) to maintain system pressure
- These calculations, along with field experience, shows that some method of making up the pressure loss associated with the mismatch between the volumetric change in the pipe versus fluid should be implemented.

Why use an expansion tank in a geothermal system?

- Current ANSI/CSA/IGSHPA C448 standard

7.1.4.2

For pressurized systems the pressure at the top of the system shall be positive to assure that air is expelled from the system and that the pumps remain flooded at all times. The installer shall include one of the following:

a) The installer shall include an expansion tank to maintain at least NPSHr to the circulator pump;

b) The installer shall include a pressurization system (commonly described as glycol or antifreeze feed system) that does not dilute the antifreeze in the system, if present (with approval of the local authority having jurisdiction, if required); or

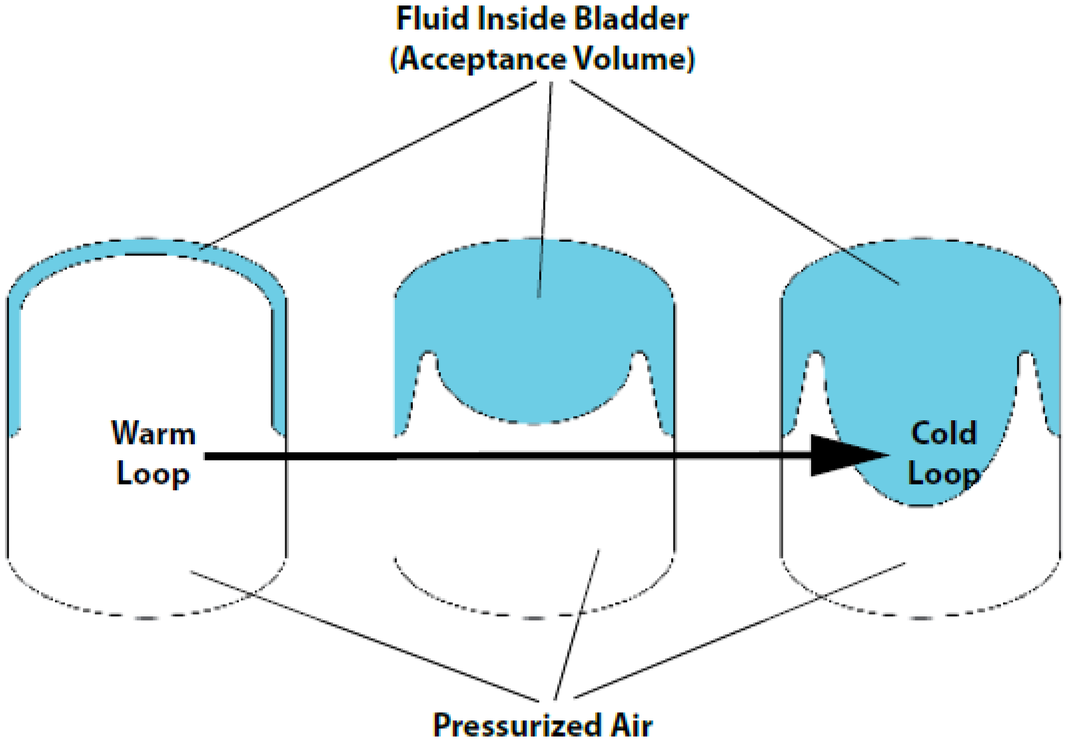
c) The installer shall determine minimum static pressure that will provide at least NPSHr to the circulator pump year-around, and pressurize the system accordingly.
If the method in Item c) is chosen, the system pressure shall not exceed the rated capacity of any of the components in the system, including all piping, valves, pumps, and flow centres.

Expansion tanks in boiler versus geothermal systems

- Purpose of expansion tank in traditional hydronic/boiler system is to prevent over pressurization
  - Boiler piping consists of rigid piping that expands/contracts very little over the operating range
  - Fluid expands rapidly causing dangerous pressure increase without an expansion tank
  - Boiler systems include pressure relief valves (PRV); typically, not installed in earth loop systems
  - Expansion tank sized to prevent dangerous system pressures, fluid exiting PRV, and to keep pressure below ratings of installed components
- Purpose of expansion tank in geothermal system is to prevent low system pressure
  - Properties of HPDE pipe and typical start-up pressures mean over pressurization is usually not a concern
  - In rare circumstances, system pressures may spike; expansion tanks in these situations are used to control over pressurization

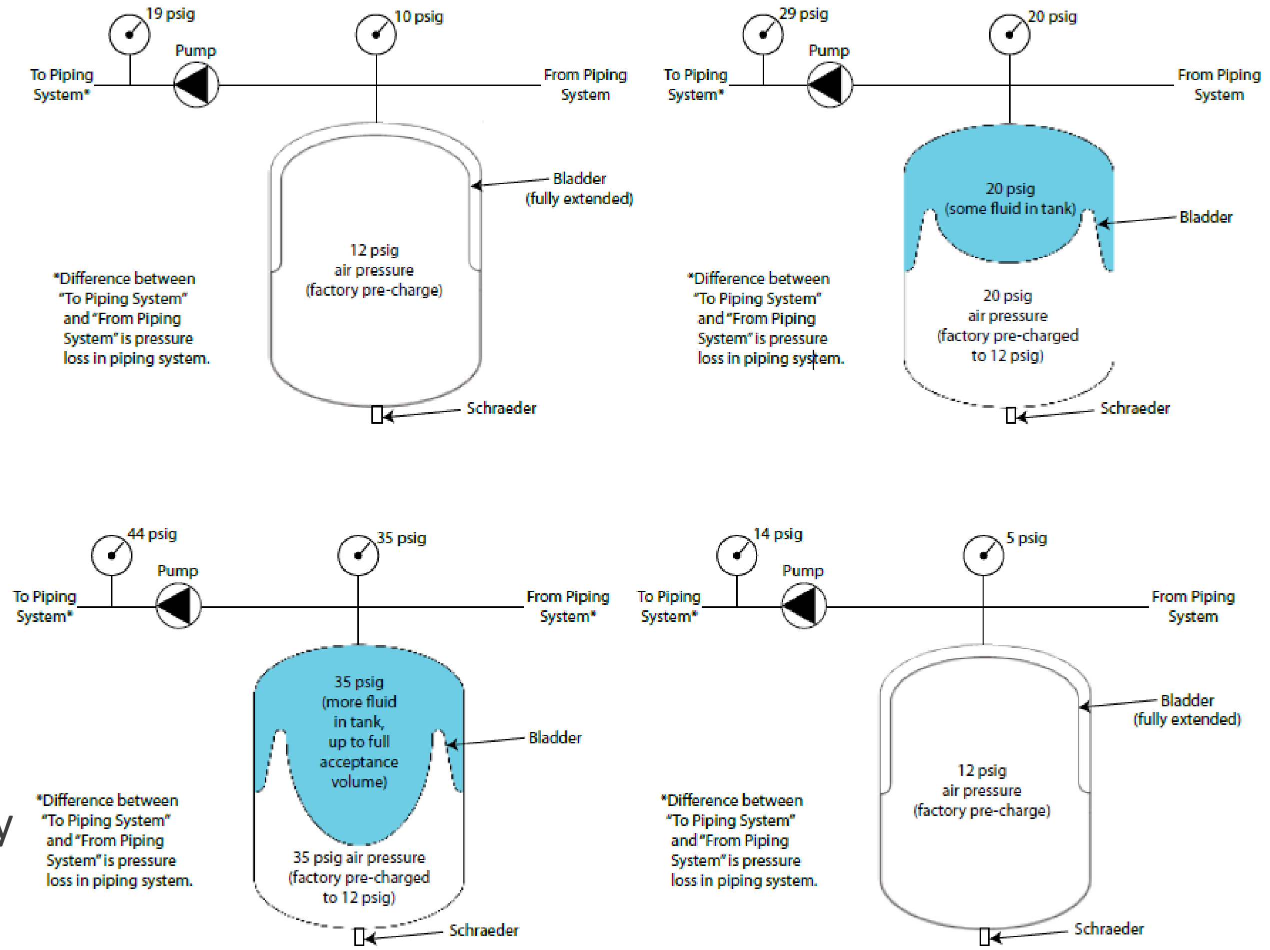
How an Expansion Tank Functions in Geothermal

- Loop pressure highest when loop temperature is coldest (heating season), and lowest when loop temperature is highest (cooling season)
- Works well because the air trapped inside the tank expands and contracts at a much greater rate than the HPDE pipe.



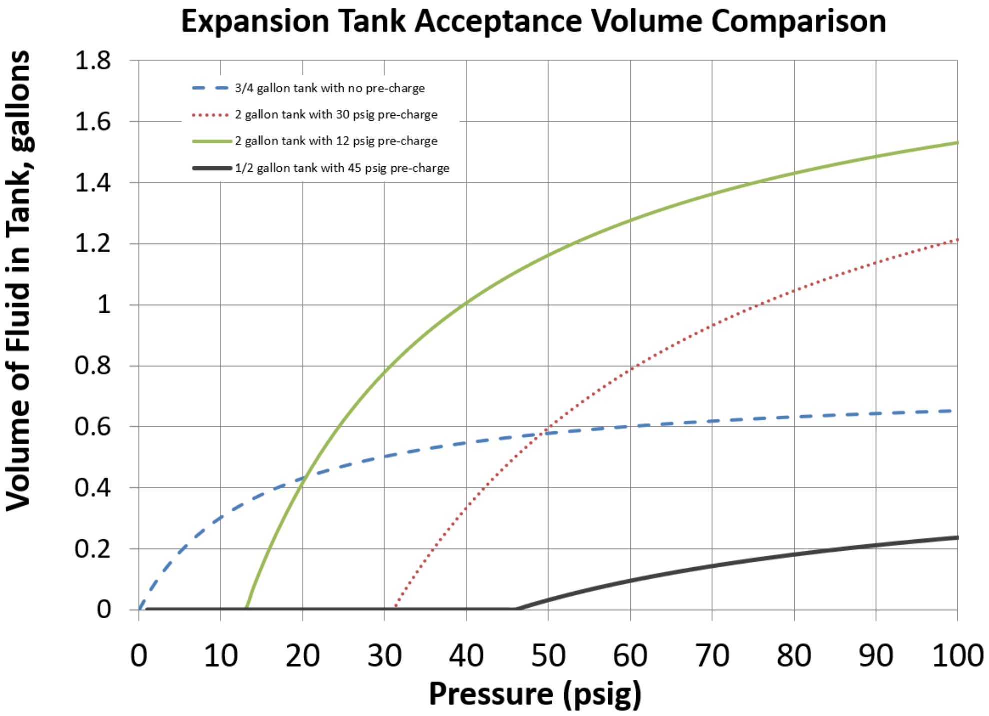
How an Expansion Tank Functions in Geo

- Pre-charge pressure is the air side pressure at which the diagram is fully extended
- Boiler systems: pre-charge set at installation temperature (cool) allowing the tank to start functioning as fluid warms
- Geo systems: system pressure higher than the pre-charge will allow fluid into the tank, and will help maintain system pressure
- Geo systems: pre-charge is pressure at which the tank stops functioning to prevent low pressure
  - Still works for over-pressurization, but not typically a concern
  - Should be as low as possible to get maximum capacity from tank selected



Pre-Charge and Acceptance Volume

- Pre-charge pressure affects the ability of tank to absorb (accept) fluid
- Acceptance volume of a diagraph tank is the amount of fluid that it can hold at the maximum system pressure
- Recall, 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
- Tank pre-charge should be set to match the water column (elevation head) at the tank's installation point
- Pre-charge (psig)=height of piping above install point (ft)/ 2.31 ft-hd/psig
- Most commercially available *hydronic* tanks have a pre-charge of 12 psig
  - Allows 12 psig*2.31 psi/ft-hd= 27.7 ft



Note: Chart assumes zero elevation head at tank installation point.

Pre-Charge and Acceptance Volume

- Amount of air in tank can be calculated from Boyles Law:

$P_1 V_1 = P_2 V_2$

$V_2 = V_1(P_1/P_2)$

Where:

P_1 = Initial air pressure (P_i)

V_1 = Initial air volume

P_2 = Final air pressure (P_{max})

V_2 = Final air volume

Assuming fully extended diaphragm:

$V_1 = V_{tank}$

Amount of fluid $V_{water\ final} = V_{air\ initial} - V_{air\ final}$ = acceptance volume

$= V_1 - V_2$

Substitute for V_2

$= V_1 - V_1(P_1/P_2)$

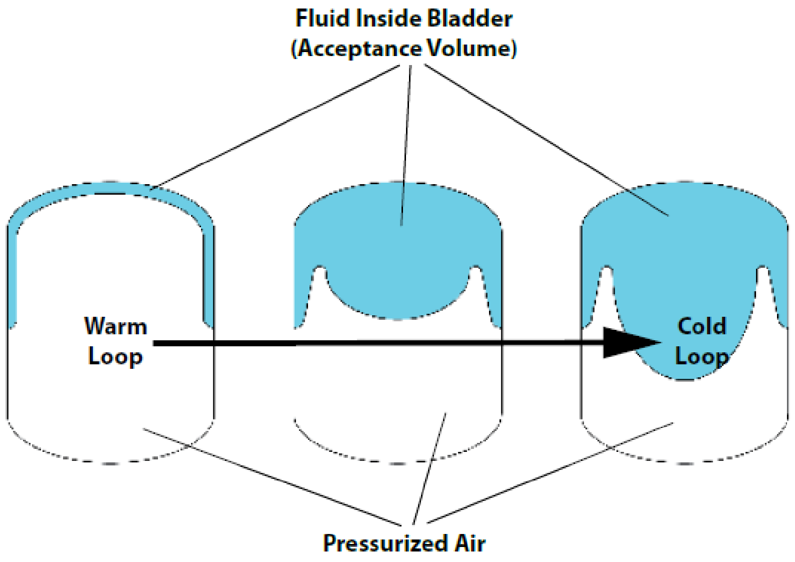
Divide equation by V1 to normalize for any tank size:

$V_{water\ final}/V_1 = 1-(P_1/P_2)$

Also expressed as

$=1-(P_i/P_{max})$ [This term is sometimes called "acceptance factor"]

Fluid in tank= Tank Volume X acceptance factor



Expansion Tank Sizing

- Tank with too small of acceptance volume (small tank or wrong pre-charge) is not helpful (see previous slide)
- Tank larger than needed (conservative selection) will not cause problems
  - Slightly higher installation cost
  - Slightly more mechanical room space required
- Need to select tank(s) with a total acceptance volume > pipe expansion over the expected temperature range
  - Two small tanks may be installed instead of one large tank
- Boiler system: Acceptance volume (tank volume) > volume of fluid expansion
- Ground loop system: Acceptance volume (tank volume) > volume pipe expansion
  - Tank size depends on acceptance volume of tank at system charge pressure (typically flush cart dead-head pressure)

Expansion Tank Sizing

ASHREA formula(*2016 ASHRAE Handbook – HVAC Systems and Equipment)*

$$V_t = V_s \frac{[(\nu_2/\nu_1)-1]-3\alpha\triangle T}{1-(P_1/P_2)}$$

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
ν_1 = specific volume of water at lower temperature, ft^3/lb
ν_2 = specific volume of water at higher temperature, ft^3/lb
α = linear coefficient of thermal expansion, in/in • °F
for steel piping, $\alpha = 6.6 \times 10^{-6}$
$\Delta t = (t_2 - t_1)$, °F
α (HDPE)= 67×10^{-6} (This value is reported to be in the range of 67 to 100 x 10^{-6})

Taylor proposes: (See Reference 5)

$$V_a \geq V_e$$

$$\geq V_s [(\nu_2/\nu_1)-1]$$

$$V_t \geq \frac{V_e}{1-(P_i/P_{max})}$$

V_a = tank acceptance volume
V_e = increase in volume of water as it expands from its min to max temperature
P_i= Pre-charge pressure, psia
P_{max}= Maximum system pressure, psia

- Term in denominator serves to make the tank larger since Pmax is always greater than the pre-charge pressure Pi
- Ignores change in pipe volume resulting in slightly large tank

Expansion Tank Sizing

Example 2: A system has 100 gallons of fluid and HDPE piping. The minimum desired system static pressure is 12 psig, and the system static start-up 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.

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

where:

V_t = volume of expansion tank, gallons

V_s = 100 gallons

t_1 = 35 °F

t_2 = 85 °F

P_1 = 64.7 psia at lower temp

P_2 = 26.7 psia at higher temp

v_1 = .01602 ft^3/lbm at lower temp,

v_2 = .01609 ft^3/lbm at higher temp

$\alpha = 67 \times 10^{-6}$ (This value is reported to be in the range of 67 to 100 x 10^{-6})

Δt = 50 °F

$[(v_2/v_1)-1]$ = (0.01609/.01602)-1=0.0044

$V_s [(v_2/v_1)-1]$ =.44 gallons

$3\alpha\triangle T$=(3 X 0.000067 X 50)= 0.01005

$V_s(3\alpha\triangle T)$= 1.005 gallons

- Pipe expansion is greater than water expansion, as discussed previously (.44-1.005)=-.57 gallons (note negative volume)

$1-(P_1/P_2)$ = 1-(64.7/26.7) = 1-2.42=-1.42

Since $P_1 > P_2$, denominator is negative resulting in a positive tank volume

V_t=(-.57/-1.42)= 0.4 gallons

- However, this $V_t < V_a$

Expansion Tank Sizing

- What if we flip the P_1/P_2 to P_2/P_1 (as Taylor proposes, P_i/P_{max})?

  $1–(P_2/P_1) = 1-(26.7/64.7) = 1-.41= .59$

  Then,

  $V_t =(-.57/.59)= -0.97$ gallons

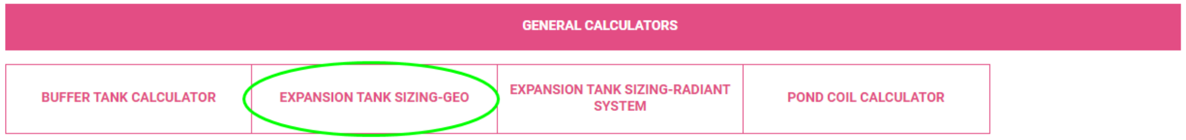
- This results in a negative volume; do we take the absolute value, or?

- As it turns out, a 0.97 gallon tank will accept .59 gallons of fluid when it is pressured to 50 psig with a 12 psig pre-charge
  - Recall fluid accepted into tank = Tank volume (size) X acceptance factor = 1 gallon X $(1- (P_i/P_{max})=1 \times (1- 26.7/64.7)=$ .59 gallons
  - This indicates that rearranging the values in the ASHREA formula is necessary to use for tank sizing for minimum fluid pressures:

$$V_t = V_s \frac{3\alpha\triangle T–[(v_2/v_1)–1]}{1–(P_i/P_{max})}$$

Expansion Tank Sizing Summary

- ASHREA formula has been successfully used by engineers for decades so empirical evidence indicates that it is valid for both boiler systems and geothermal systems to prevent over pressurization
  - Caution should be exercised when using this formula for maintaining a minimum loop pressure particularly in unrestrained loops
- Taylor’s approach of ignoring the pipe expansion is more conservative than ASHREA formula when sizing for over pressurization
- Correct approach is to compare the volumetric expansion of the HPDE pipe to the volumetric expansion of the fluid and chose a tank that will provide enough capacity to maintain the desired loop pressures
  - Several ways to get to this solution including fundamental calculations (Slides 5-9) or rearranging the ASHREA formula
- Geo-Flo’s *Expansion Tank Sizing for Geo* Calculator currently uses the fundamental approach and is based on maintaining a minimum loop pressure, not controlling maximum pressure
  - https://geo-flo.com/calculators/



Expansion Tank Sizing: Calulator

- Geo-Flo *Expansion Tank Sizing for Geo* Calculator

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

Version 2.2

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.

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), typically 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).

System Volume Input:

Volume Calculation: Manually enter system volume

Enter length of various pipe type/diameter
- Manually enter system volume
- Enter length of various pipe type/diameter

Manual Entry (US Gallons)*: 100

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

Expansion Tank Selection Parameters:

Tank Pre-charge (psig)	12	see Note 1.
System Static Pressure at start-up (psig)	50	see Note2.
Min. System Temp (deg F)	40	
Max. System Temp. (deg F)	90	
% of HDPE pipe	0%	Enter % of PE3408/3608 and PE4710 pipe in the system
Other pipe	Copper Type	Enter most predominent pipe type in system other than HDPE

Parameters from Example 1

Solution to Example 1

Pipe Lengths and Diameters for Calculating System Volume (Skip if using Manual Entry)

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

System Volume Output (US Gallons) 108.6 (Calculated based upon pipe length/diameter/type entered above)

Minimum Expansion Tank Acceptance Volume (US Gallons). See Notes 3 & 4. 0.6

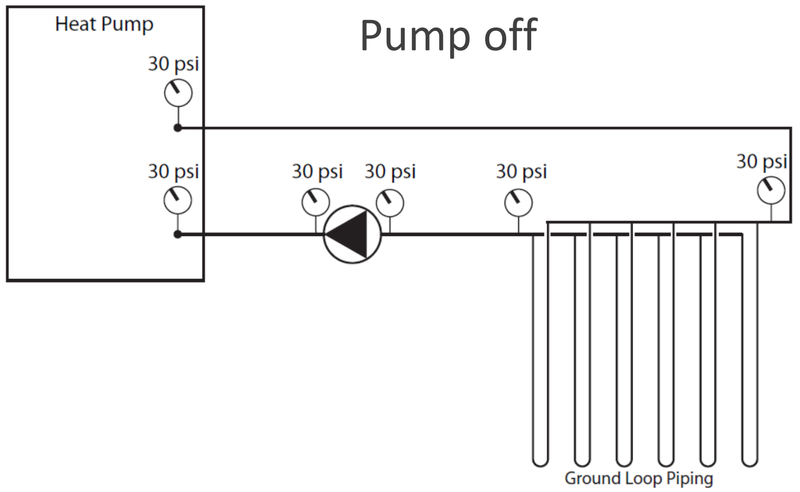
Closest Geo-Flo Model: ETN-FX-HTX15 — 2.1 Gallon fixed diaphragm expansion tank, non-ASME, 1.2 gal. acceptance volume (at input pressures), wall/piping mounted

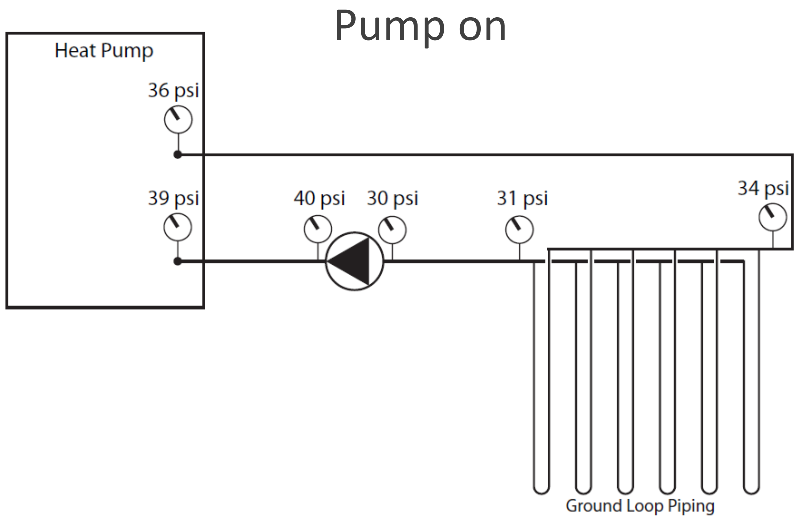
Enter Selected Expansion Tank Size (US Gallons) 1 — Use this input to calculate acceptance volume for tanks other than suggested Geo-Flo models.

Acceptance Volume of Selected Tank (US Gallons) 0.6 — At above pressures entered in "Expansion Tank Selection Parameters" above

Installation: Location

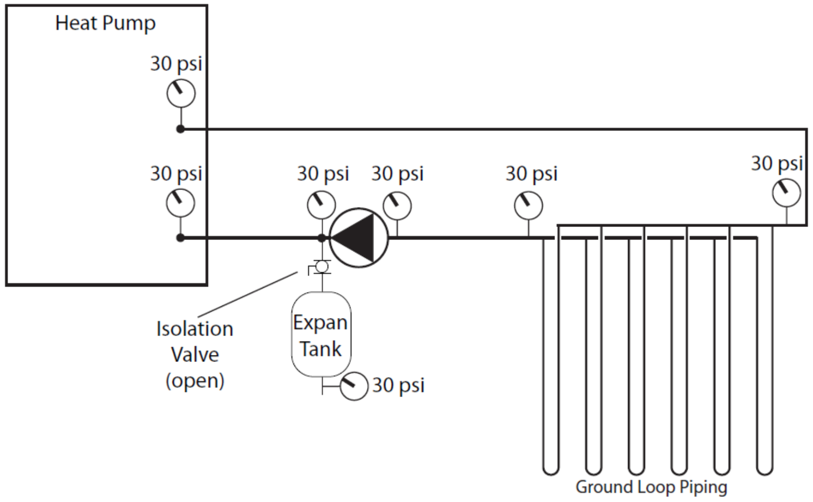
- Expansion tank should be installed on the suction side of the circulator (pump)
  - This location is the best to prevent issues with low loop pressures (air bubble increases, noise, cavitation, noise, system lock out)
  - Installation at other locations is permissible, but other considerations/calculations must be made (see Reference 5)
- Example:



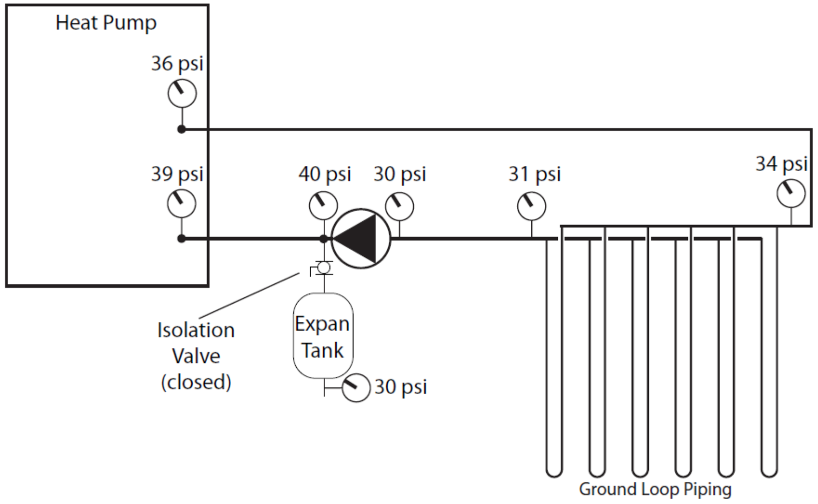


Installation Example: Discharge side of pump

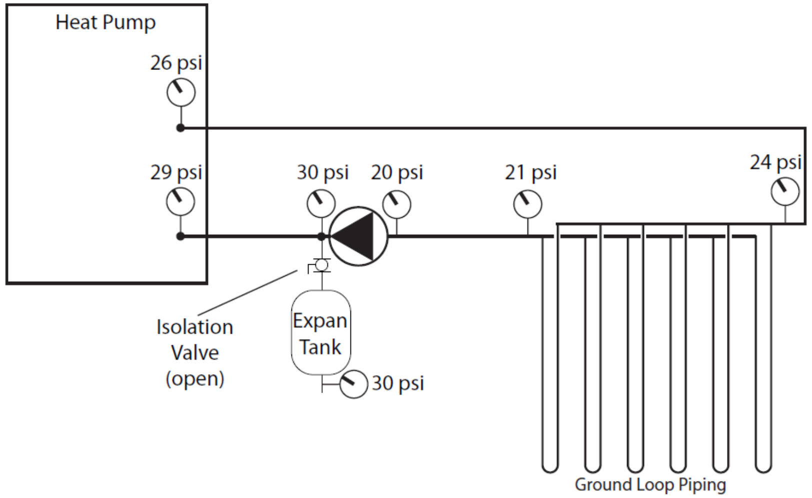
Pump off/Valve open



Pump on/Valve closed

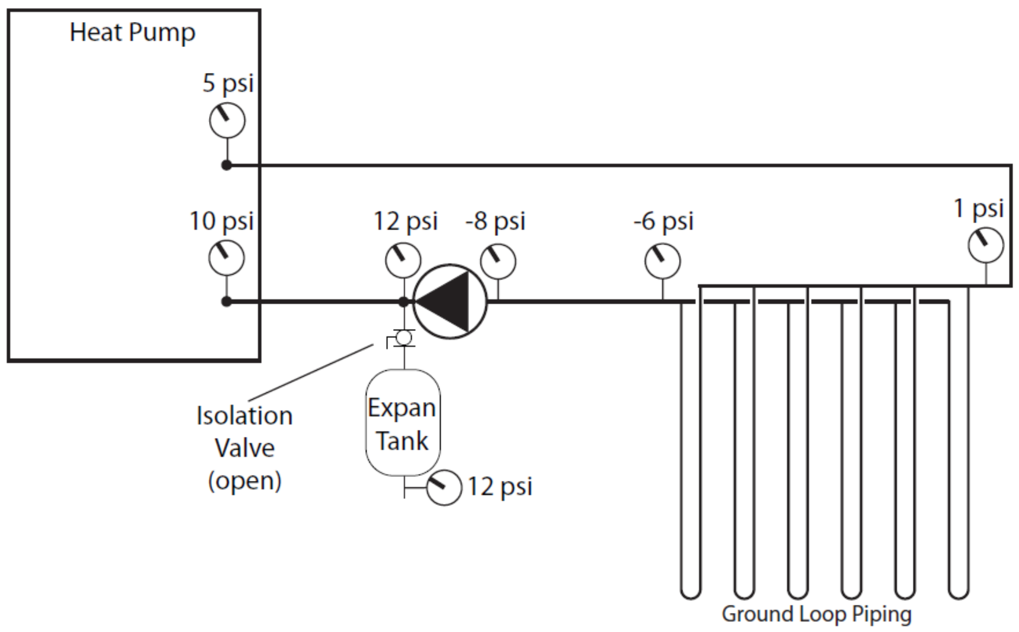


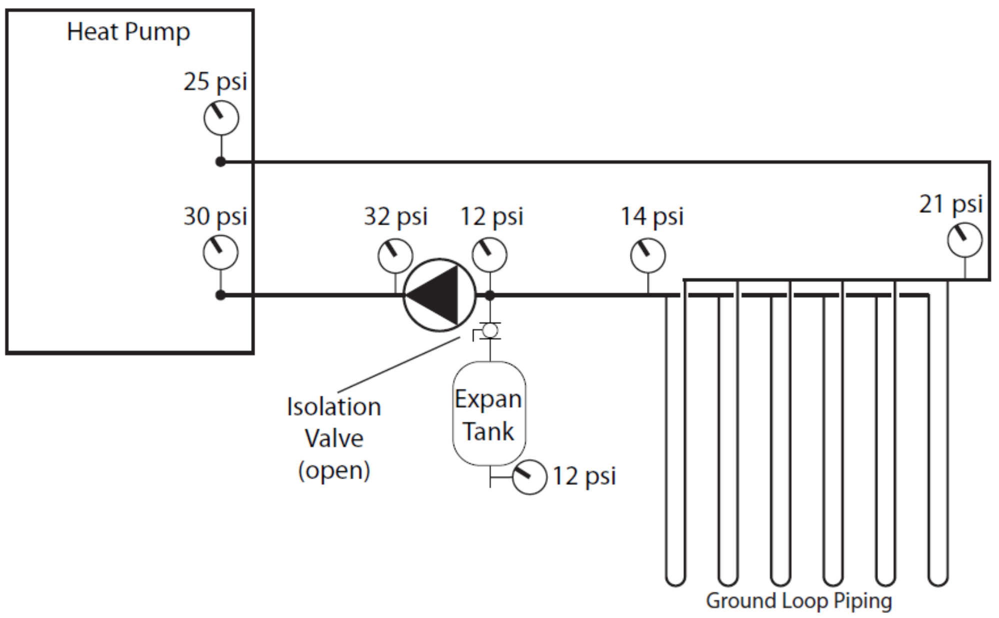
Pump on/Valve open



Installation Example: Suction side of pump

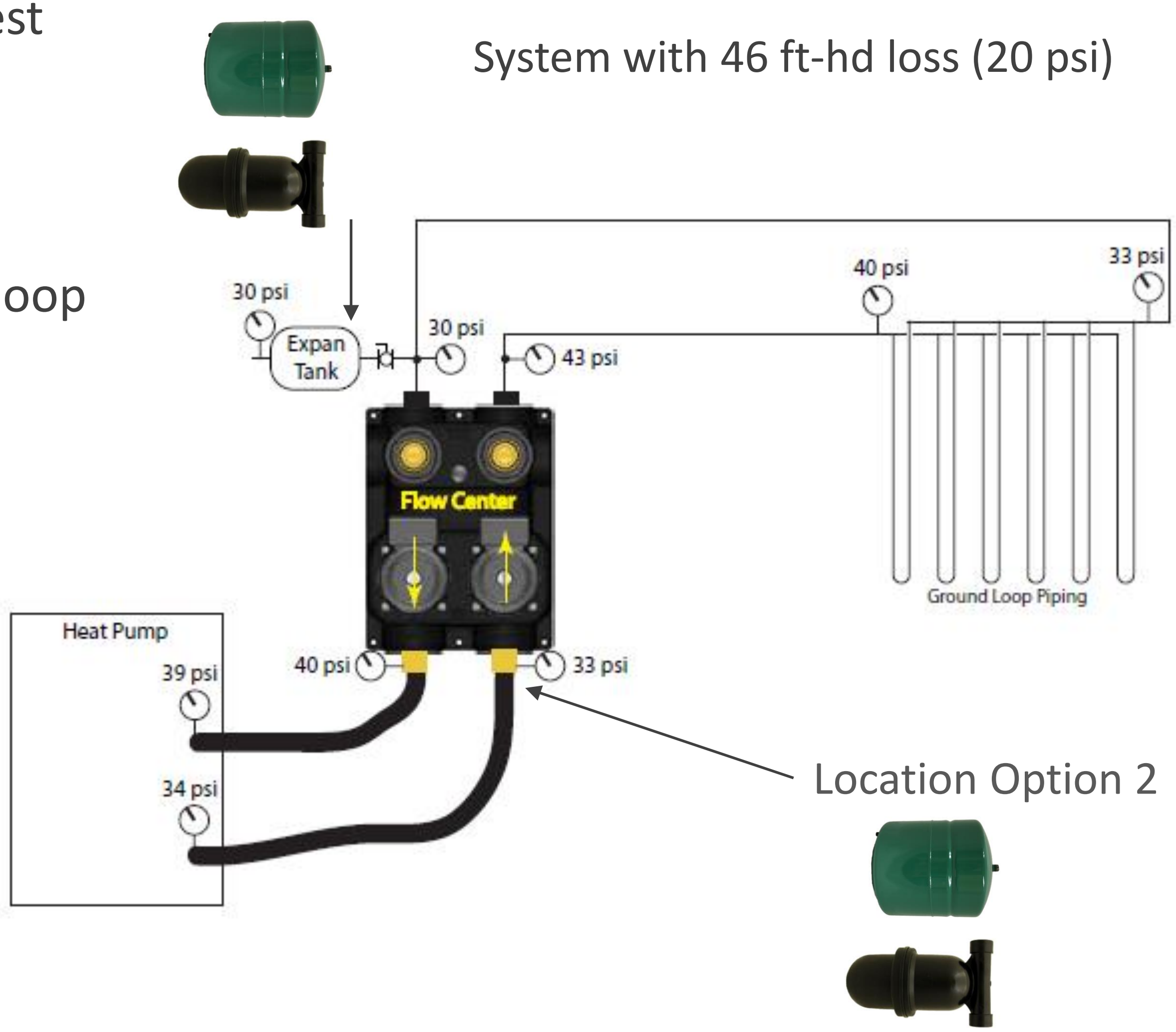
- System installed with 12 psig (28 ft-hd) of static pressure and matching pre-charge pressure on expansion tank
- Dynamic head loss in system is 46 ft-hd (20 psi)





Installation: Flow Center

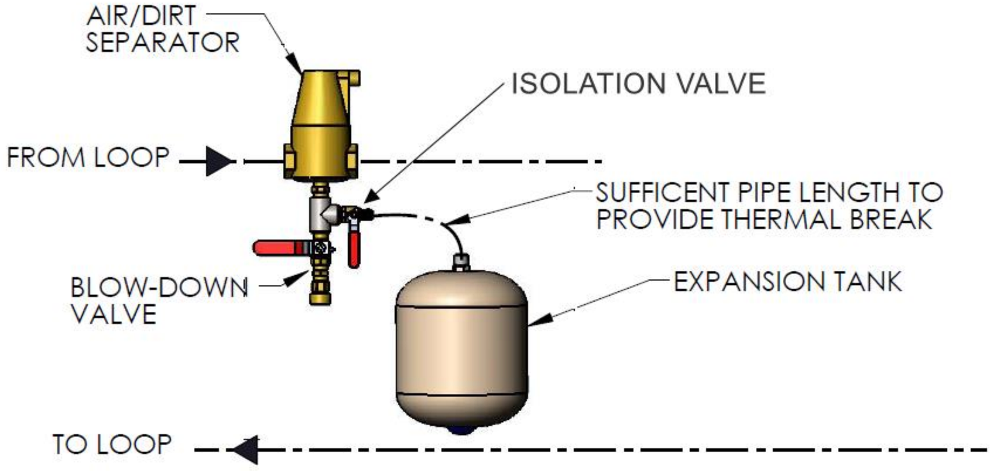
- Flow centers: Install at suction side of pump at lowest pressure point in system (typically on return side of loop)
  - Constant speed circulators split total system head loss
- Second option is suction side of pump going to the loop field



Installation: Other Considerations

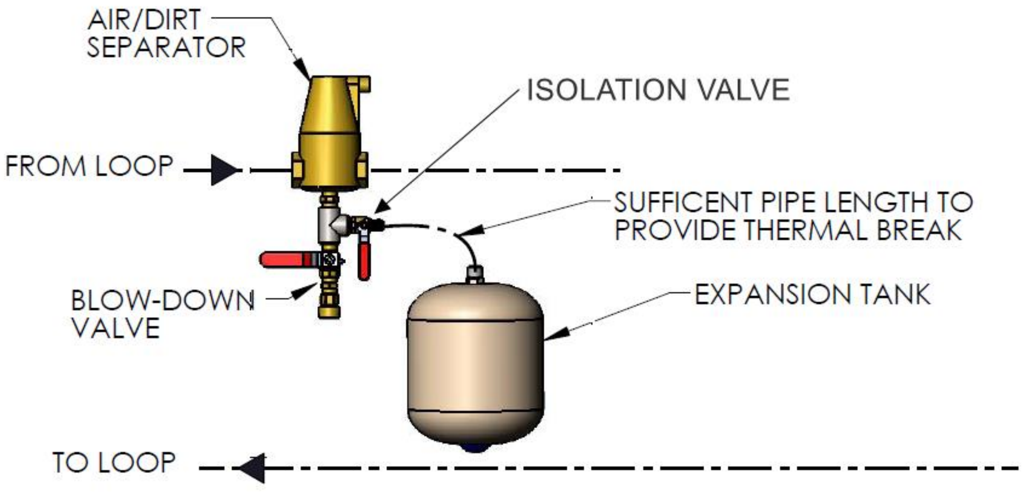
- Install with thermal break so tank will not sweat/rust or use HPDE tank, if possible
- Do not install directly below air/dirt separator
- Include isolation valve for start-up and service if possible; becomes more important with increasing tank size
- Preferably installed with body down/connection point up
  - Prevents air from being trapped inside the tank on the fluid side of the diagram
- Two small tanks can be installed instead of one large tank
  - Connect both at same point
- 1-1/4” and 2” HPDE tees are available with FPT ports





Installation: Start-up

- Set tank pre-charge, if applicable
- Fill system with tank isolation valve open (if installed)
- Flush system with tank iso valve closed
- Dead-head flush cart to check for air in system
  - If no isolation valve installed, remember to account for the compression of air in the expansion tank
- Open isolation valve during system pressurization (typically done by dead-heading flush cart) to charge tank



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QUESTIONS/COMMENTS?

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