Misleading and sometimes incorrect statements regarding how to select and pipe expansion tanks can be found in design manuals and manufacturers' installation guides. Some of the more common claims follow. **Claim:** Expansion tanks must be connected to the system near the suction of the pump. **Fact:** Closed expansion tanks (those not vented to the atmosphere) may be connected anywhere in the system provided their precharge (initial) pressure and size are correctly selected. However, maximum pressure ratings of some system components may limit expansion tank connection location.

**Claim:** The best connection point for expansion tanks is near the suction of the pump. **Fact:** If “best” means the point that will result in the smallest (lowest cost) expansion tank, the best location is at the point in the system that has the lowest gauge pressure when the pump is on. For a system that is distributed horizontally (e.g., a one-story building), the low-pressure point will be at the pump suction. However for a system that is distributed vertically (e.g., a multi-story building), the low-pressure point will be near the highest point in the system on the return piping to the pump. But the “best” location may not be the one that results in the smallest tank size. It may be where the tank may be most conveniently located, such as in a mechanical room where space is available and the tank is readily accessible for service. The low-pressure point may, for instance, be located over a hotel guest room that is not a convenient location for an expansion tank.

**Claim:** The connection point of the expansion tank is the “point of no pressure change,” i.e., the pressure at the expansion tank remains constant. **Fact:** This claim has resulted in unnecessary confusion and concern among operating engineers when they find system operating pressures varying widely. The pressure at the expansion tank will not change when pumps are started and stopped (other than a brief pulse), but the pressure will change when the temperature of the fluid in the system changes, causing the water volume to expand or contract. The amount of pressure change is a function of the size of the tank and the change in fluid temperature. As shown in the examples below, the designer can select a tank to operate over a wide range of pressures, e.g., 10 to 1 or more.

To better understand these facts and to properly select expansion tanks, we must start with the fundamentals.

**Purpose**
Expansion tanks are provided in closed hydronic systems to:

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• Accept changes in system water volume as water density changes with temperature to keep system pressures below equipment and piping system component pressure rating limits.
• Maintain a positive gauge pressure in all parts of the system in order to prevent air from leaking into the system.
• Maintain sufficient pressures in all parts of the system in order to prevent boiling, including cavitation at control valves and similar constrictions.
• Maintain required net positive suction head \( (NPSH_r) \) at the suction of pumps.

The latter two points generally apply only to high-temperature hot water systems. For most HVAC applications, only the first two points need be considered.

### Types

There are basically two types of expansion tanks:

• Tank type or “plain steel” tanks (water in contact with air), which may be atmospheric (vented to atmosphere) or pressurized, and
• Diaphragm or bladder-type tanks (air and water separated by a flexible diaphragm or bladder, typically made of heavy-duty butyl rubber). The bladders in bladder-type tanks generally are field replaceable should they fail while failure of a diaphragm tank would require complete replacement of the tank.

Both types of expansion tanks work by allowing water to compress a chamber of air as the water expands with increasing temperature. When the system is cold and the water in the tank is at the minimum level (which may be no water at all), the tank pressure is at its initial or precharge pressure \( P_i \). As the water in the system expands upon a rise in temperature, water flows into the tank and the air pocket is compressed, increasing both the air and water system pressure.

When the system is at its highest temperature and the tank water volume is at its design capacity, the resulting air and water system pressure will be equal to or less than the design maximum pressure \( P_{max} \). Both \( P_i \) and \( P_{max} \) are predetermined by the designer as part of the tank selection process outlined below.

### Initial Pressure

The tank initial or precharge gauge pressure \( P_i \) must be greater than or equal to the larger of the following:

1. The minimum pressure required to prevent boiling and to maintain a positive gauge pressure at any point in the system.

This pressure can be determined as follows:

1. Find the low pressure point (LPP) in the system when the pump is on. To do this, start at the highest point in elevation on the return side closest to the pump suction (Point A in Figure 1). Calculate the net pressure drop from that point to the pump suction with friction and dynamic head losses as negative and static head increase due to elevation as positive. The point with the lowest net pressure is the LPP. The static pressure increase as you move down in elevation from the high point increases 1 foot of head for every foot of elevation drop (3 kPa for every 0.3 m). In normal practice, the frictional pressure drop rate will be almost two orders of magnitude smaller, so the increase in pressure due to a reduction in elevation is always a much larger factor than the pressure decrease due to friction. Hence, the \( LPP \) will almost always be the highest point of the return line just after it drops down to the pump.

2. Determine \( P_{min} \) the minimum pressurization required at the \( LPP \) to maintain a positive gauge pressure (to prevent air from leaking into the system when a vent is opened) and to prevent boiling. A commonly recommended minimum pressurization is 4 psig (28 kPa) plus 25% of the saturation vapor pressure when this pressure exceeds atmospheric pressure (Figure 2). For chilled water, condenser water, and typical hot water (<200°F [93°C]) systems, the recommended minimum pressure is 4 psi (28 kPa).

For high temperature hot water, the minimum pressure will need to be higher as shown in Figure 2. For hot water systems that have high pressure-drop control valves located near the \( LPP \), the minimum pressure may need to be even higher to prevent cavitation downstream of the valve.¹

3. Locate the tank position. The tank will be the smallest and least expensive if located near the \( LPP \). However, space or other considerations (e.g., convenient makeup water source, which should be connected near the same point in the system) may make another location more desirable.

4. Calculate the static pressure rise \( \Delta P_{s,LPP→tank} \) from the \( LPP \) to the point of connection. This is simply the elevation difference between the two (or pressure in units of feet of water).

5. If the tank is upstream of the \( LPP \), calculate the frictional pressure drop \( \Delta P_{f,tank→LPP} \) from the connection point to the \( LPP \) when the pump is on. \( \Delta P_{f,tank→LPP} \) will be negative if the tank is downstream of the \( LPP \), but if included in the calculation of \( P_s \), minimum pressures would only be maintained when the pump is running. Once it stops, the pressure at the \( LPP \) will drop by \( \Delta P_{f,tank→LPP} \) below the desired minimum pressure. Thus if the tank is downstream of the \( LPP \), \( \Delta P_{f,tank→LPP} \) should be ignored (assumed to be zero).

‘But the “best” location may not be the one that results in the smallest tank size. It may be where the tank may be most conveniently located, such as in a mechanical room where space is available and the tank is readily accessible for service.’
6. Calculate the minimum tank initial or precharge gauge pressure $P_i$ as:

$$P_i = P_{min} + \Delta P_{s,tank} + \Delta P_{f,tank}$$

(1)

The tank precharge pressure $P_i$ is often selected at a minimum of 12 psig (83 kPa), which is the industry standard precharge for diaphragm and bladder tanks when no other value is specified.

Tanks typically are precharged to the specified pressure in the factory. However, the precharge pressure should be field verified and adjusted if necessary. First, turn off any heat-producing equipment in the system, then close the tank isolation valve so it is isolated from the system. Fully drain the tank, then check and adjust the tank air pressure to the desired $P_i$ setpoint using an air compressor. Before opening the tank isolation valve, the system must be near its lowest temperature (as determined under Selection later). Connecting the tank to a system that is warmer than the minimum temperature will result in pressures below $P_i$ when the system temperature drops and water volume decreases.

B. The minimum pressure required to maintain the available net positive suction head ($NPSH_r$) at the pump suction above the pump’s minimum required net positive suction head ($NPSH_{pmin}$):

This criterion is only a factor in determining $P_i$ for high temperature (>200°F [93°C]) hot water systems where the pump is a long distance (hydraulically) from the expansion tank or located well above the tank. In almost all other applications, the minimum pressurization resulting from Step A will result in pump suction pressures well above the $NPSH_r$. Hence, for the large majority of common HVAC applications, the calculations in Step B may be skipped. This step is listed here for completeness.

The precharge pressure required to maintain $NPSH_r$ is determined as follows:

1. Find the required pump net positive suction head ($NPSH_r$) from the manufacturer’s pump curve or selection software.
2. Calculate the frictional pressure drop $\Delta P_{f,tank} \rightarrow suction$ from the tank to the pump suction in the direction of flow.
3. Determine the gauge saturation vapor pressure of the fluid $P_v$ at its maximum expected temperature. See discussion under Selection later for determining the maximum fluid temperature. See Figure 2 for a curve of $P_v$ in psig versus temperature. ($P_v$ is more commonly listed in absolute pressure rather than gauge pressure, but gauge pressure is used here since we are calculating $P_i$ in gauge pressure.)
4. Calculate the static pressure difference $\Delta P_{static,tank} \rightarrow suction$ from the tank to the pump suction. This is simply the elevation difference between the two (for pressure in units of feet of water).
5. Calculate the difference in velocity pressure $\Delta P_{v,tank} \rightarrow suction$ in the piping at the point where the tank is connected to that at the pump suction. The velocity pressure is proportional to the square of the velocity in the pipe (equal to $V^2/64.3$ in units of psi with velocity $V$ expressed in ft/s). Typically this term is negligible and may be ignored, particularly when the pipe size at the expansion tank connection point is close to the pump suction pipe size, resulting in nearly equal velocity pressures.
6. Calculate the minimum tank initial or precharge gauge pressure $P_i$ as:

$$P_i = NPSH_r + \Delta P_{f,tank} \rightarrow suction + P_v - \Delta P_{v,tank} \rightarrow suction$$

(2)

Maximum Pressure

Tank maximum pressure $P_{max}$ is determined as follows:

1. Determine the maximum allowable system pressure $P_{sys}$ and critical pressure point, CPP. The CPP is the “weakest
link” in the system. It is a function of the pressure ratings at the maximum expected operating temperature of components and equipment (obtained from the manufacturer) and their location in the system in elevation and relative to the pump. To find the CPP, make a list of the components and equipment with the lowest pressure ratings (often boilers and other pressure vessels) and calculate the difference between their rating and their vertical elevation, in consistent units (e.g., convert the psig pressure ratings into units of head (feet of water) and subtract the elevation of the component). The component with the smallest difference is the “weakest link.” Its location on discharge side of the pump is the CPP and the maximum pressure $P_{ma}$ is the rating pressure of the equipment.

2. Locate the pressure relief valve. Typically, the best location is near the CPP and the component the relief valve is intended to protect, but a common location is near the expansion tank connection to the system, on the system side of the tank isolation valve.

3. Calculate the static pressure difference $\Delta P_{s,CPP \rightarrow PRV}$ from the CPP to the connection point of the pressure relief valve. This is simply the elevation difference between the two (for pressure in units of feet of water) and may be positive (CPP above PRV) or negative (CPP below PRV).

4. If the relief valve is downstream of the CPP, calculate the frictional pressure drop $\Delta P_{f,CPP \rightarrow PRV}$ from the CPP to the relief valve when the pump is on. (This term is ignored if the relief valve is upstream of the CPP because maximum pressure will need to be maintained even when the pump is off.)

5. Calculate the pressure relief valve setpoint $P_{rv}$ as:

$$P_{rv} = P_{ma} + \Delta P_{s,CPP \rightarrow PRV} - \Delta P_{f,CPP \rightarrow PRV}$$

6. Calculate the static pressure difference $\Delta P_{s,PRV \rightarrow tank}$ from the connection point of the pressure relief valve to that of the expansion tank. This is simply the elevation difference between the two (for pressure in units of feet of water) and may be positive (PRV above tank) or negative (PRV below tank).

7. If the tank is downstream of the relief valve, calculate the frictional pressure drop $\Delta P_{f,PRV \rightarrow tank}$ from the relief valve to the tank when the pump is on. (This term is ignored if the tank is upstream of the relief valve because maximum pressure will need to be maintained even when the pump is off.)

8. Calculate the tank maximum gauge pressure $P_{max}$ as:

$$P_{max} = P_{rv} + \Delta P_{s,PRV \rightarrow tank} - \Delta P_{f,PRV \rightarrow tank}$$

### Tank Selection

Typically, expansion tanks are selected using manufacturers’ software or selection charts based on the following data:

- The minimum temperature the system will see, $T_c$. For heating systems, this would generally be the initial fill temperature, e.g., 50°F (10°C). For cooling systems, this would be the design chilled water temperature, e.g., 40°F (4°C).
- The maximum temperature the system will see, $T_h$. For heating systems, this would be the design hot water temperature, e.g., 180°F (82°C). For cooling systems, this would generally be the system may rise to when it is off, e.g., 80°F (27°C) or so depending on the location of piping (indoors or outdoors).
- The total volume of water in the system, $V_s$, including all piping and vessels.
- The precharge pressure $P_i$ and the maximum pressure $P_{max}$ determined previously.

Tank volume also may be selected from fundamental equations such as Equations 5 and 6, which apply to bladder/diaphragm type tanks:

$$V_a \geq V_e \geq V_a \left(\frac{V_h}{V_c} - 1\right)$$

$$V_f \geq \frac{V_e}{1 - (P_a + P_i)/(P_a + P_{max})}$$

where

- $V_t$ = the tank volume
- $V_a$ = the tank “acceptance” volume. This is the capacity of the bladder (for bladder tanks) or the volume of the waterside of the tank when the diaphragm is fully extended (for diaphragm tanks). With so-called “full acceptance” tanks, the bladder can open to the full shape of the tank, so the tank’s acceptance volume and total volume, $V_f$, are equal.
- $V_e$ = the increase in volume of water as it expands from its minimum temperature to its maximum temperature.
- $V_c$ = the specific volume of water at the minimum temperature, $T_c$.
- $V_h$ = the specific volume of water at the minimum temperature, $T_h$.

### Table 1: Specific volume of saturated water at various temperatures.

<table>
<thead>
<tr>
<th>°F</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
<th>200</th>
<th>220</th>
<th>240</th>
<th>260</th>
<th>280</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft³/lb</td>
<td>0.01602</td>
<td>0.01604</td>
<td>0.01608</td>
<td>0.01613</td>
<td>0.01620</td>
<td>0.01629</td>
<td>0.01639</td>
<td>0.01651</td>
<td>0.01663</td>
<td>0.01677</td>
<td>0.01692</td>
<td>0.01709</td>
<td>0.01726</td>
<td>0.01745</td>
</tr>
<tr>
<td>°C</td>
<td>4</td>
<td>16</td>
<td>27</td>
<td>38</td>
<td>49</td>
<td>60</td>
<td>71</td>
<td>82</td>
<td>93</td>
<td>104</td>
<td>116</td>
<td>127</td>
<td>138</td>
<td>149</td>
</tr>
<tr>
<td>cm³/g</td>
<td>1.000</td>
<td>1.001</td>
<td>1.004</td>
<td>1.007</td>
<td>1.011</td>
<td>1.017</td>
<td>1.023</td>
<td>1.031</td>
<td>1.038</td>
<td>1.047</td>
<td>1.056</td>
<td>1.067</td>
<td>1.078</td>
<td>1.089</td>
</tr>
</tbody>
</table>
Equation 5 ensures that the acceptance volume $V_a$ exceeds the expanded water volume $V_e$ to avoid damage to the bladder or diaphragm when the system is at its highest temperature and pressure. Equation 6 ensures that the tank volume $V_t$ is sufficient for both the expanded water $V_e$ and the air cushion necessary to maintain pressures in the tank between $P_i$ and $P_{max}$.

Equation 6 conservatively ignores the expansion of the system piping since the resulting increase in volume is relatively small and the calculation is complicated in systems with various piping materials, each with different coefficients of expansion.

Specific volume at various temperatures is shown in Table 1.

Examples

**Example 1: Chilled Water System**

Assume the system is a chilled water system with a design chilled water temperature of 40°F and system volume of 1,000 gallons (3785 L). The layout is as shown in Figure 1 with the pump at the bottom of a multistory building. Pump head is 80 ft (240 kPa).

First calculate the initial precharge pressure $P_i$. Since the system is chilled water, there is no concern about net positive suction head, so only Step A needs to be followed:

1. The LPP in the system is the highest point on the return line just as it drops down to the pump (Point A in Figure 1).
2. $P_{min}$ is 4 psig (28 kPa) as shown in Figure 2.
3. The tank will be the smallest and least expensive if located near the LPP. However, for this example, assume the tank is located near Point B at the pump suction, which is often the most convenient location since space is usually available.
4. The static pressure rise $\Delta P_{s,LPP\rightarrow tank}$ from the LPP to the tank is 100 ft (or $100/2.31 = 43$ psi [296 kPa]).
5. The frictional pressure drop $\Delta P_{f,tank\rightarrow LPP}$ from tank to the LPP is taken as zero since the tank is downstream of the LPP.
6. The minimum tank initial or precharge gauge pressure $P_i$ is:

\[
P_i = P_{min} + \Delta P_{s,LPP\rightarrow tank} + \Delta P_{f,tank\rightarrow LPP} = 4 + 43 + 0 = 47\text{ psig (324 kPa)}
\]

Now find the maximum pressure:

1. The standard pressure rating of all components in the system will be 125 psig (862 kPa) or higher. Hence $P_{ma}$ is taken as 125 psig (862 kPa) and the CPP is the lowest point in the system on the discharge side of the pump, Point C.
2. Assume the pressure relief valve will be located near the chiller and the expansion tank, Point B.
3. The static pressure difference $\Delta P_{s,CPP\rightarrow PRV}$ from the CPP to the pressure relief valve is zero since they are at the same elevation.
4. The relief valve (Point B) is downstream of the CPP (Point C). $\Delta P_{f,CPP\rightarrow PRV} = 4.6 \times 15 = 69$ ft (or 35 psi [241 kPa]).

The tank minimum volume (assuming a maximum temperature of 80°F (27°C) with specific volume values taken from Table 1) is then calculated as:

\[
V_a \geq V_e \\
\geq V_c \left[\frac{v_h}{v_c} - 1\right] \\
\geq 1000 \left[\frac{0.01608}{0.01602} - 1\right] \\
\geq 3.75 \text{ gallons}
\]

Now calculate the maximum tank volume for Point B at the top of the building:

\[
V_t \geq \frac{3.75}{1 - \left(\frac{P_{min} + P_i}{P_{max}}\right)} \\
\geq \frac{3.75}{1 - \left(\frac{69}{125}\right)} \\
\geq 9.1 \text{ gallons}
\]

Hence, the expansion tank must have an acceptance volume greater than 3.75 gallons (14 L) and an overall volume greater than 9.1 gallons (34 L).

**Example 2: Chilled Water System**

Assume the system is as in Example 1, but instead of locating the tank at the pump, assume it is located at the LPP (Point A). The precharge pressure would then be calculated as (start-
ing at Step 4):
4. The static pressure rise $\Delta P_{\text{LPP}\rightarrow\text{tank}}$ from the LPP to the tank is zero since the tank is located at this point.
5. The frictional pressure drop $\Delta P_{\text{f,tank}\rightarrow\text{LPP}}$ from the tank to the LPP is zero since the tank is located at this point.
6. The minimum tank initial or precharge gauge pressure $P_i$ is:
   
   $P_i = P_{\text{min}} + \Delta P_{s,\text{LPP}\rightarrow\text{tank}} + \Delta P_{\text{f,tank}\rightarrow\text{LPP}}$
   
   $= 4 + 0 + 0$
   
   $= 4$ psig

Now find the maximum pressure (starting at Step 6):
6. The static pressure difference $\Delta P_{s,\text{PRV}\rightarrow\text{tank}}$ from the relief valve to the tank is $-100$ ft (or $-100/2.31 = -43$ psi $[-296$ kPa]). It is negative since the PRV is below the tank.
7. The frictional pressure drop $\Delta P_{\text{f,PRV}\rightarrow\text{tank}}$ from the relief valve to the tank is taken as zero since the tank is upstream of the relief valve.
8. The tank maximum gauge pressure $P_{\text{max}}$ is:

   $P_{\text{max}} = P_{\text{rv}} + \Delta P_{s,\text{PRV}\rightarrow\text{tank}} - \Delta P_{\text{f,PRV}\rightarrow\text{tank}}$
   
   $= 90 - 43 - 0$
   
   $= 47$ psig

The tank volume is then calculated as:

   $V_t \geq \frac{3.75}{1 - (P_a + P_i)/(P_a + P_{\text{max}})}$
   
   $\geq \frac{3.75}{1 - (14.7 + 4)/(14.7 + 47)}$
   
   $\geq 5.4$ gallons

As in Example 1, the expansion tank must have an acceptance volume greater than 3.75 gpm (0.24 L/s) (the volume of expanded water is unchanged), but the total volume required falls to 5.4 gallons (20 L). This demonstrates that a tank located at the LPP in a multi-story system is smaller and therefore less expensive than a tank located at the pump suction (Example 1).

**Example 3: High Temperature Hot Water System**

Assume the system is a high temperature hot water system with a design hot water temperature of 300°F (149°C) and system volume of 1,000 gallons (3785 L). The pumps’ required $NPSH_r$ is 5 ft (15 kPa) and its head is 50 ft (150 kPa). The layout is horizontal as shown in Figure 3.

First calculate the initial precharge pressure $P_i$, which will be the larger of that required to prevent boiling and that required to maintain adequate net positive suction head at the pump. The pressure required to prevent boiling is determined as:

1. The LPP in the system is the highest point on the return line just after it drops down to the pump (Point A in Figure 3).
2. $P_{\text{min}}$ is recommended to be 70 psig (482 kPa) as shown in Figure 2. If there are control valves located near the LPP, the minimum pressure may need to be higher.$^1$
3. For this example, assume the tank is located near Point B at the pump suction.
4. The static pressure rise $\Delta P_{s,\text{LPP}\rightarrow\text{tank}}$ from the LPP to the tank is 15 ft (or 15/2.31 = 6.5 psi [45 kPa]).
5. The frictional pressure drop $\Delta P_{\text{f,tank}\rightarrow\text{LPP}}$ from the tank to the LPP is taken as zero since the tank is downstream of the LPP.
6. The minimum tank initial or precharge gauge pressure $P_i$ is:

   $P_i = P_{\text{min}} + \Delta P_{s,\text{LPP}\rightarrow\text{tank}} + \Delta P_{\text{f,tank}\rightarrow\text{LPP}}$
   
   $= 70 + 6.5 + 0$
   
   $= 76.5$ psig

The initial pressure must also be sufficient to maintain the required net positive suction head ($NPSH_r$) at the pump inlet:

1. The required net positive suction head ($NPSH_r$) is 5 ft (or 5/2.31 = 2 psi [15 kPa]).
2. The frictional pressure drop $\Delta P_{\text{f,suction}\rightarrow\text{tank}}$ from the tank to the pump suction is zero since the tank is located at the pump suction.
3. The gauge vapor pressure of the fluid $P_v$ is 53 psig (365 kPa) per Figure 2.
4. The static pressure difference $\Delta P_{s,\text{suction}\rightarrow\text{tank}}$ from the pump to the suction is zero since the tank is located at this point.
5. Assume velocity pressure difference $\Delta P_{v,\text{tank}\rightarrow\text{suction}}$ is negligible.
6. Calculate the minimum tank initial or precharge gauge pressure $P_i$ as:

   $P_i = NPSH_r + \Delta P_{\text{f,tank}\rightarrow\text{suction}} + P_v - \Delta P_{s,\text{tank}\rightarrow\text{suction}}$

   $= 2 + 0 + 53 - 0 - 0$

   $= 55$ psig

This pressure is lower than that required to prevent boiling at the LPP, so it may be ignored. As noted above, this is typically the case unless the pump is a long distance from the expansion tank or located well above the tank.

Now find the maximum pressure:
1. The standard pressure rating of all components in the system will be 125 psig (862 kPa) or higher. Hence $P_{\text{ma}}$ is taken as 125 psig and the CPP is the lowest point in the system on the discharge side of the pump, Point C.
2. The pressure relief valve will be located at the boiler.
3. The static pressure difference $\Delta P_{s,\text{CPP}\rightarrow\text{PRV}}$ from the CPP to the pressure relief valve is zero since they are roughly at the same elevation.
4. The relief valve (at the boiler) is downstream of the CPP (Point C). $\Delta P_{\text{f,CPP}\rightarrow\text{PRV}}$ is the then approximately equal to pump head (50 ft or 22 psi [152 kPa]).
5. The pressure relief valve setpoint $P_{rv}$ is then:
\[ P_{rv} = P_{ma} + \Delta P_{s,CPP \rightarrow PRV} - \Delta P_{f,CPP \rightarrow PRV} \]
\[ = 125 + 0 - 22 \]
\[ = 103 \text{ psig} \]

6. The static pressure difference \( \Delta P_{s,PRV \rightarrow tank} \) from the relief valve to the tank is zero since they are roughly at the same elevation.

7. The frictional pressure drop \( \Delta P_{f,PRV \rightarrow tank} \) from the relief valve to the tank may be ignored since they are near the same location.

8. The tank maximum gauge pressure \( P_{max} \) is:
\[ P_{max} = P_{rv} + \Delta P_{s,PRV \rightarrow tank} - \Delta P_{f,PRV \rightarrow tank} \]
\[ = 103 + 0 - 0 \]
\[ = 103 \text{ psig} \]

The tank minimum acceptance volume (assuming a minimum temperature of 60°F [16°C] with specific volume values taken from Table 1) is then calculated as
\[ V_a \geq V_e \]
\[ \geq V_d \left( \frac{v_h - 1}{v_c} \right) \]
\[ \geq 100 \left[ \frac{0.01745 - 1}{0.01604 - 1} \right] \]
\[ \geq 88 \text{ gallons} \]
\[ V_r \geq \frac{88}{1 - \left( P_a + P_f \right) / \left( P_a + P_{max} \right)} \]
\[ V_r \geq \frac{88}{1 - (14.7 + 76.5) / (14.7 + 103)} \]
\[ \geq 390 \text{ gallons} \]

Hence, the tank must have an acceptance volume 88 gallons (333 L) or larger and a total volume 390 gallons (1476 L) or larger.

As a home exercise, redo the above calculations with the tank at the pump discharge, Point C. You will find that the precharge pressure increases while all other variables remain the same, resulting in a somewhat larger tank. Nevertheless, the tank will still meet all of its intended functions so this is a perfectly acceptable, if unusual, location.

**References**