TECHNICAL MANUAL
TEH-1196C

Air Management

For Closed Hydronic Heating/Cooling Systems

NOT FOR POTABLE WATER SYSTEMS

Bell & Gossett
a xylem brand

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INTRODUCTION

Hydronics is the science of heating and cooling with liquids. The liquid which is still the most practical and economical heat transfer medium is water.

Today's hydronic system is best considered a heat transfer machine where the heat transfer medium is used to heat or cool an area in accordance with the controls installed. Once the requirements of the structure are determined, the versatility of the hydronic system is limited only by the imagination of the designer. Only a few basic fundamentals must be followed to enable the designer to do anything with the heat transfer versatility of a hydronic system. It matters not whether the system is the largest multi-building project supplied by a central mechanical plant, or the smallest residence, the basic fundamentals apply.

The purpose of this technical manual is to examine the important points of these basic design fundamentals with regard to air management systems. Every design engineer is concerned with having the completed installation perform as intended. Every owner is concerned with having trouble free, quiet and economical operation with minimal maintenance. However, any heating, cooling or dual hydronic system installed without effective air management will provide ample reason for concern. Air bound circuits, questionable hydraulics, noisy operation, poor efficiency and short system life are the result of inadequate air management.

The fundamentals presented here are considered to be basic for all closed hydronic systems which are to operate in the chilled or low temperature water (LTW) heating range. (LTW range is defined as any heating system designed to operate up to 250°F (121°C) as per ASME Section IV Code Rules for Construction of Heating Boilers.)

CLOSED SYSTEM DESIGN

Piping systems for water transmission can be considered in two general categories: open systems or closed systems. Open systems are piping circuits, pumped or gravity circulated, that are open to the atmosphere at some point. Closed systems are designed and installed as sealed systems and offer several important advantages:

1. When a system is closed, little, if any, make-up water is ever required. With no fresh water added, there will not be an accumulation of oxygen or other corrosive materials. System life is extended indefinitely.
2. Closed systems can be pressurized permitting elevated operating temperatures and greater temperature drops. Piping, installation and operating costs can be reduced drastically.
3. With positive air management, closed systems offer improved control, faster temperature response, and quieter system operation.

Because the system is closed, provision must be made to absorb the changes in water volume due to the changes in system temperature. For this purpose a properly sized air management tank is required. The tank is also used to set the initial cold static fill pressure and to maintain a minimum system operating pressure. Two basic tank styles are used in hydronic systems. One is the compression type where an air cushion is in direct contact with system water and air control is required (Ref. Figure A). The second tank is a pressurized or pre-charged type where the air cushion and the system water are separated by a flexible membrane. Here air elimination is required. (Ref. Figure B).

Figure A: Typical Air Control System

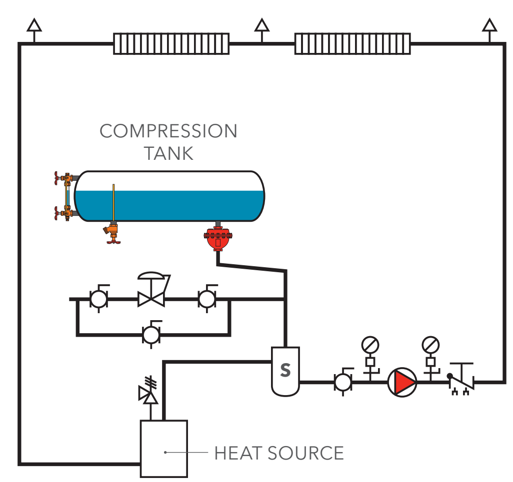
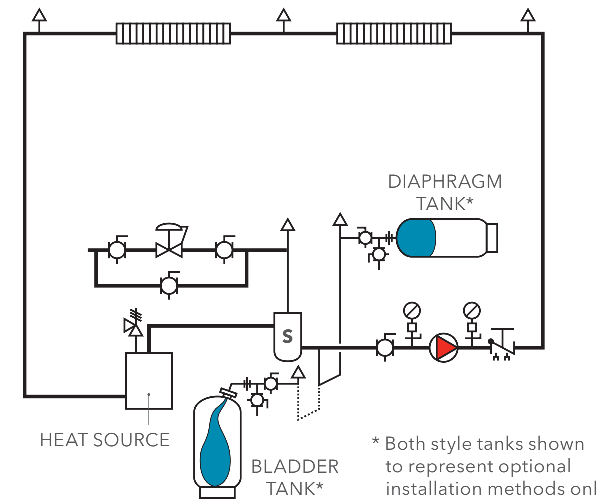


Figure B: Typical Air Elimination System



Obviously closed systems are used whenever possible. However, many systems intended to be closed are not pressure tight, and consequently, operate as an open system. Undiagnosed and/or unrepaired leaking pipe joints, valve seats, stem packing, and equipment coils are frequent causes for this condition. Special attention must also be given to pump seals and air vents.

All closed system pumps should be constructed with mechanical seals. Pumps constructed with packing require constant water leakage for lubrication and heat removal. This means fresh water must be constantly added to the system. Since fresh water contains oxygen, particles and other corrosive agents, system life and operation will be seriously affected.

It is recommended to use manual air vents in both Air Control and Air Elimination systems, at all system piping high points, to vent air during the initial system filling and pressurization procedure. Once the system is filled and pressurized, manual air vents are closed.

In air control systems only manual air vents are recommended to ensure the initial air charge can be maintained in or returned to the compression tank.

However, in air elimination systems, the addition of automatic air vents is necessary to vent any air accumulated or separated after the initial fill and manual vent. Since automatic air vents are a potential source of leaks, they must be carefully monitored, to ensure the system remains closed to the atmosphere. In larger hydronic systems, automatic air vent outlets are piped to a drain or recovery unit depending on the type of heat transfer fluid used.

PROPER CLOSED SYSTEM PRESSURIZATION

Four modes of pressurization must be considered in closed hydronic systems:

1. Initial Cold Static Fill Pressure: Pressure required at the systems water inlet to fill the system to the highest elevation plus a minimum pressure at the top. Typically, 4 psi (28 kPa) minimum at the top is recommended to positively pressurize the system. At elevated system water temperatures a higher cold static fill pressure may be required to properly pressurize the pump. (Ref. Figure C).
2. Static Pressure: Pressure created by the height of water above any given point. Approximately 2.31 feet (0.7 m) of water height equals 1 psi (7 kPa).
3. Operating Pressure Increase: Pressure increase caused by the expanded water entering the air management tank and reducing the air cushion volume.
4. Pump Pressure: Pressure differential created by an operating pump in a system.

Closed system design requires the designer to establish values for both the minimum pressurization and the maximum allowable pressure increase. The minimum pressure will exist at the top of the system when it is cold and the circulating pump is not operating. Maximum pressure will be determined by the pressure limits of the system's components and their location in the system. It occurs when the system is hot and at design condition with all pumps in operation, at full design speed. From the standpoint of both the initial cost and the space required, it is desirable to have the air management tank as small as possible. The tank size for any closed system is affected by the following:

1. Water Expansion: A function of the system's final fill water volume and the amount of temperature change applied to that volume.
2. System Pressure Range: A function of the systems initial cold static fill pressure and the maximum allowable system pressure increase at the safety relief valve.

Minimum System Pressurization

Generally, minimum cold static pressurization at the top of systems operating in the low temperature water (LTW) range can be as low as 4 psi (28 kPa). For systems designed to operate above 210°F (99°C), the air management tank will develop the additional pressure required above 4 psi (28 kPa) when the system has reached its maximum design temperature. While it is usually safe to rely on the tank to create the necessary pressure increase for the LTW piping system, additional pressurization at the system pump is recommended when the operating temperature is above 210°F (99°C) or additional pressure is required to assure minimum NPSH required by the pump. Inadequate pressurization at the pump causes noise, loss of circulation and often serious damage to the pump. In the LTW range, adequate initial pressurization for a pump will usually be any pressure that prevents boiling plus a suitable safety factor. Up to 250°F (121°C), a 15°F (8°C) safety factor and its equivalent anti-boiling pressure is usually adequate. For example, a system with design temperatures of 250°F (121°C), should be pressurized at the pump to the anti-boiling point for 265°F (129°C) or 25 psi (172 kPa). (Ref. Figure D).

Cold initial static pressurization at the pump is therefore recommended without consideration of the pressure increase that will be created by the system's air management tank. Both the static head above the pump and cold static pressurization at the top of the system can be combined to equal or exceed this minimum level of pump pressurization. The pump's operating suction pressure must exceed the pump's Net Positive Suction Head Requirement (NPSHR), as specified from the manufacturer.

Figure C is based on filling a system so that the pressure at the top (the value from the table) and the static height of the water above the pump, typically produce adequate pump pressurization (to provide a 15°F (8°C) safety factor above the boiling point) when operating at the maximum design system temperature.

Initial cold fill then must fulfill three requirements:

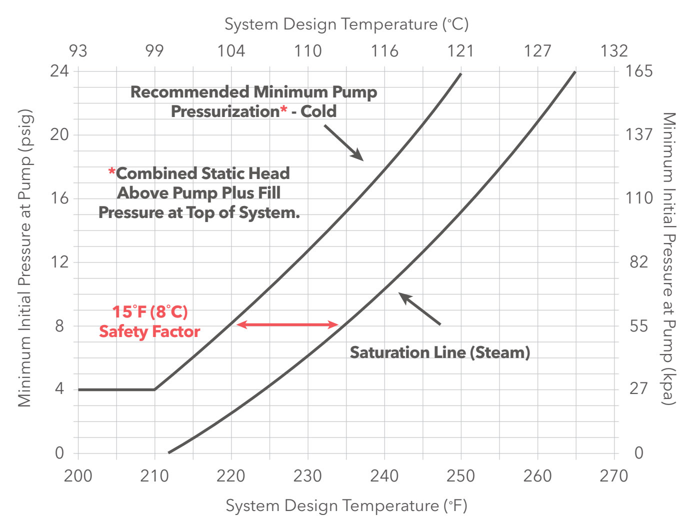
1. The entire piping system must be filled with water.
2. The pressure at the top of the system must be high enough to vent air from the system (4 psi (28 kPa) is typically adequate).
3. The pressure at all points in the system must be high enough to prevent flashing in the piping or cavitation in the pump.

In the LTW range, the use of Figure C and D will provide the proper system pressurization.

Figure C – Minimum Cold Pressurization at System's Top

Static Head Above Pump In Feet (m)	Maximum System Design Temperature °F (°C)				
	≤ 210 (98)	220 (104)	230 (110)	240 (115)	250 (121)
	Minimum Cold Pressurization at Top of Closed Low Temperature Water System (Pumps Off) psig (kpa)				
Pump at Top	4 (28)	8 (56)	13 (90)	18 (124)	25 (173)
5 (1.5)	4 (28)	6 (42)	11 (76)	16 (111)	23 (159)
10 (3.0)	4 (28)	4 (28)	9 (62)	14 (97)	21 (145)
20 (6.1)	4 (28)	4 (28)	5 (35)	9 (62)	16 (111)
30 (9.1)	4 (28)	4 (28)	4 (28)	5 (35)	12 (83)
40 (12.2)	4 (28)	4 (28)	4 (28)	4 (28)	8 (56)
50 (15.2)	4 (28)	4 (28)	4 (28)	4 (28)	4 (28)
≥60 (18.3)	4 (28)	4 (28)	4 (28)	4 (28)	4 (28)

Figure D – Minimum Cold Pressurization at the Pump



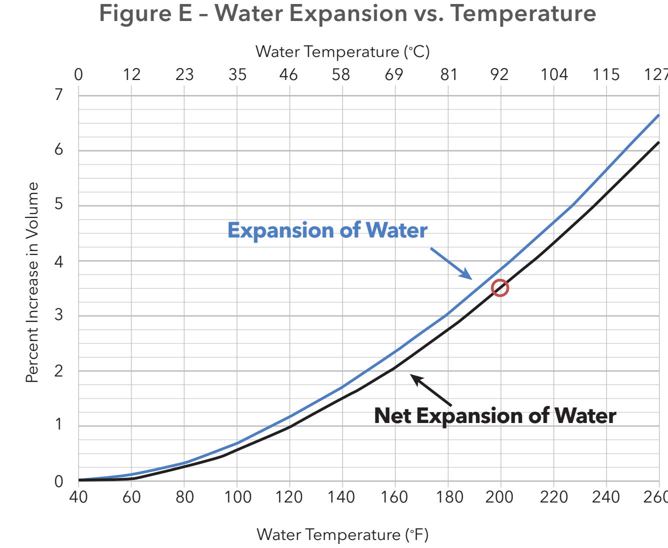
Minimum System Pressurization Example:
A three story apartment building with hot water heat has the boiler and pump located in the basement. The maximum design temperature is 200°F (93°C). (This is the highest temperature the pump would see.) The highest point in the system is 26 feet (7.9 m) above the pump. Determine the non-operating cold static fill pressure at the pump.

Solution:
From Figure D, the minimum cold pressure at a pump operating at 200°F (93°C) is 4 psi (28 kPa). But, 4 psi (28 kpa) at the pump would not completely fill the system since the static height of water column would only be equal to 9.2 feet (3 m) [4 psi (28 kPa) X 2.31 feet/psi (0.1 m/kPa) = 9.2 feet (3 m)]. If just enough pressure is added to fill the system, the initial pressure due to the height of the water column would be 11.3 psi (79 kPa) [26 feet (7.9 m) / 2.31 feet/psi (0.1 m/kPa) = 11.3 psi (79 kPa)]. The system would be full and there would be adequate pressure at the pump, but there would not be any pressure at the top to vent off air. Refer to Figure C. With a static head above the pump of 26 feet (7.9 m) of water a pump operating at 200°F (93°C) requires a cold, non-operating pressure at the top of the system of 4 psi (28 kPa). The cold pressure at the pump then should be equal to the static pressure due to the height of the water column 11.3 psi (79 kPa) plus 4 psi (28 kPa) or a total of 15.3 psi (105 kPa). With 15.3 psi (105 kPa) cold pressure at the pump, the system top will be pressurized at 4 psi (28 kPa) and the pumps pressure will exceed the 15°F (8°C) safety factor above the water boiling point.

Water Expansion

Figure E illustrates the rate at which water expands or contracts as its temperature rises or falls. As the water heats up, so does the piping system. The curve labeled "Net Expansion of Water" takes this into account and is used for sizing a tank. For example, a system design temperature of 200°F (93°C) would indicate a 3.5% increase in volume of water due to density changes. A tabular representation is shown in Figure F, which is also used to size air management tanks. Since water is incompressible, a closed system filled with water must have space for any increase in volume as the temperature rises. This is true even in a chilled water system for two reasons. First, the chilled water return temperature may be higher than the cold fill temperature. Secondly, during system shutdown or component malfunction, water can reach the higher ambient temperature. To accommodate this water volume increase, a compression or pre-charged (pressurized) tank is commonly used.

Figure E – Water Expansion vs. Temperature



*Based on initial water temperature of 40°F (4°C) & 6.8 x 10-6 in/in°F (12.2 x10-6 m/m°C) Steel Linear Coefficient of Thermal Expansion

Figure F – Net Water Expansion Factor*

AWT** °F (°C)	Factor	AWT** °F (°C)	Factor
100 (38)	0.0057	140 (60)	0.0149
105 (41)	0.0068	145 (63)	0.0167
110 (43)	0.0080	150 (66)	0.0178
115 (46)	0.0085	155 (68)	0.0196
120 (49)	0.0097	160 (71)	0.0208
125 (52)	0.0115	165 (74)	0.0225
130 (54)	0.0126	170 (77)	0.0243
135 (57)	0.0138	175 (79)	0.0261

AWT** °F (°C)	Factor	AWT** °F (°C)	Factor
180 (82)	0.0279	220 (104)	0.0433
185 (85)	0.0296	225 (107)	0.0454
190 (88)	0.0314	230 (110)	0.0475
195 (91)	0.0332	235 (113)	0.0499
200 (93)	0.0350	240 (116)	0.0523
205 (96)	0.0374	245 (118)	0.0547
210 (99)	0.0391	250 (121)	0.0571
215 (102)	0.0412	255 (124)	0.0595

*Based on initial water temperature of 40°F (4°C) & 6.8 x 10^{-6} in/in°F (12.2 x10^{-6} m/m°C) Steel Linear Coefficient of Thermal Expansion

**AWT – The System Design Average Water Temperature

Maximum System Pressure

The required ASME safety relief valve set pressure for the system establishes the allowable increase in pressure. The safety relief valve should be located so that it protects the required system components and is not affected by pump operation. Good system design and operation will prevent pressurization from reaching the safety relief valve setting unless the system temperature exceeds the maximum design operating temperature. Valve installation should minimize field pipe and fittings on the outlet to avoid creating a back-pressure, affecting the safety relief valve's operation and rated capacity.

Hydronic systems designed to ASME Section IV Code Rules for Construction of Heating Boilers are limited to 250°F (121°C) and 160 psi (1103 kPa) providing the installed components are so constructed.

Usually, the boiler establishes the maximum working pressure limitation for a hydronic hot water heating system. If the boiler is suitable for only 30 psi (206 kPa) working pressure, a 30 psi (206 kPa) ASME safety relief valve should be installed on the top of the boiler. The initial cold static fill pressure at the safety relief valve will, of course, be equal to the static head of the water above the boiler plus the additional pressure applied at the top of the system. Depending upon the location of the pump in relation to the valve, its operation also may affect the pressure at the safety relief valve.

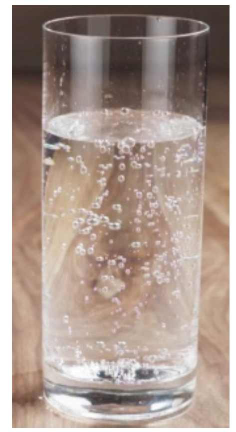
The difference between the initial cold static fill pressure at the safety relief valve, and the valve's set pressure, will determine the allowable pressure increase for the system. This difference is referred to as the system Pressure Band. This increase in system pressure is used to determine the required tank size. The larger the allowable system pressure increase, the smaller the tank.

High rise buildings, for instance, create high static pressures at the lower floors due to the tall water column. Unless system components on lower floors are constructed to allow a sizable increase in the operating pressure above the cold static fill pressure, the air management tank will have to be relatively large. Heat exchangers (converters), such as a shell and tube, brazed plate, or gasketed plate and frame type, with higher working pressure ratings, can be used to isolate low pressure rated boilers from the piping in high static head buildings. Boilers designed to operate within the limits of the ASME Section IV Code Rules for Construction of Heating Boilers may be constructed for working pressures above 30 psi (206 kPa) as long as the temperature doesn't exceed 250°F (121°C). These then could be used in buildings where high static head pressures will exist at the boiler location in the system. Another alternative is to locate the boiler at some elevated position which reduces the static pressure. In regards to the air management tank, installing it at a higher elevation reduces the initial pressure on the tank, which allows a larger pressure increase and reduced tank size.

AIR SEPARATION

The amount of air water can hold in solution varies depending on the temperature and pressure. Higher pressure or lower temperature water can absorb or hold more air in solution than water that is warmer or at lower pressure. Even the narrow temperature range of chilled water systems demonstrates the effect of temperature on solubility. Figure G is an example of how a change in temperature coupled with a decrease in pressure will cause tap water, which has been allowed to rise to room temperature, to give off free air from solution.

Figure G – Air Released from Tap Water with Pressure and Temperature Change



Deep sea divers experience a similar effect during underwater ascents. Nitrogen, which doesn't combine with elements in the human body at atmospheric pressure, is absorbed into the blood stream under the increased pressure of water depth. As the diver rises and the water pressure on the body is reduced, the nitrogen expands. If the ascent is too fast, the expanded nitrogen gas doesn't have a chance to escape from the blood stream causing the so-called "bends".

Point of Air Separation

Free air in a hydronic piping system can create noise, reduce terminal output capacity, or even stop fluid flow. An integral component of any air management system is the air separator, used to split free air from the system fluid, and direct it to a desired location. In order to evaluate air management of a specific application, a better understanding of how temperature and pressure affect the solubility of air in water is required. Air is a mixture of gases, approximately 80% nitrogen, 20% oxygen and trace amounts of others. Within a short time after the initial fill, air in a properly operating closed system begins to lose its oxygen content through oxidation. Unless fresh water with its 2% air is added, the gas remaining is predominately nitrogen, an inert gas. Figure H illustrates the effects of pressure and temperature on the solubility of nitrogen in water. This interpretation is based on D.M. Himmelblau's paper published in the Journal of Chemical and Engineering Data, Volume 5, No. 1, January 1960.

Figure H – Solubility of Nitrogen in Water vs. Temperature and Pressure

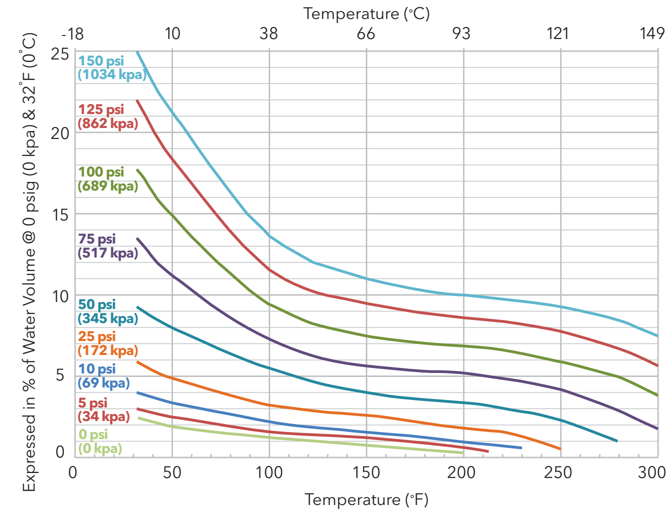


Figure H shows the maximum amount of nitrogen that can be held in solution expressed in percentage of water volume at various temperatures and pressures. It is based on nitrogen being released from solution and then expanded to atmospheric pressure at 32°F (0°C). Obviously, if water is saturated with the maximum amount of air in solution, increased temperature or reduced pressure will allow some of the gas to come out of solution. If the water temperature and pressure are returned to their original level and this free nitrogen is present, it will be reabsorbed. However, if this free nitrogen is separated and vented off, or moved somewhere else in the system, water will remain in a de-aerated condition.

Effective air management for the design engineer of a closed hydronic system means devising a system so that any nitrogen (system air) released from solution, either by heating or a reduction in pressure, will be at only one point. This point of separation should be the connecting point for air separation equipment.

Figure H illustrates maximum solubility of nitrogen in water. However, if the total nitrogen in solution can be measured only if removed as a gas, and measured at atmospheric pressure and 32°F (0°C), how does it enable design engineers to understand the management of air in closed hydronic systems? Simply, by stressing the importance of locating air separating equipment at the point of lowest air solubility, based on both temperature and pressure.

If it were possible to install the air separator at a point where the absolute lowest pressure and absolute highest temperature occurred, management of the air in the system would be complete. Obviously, this is seldom possible. Consequently, the designer must also provide piping circuitry that will be able to move any free air back to the point where it can be separated from the water and properly directed. Normally a water velocity of 2 ft/sec (0.6 m/sec) will keep free air entrained and prevent it from forming air pockets. High points in various piping circuits in particular, can be collecting points for free air. Proper system pipe sizing is often effective in preventing air traps at high points.

The best location for air separating equipment, of course, depends upon the particular system. No single rule can apply to all systems. When possible, select a point which will have both the highest temperature and the lowest pressure. When this isn't possible, the point of highest temperature should receive first consideration as the air separation point. Figure H shows that a large percentage of nitrogen is released from solution when water temperatures rise above 200°F (93°C). With the possible exception of high rise buildings, air separation at points of elevated temperatures is generally an effective way to de-aerate system water sufficiently to prevent further release of nitrogen due to the reduced pressure at system high points.

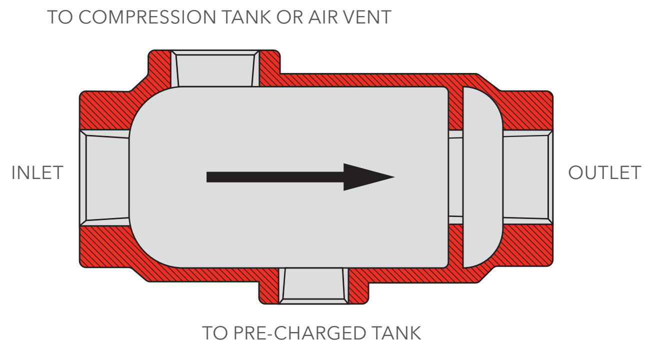
Air Separators

Every closed hydronic system requires a device to enhance separating free air from the water and redirecting it. In the case of an Air Control System, separated free air is returned to the compression tank. The separated free air in an Air Elimination System is vented to atmosphere. Three principles governing the design of air separators are reducing water velocity, coalescence, and centrifugal force.

By reducing water velocity to 0.5 ft/sec (0.15 m/sec) or less, water will not carry along free air bubbles. In boilers having large internal water passages, water velocity is low and free air carried to the boiler by the system flow, along with additional air released by heating, will readily rise to a convenient high point. Few boilers have internal provisions at this point to allow free air to be managed based on the type of air management strategy being used. A boiler is not always available, or usable, as the point of air separation, and some other means of separating free air from the system water must be employed.

Air separators that have large internal areas reduce water velocity, which allows air to rise to the top and be managed. (Ref. Figure I).

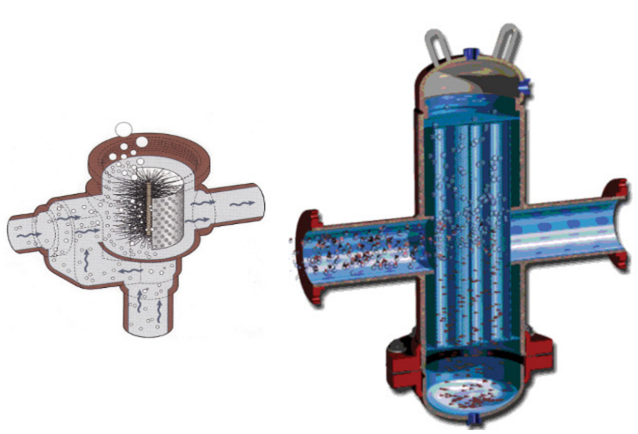
Figure I – In-Line® Air Separator



An In-Line® Air Separator operates by collecting air off the top of the water flow, and directing it to an opening on top. Installed in an Air Control System, this opening is connected to the compression tank. Otherwise, in an Air Elimination System, an automatic air vent is installed, and the pressurized (pre-charged) type expansion tank would be connected to the bottom opening. Because proper operation is a function of the velocity, sizing is determined by the flow rate.

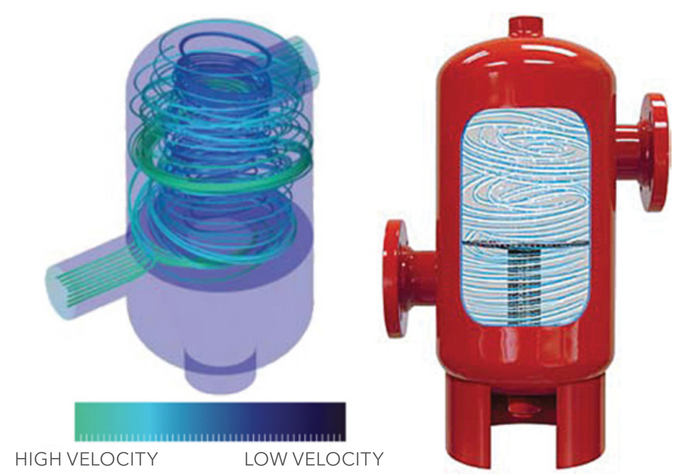
The principle of coalescence is another strategy for air separation equipment. The internal coalescing medium allows small micro-bubbles to "coalesce", increasing bubble size, and enhancing separation from water. Combine coalescence with velocity reduction increases air separation efficiency. Larger coalescing units may also allow for suspended sediment to come out of solution and be removed through a blow down valve. Sizing coalescing separators is also a function of the flow rate. (Ref. Figure J).

Figure J – Coalescing Air Separators



The third principle used in the design of air separators is centrifugal force. Combining both centrifugal force and velocity reduction produces maximum air separation efficiency. Unwanted air is separated by the differences in density between air and water. Its tangential nozzle design creates a vortex inside the cylindrical vessel, sending denser air-free water to the outer section near the shell, while the separated air migrates to the low velocity center where it is drawn to the air collector. (Ref. Figure K). The separated air is removed from the system through a high capacity air vent in an Air Elimination System, or directed to the compression tank in an Air Control System. These units can also eliminate undissolved solids through centrifugal force, or the addition of an internal, serviceable strainer. Utilizing both centrifugal force and velocity reduction strategies remove more air per water flow pass than any other air separator principle alone.

Figure K – Rolairtrol® Air Separator



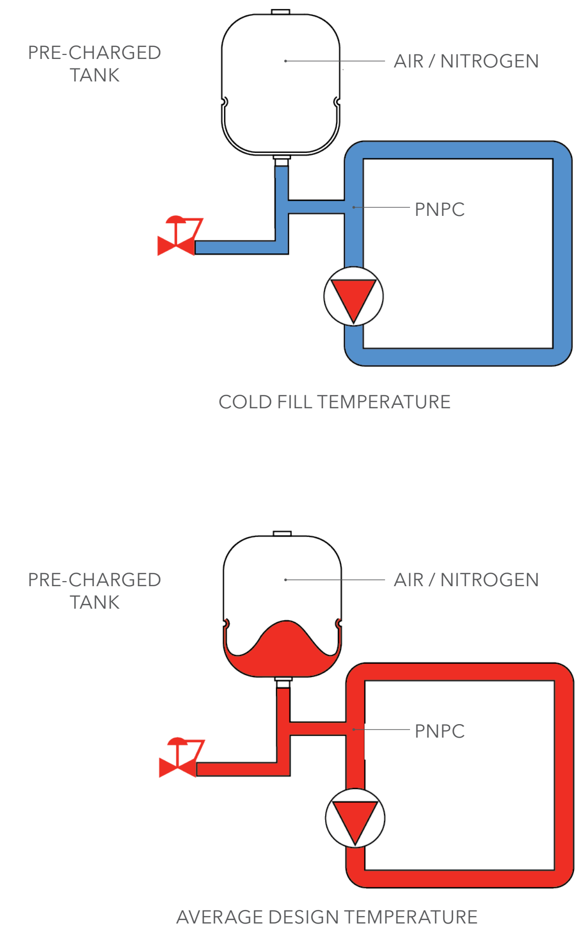
EQUIPMENT LOCATION

Point of No Pressure Change (PNPC)

Figure L represents a typical closed hydronic system consisting of a boiler or heat exchanger, pump, pre-charged tank, radiation, and supply/return and piping. The entire system will be filled with water, except for the pre-charged tank, which will have an air or nitrogen volume to act as a cushion. When the water in the system is heated, the volume of water expands, and the additional water volume enters the tank. The same amount of water is still in the system, the number of pounds of water has not changed. The only way the pressure in the tank can change further is to add or subtract water from the tank. "What happens when the pump starts up?" The pump can't add or remove water

from the system, therefore it cannot change the pressure in the tank, or at the point where the tank is connected to the system. The pressure at the connection point of the tank to the system then cannot change whether or not the pump is operating. This connection point is the **Point of No Pressure Change (PNPC).**

Figure L – Typical Closed Hydronic System

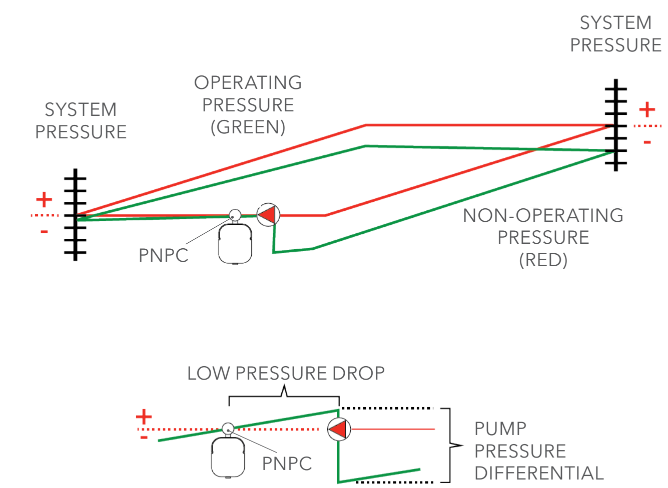


Pump Location

However, other changes will occur in the system depending upon where the pump is located in relation to that point of no pressure change. There are two possibilities; the pump can pump towards the point of no pressure change, or the pump can pump away from the point of no pressure change. To simplify the discussion, the pressure loss due to flow between the pump and the point of no pressure change can be neglected if that connection is very close to either the pump suction or the pump discharge.

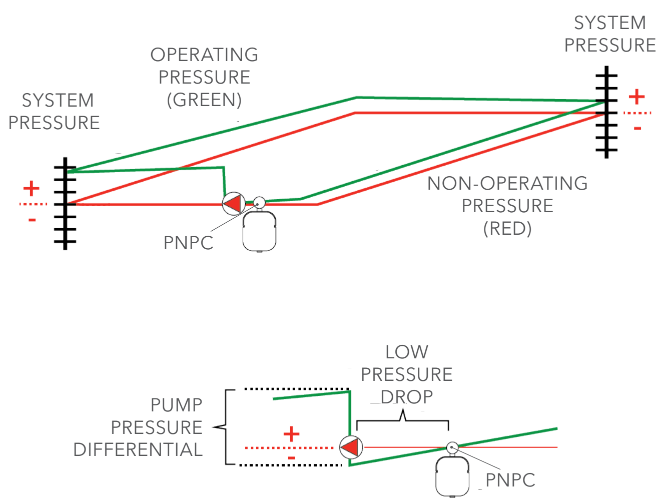
Connecting the pre-charged or compression tank to the pump discharge can negatively affect the systems air management capabilities. When the pump starts up, it will develop a pressure differential based on the resistance in the system. But since the pump is discharging towards the point of no pressure change, the pressure at the pump's suction will be reduced by the total friction loss of the system. (Ref. Figure M). The pressure then at every place in the system is less with the pump operating than it is with the pump off. This is not an ideal situation. If the existing non-operating pressure acting on the system is not adequate to offset the negative pressure produced by the pump, many problems can result. Air is released at the lower pressures throughout the system instead of one point. Water can flash to steam, possible pump cavitation, and a lack of fluid flow in circuits are a few possibilities. If automatic air vents are installed at points where a partial vacuum exists, air can be sucked into the system. None of these scenarios are desirable.

Figure M – Pumping Towards the Point of No Pressure Change



However, moving the point of no pressure change to the pump's suction side can produce a positive affect for the air management system. The pump's pressure differential shows up as a positive at it's discharge, and any available pump head is added to the non-operating pressure throughout the system. (Ref. Figure N). Therefore, when the pump operates, the pressure at every point in the system is always greater than the non-operating pressure. System air stays in solution until it reaches the air separation equipment.

Figure N – Pumping Away from the Point of No Pressure Change

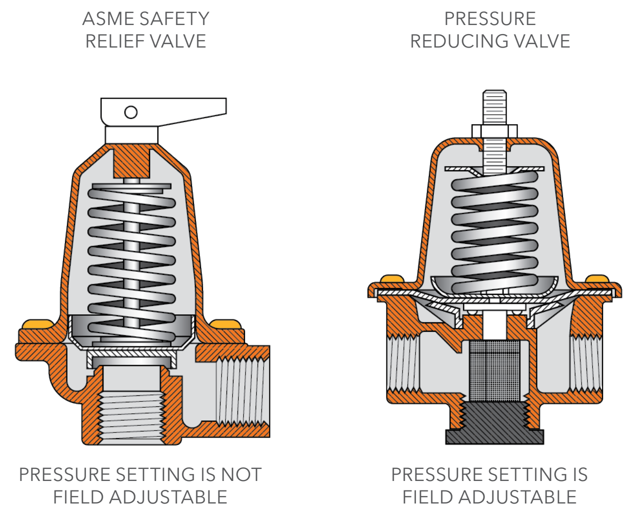


Generally, on small systems where the pumps do not produce more than 15 feet (4 m) of head, pump location may not be important. However, for larger pumps that produce greater pressure differentials, location is very important. A good rule to follow is to install the system pump, or pumps, such that the point of no pressure change is located on the suction side. In this way the pressure differential produced by the pump will, at every point in the system, always increase the operating pressure above that of the non-operating pressure.

Pressure Reducing Valve and ASME Safety Relief Valve Location

Although the operation of the system pump cannot change the air management tank pressure, it can affect tank sizing. Depending upon the location of the ASME safety relief valve, the non-operating pressure, plus the pressure added by the pump, may limit the amount the system pressure can increase without exceeding the valve's set point. Figure O illustrates a typical safety relief valve and pressure reducing valve. Note that the safety relief valve's rated pressure is not adjustable and must not be tampered with in the field. Size and locate the safety relief valve at a position to prevent over-pressurizing any component in the system.

Figure O – ASME Safety Relief Valve and Pressure Reducing Valve



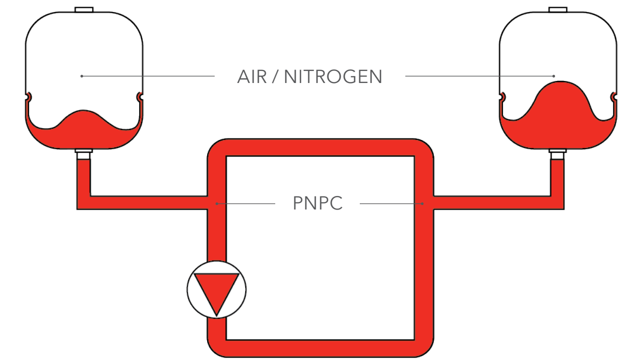
If the pressure reducing valve is positioned in the system so that the pump can reduce the pressure it sees when the pump is in operation, it will think the system pressure has dropped, and will add water to increase the pressure. When the pump stops, the non-operating pressure will have increased. Subsequent cycles can increase the pressure to that of the safety relief valve set point causing it to open.

The ideal location for the pressure reducing valve, as well as the air management tank, is at the pump suction, since the operation of the pump will not affect either of them. If a water or glycol make-up unit is being utilized in the system, installation at the pump suction is also recommended. Reference Figures Y & Z for installation examples.

Multiple Tank Locations

When any system is completely filled with water, and air is managed properly, the point where the tank connects to the system will be a point of no pressure change, and will be virtually unaffected by pump operation. However, if a second tank is installed in the system, reference Figure P, tank pressure will be affected by operation of the pump.

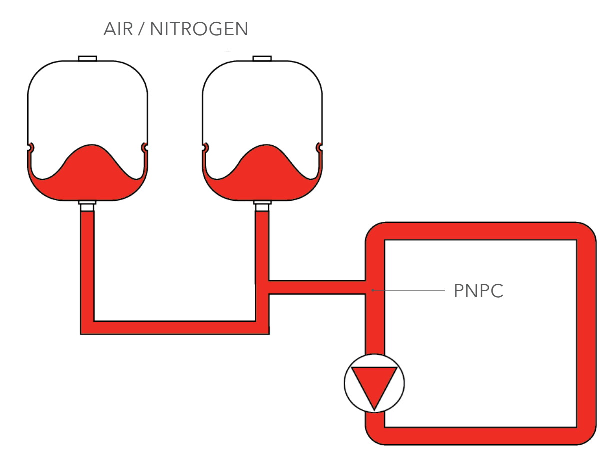
Figure P – Multiple Tank Connections and Effect of Pump Operation



With this scenario the pump will transfer water from one tank to the other in proportion to the pressure differential it can produce between both tanks. The point of no pressure change then will move to a point somewhere between the two tanks, and may even move with changes in the tanks water volume. More than one system connection to a tank, or tanks, is not recommended since unreliable pressure conditions result.

For reliable positive pressure readings throughout the system, install multiple tanks to a single manifold which is connected to the system at one location on the suction side of the pump. (Ref. Figure Q).

Figure Q – Manifold Multiple Tanks

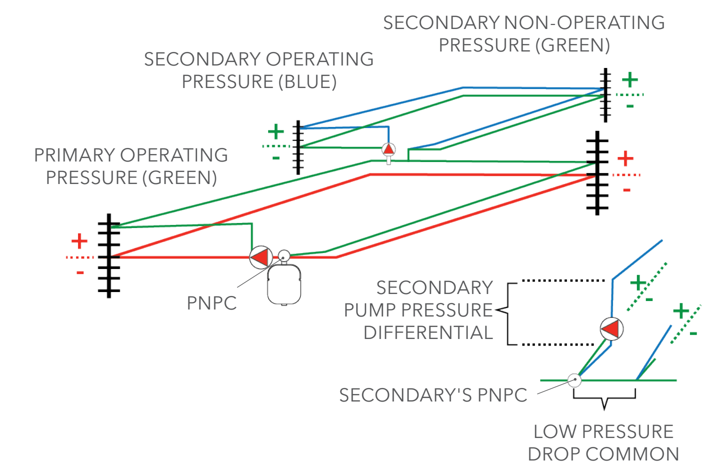


A system containing a large amount of free air in the piping and radiation can cause a similar situation. Thorough initial manual venting, and installation of efficient air separation equipment, will usually remedy this type problem, and eventually establish a fixed point of no pressure change.

Primary/Secondary and Point of No Pressure Change

If the operation of a single pump cannot change the pressure within the air management tank, it follows that the operation of many pumps installed throughout the system will not affect a single point of no pressure change. With this single reference point for a starting pressure, it is possible to analyze the hydraulics and pressure gradients for the entire system, regardless of the number of pumps installed. Primary/secondary pumping is a means of inter-connecting piping circuits so that the operation of one will not affect the other. Figure R illustrates the pressure relationship on a typical one pipe primary/secondary system.

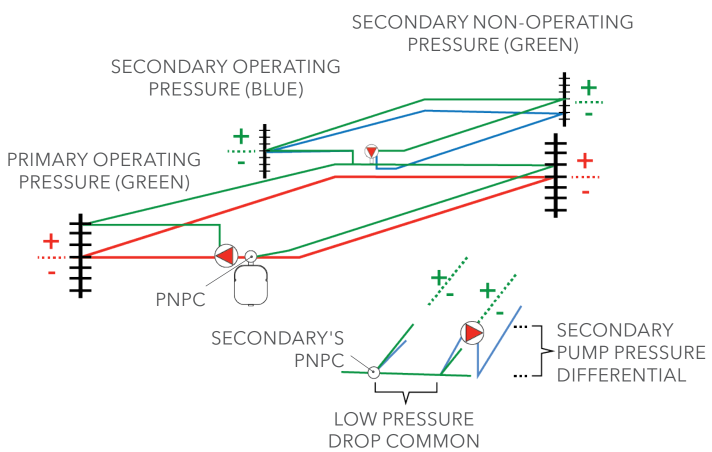
FIgure R – Primary/Secondary System Pressure Relationships, Pumping Away From PNPC



Note how the connection point between the secondary and primary circuits establishes the non-operating pressure for the secondary circuit. It also becomes the point of no pressure change for the secondary circuit pump. To ensure that the secondary pump adds its pressure differential positively throughout the circuit, it must pump away from this connection to the primary circuit. By pumping away from this point, the secondary pump will add pressure to the non-operating pressure throughout the secondary circuit. This provides the secondary circuit with the same benefits as pumping away from the point of no pressure change in the primary circuit. The pressure drop between the connection point and the pump suction, as well as the common pipe between the circuits, should be kept to a minimum.

However, if the secondary pump is pumping into the connection point (Ref. Figure S) to the primary circuit, and the head of the secondary pump is greater than the non-operating pressure of the secondary circuit, it will draw a partial vacuum in the secondary circuit when it operates.

Figure S – Primary/Secondary System Pressure Relationships, Pumping Towards PNPC



TANK SIZING

Water expands when heated, in direct proportion to its change in temperature, up to the point of saturation or boiling. As shown in Figure E, a steel piping system containing the water also expands, but only a small amount compared to the water expansion.

The purpose of the air management tank is to accommodate the fluctuations in water volume within a closed system, while maintaining a predetermined range of pressures from the minimum cold fill pressure up to the maximum system working pressure. The tank acts as a spring on the system, keeping pressure on it at all times. If the tank is too small, the system pressure increase will be excessive, and the safety relief valve will open, discharging system water. If the tank is too large, particularly in a heating application, the system pressure increase may not be enough as the system heats up and approaches boiling, particularly at system high points lacking static head. The result will be possible damage, noise and loss of circulation.

Whereas both the air control and air elimination methods of air management use a tank to absorb the volumetric expansion of the system, the design of the tanks differs. The tank used with an Air Control System allows water and air to be in contact. This type of tank is commonly called a compression tank. The tank used in an Air Elimination System separates the air from the water by means of a flexible membrane. Tanks used in this type system are frequently referred to as pressurized or pre-charged expansion tanks.

To properly size either a compression or pre-charged air management tank, the following information is required:

1. System Water Volume

   The systems water volume must be calculated as accurately as possible. Manufacturers of boilers, chillers, convectors, heat exchangers, coils, panels etc. should be contacted regarding component volume capacity. Piping and tubing manufacturers can also provide water volume per foot, based on size and materials of construction.

2. Average Design Temperature

   For hot water systems, the system's design supply and return temperatures are used to establish the average design temperature. In heating systems without temperature reset, it is possible return water temperatures can be higher than the design return water temperatures anticipated. For chilled water systems, a minimum of 100°F (38°C) is recommended. If the air management tank is to be installed in an application where 100°F (38°C) could be exceeded, use that higher temperature.

3. System's Required Cold Static Fill Pressure

   Cold static fill pressure allows for the system to be completely filled with water and have a minimum 4 psi (28 kPa) at the top.

4. Maximum Tank Pressure

   Maximum tank pressure is calculated using the pressure safety relief valve setting and the air management tank's vertical distance to this valve.

Tolerances in the pressure setting of safety relief valves may cause nuisance valve discharges. To eliminate this problem many designers discount the rated setting by 10%, 5 psi (34 kPa) minimum, when determining the maximum pressure at the tank.

Chilled Water Applications

In a heating application, under normal operating conditions and no loss of initial system fluid volume, the air management tank is sized to maintain a minimum required pressure at any point within the piping system, which is a function of the maximum fluid operating temperature and the pump location in the system. It must also absorb the volume of fluid "expanded" between the **initial fill** and **mean operating** system temperatures.

A chilled water system also needs an air management tank to provide a minimum pressure, 4 psi (28 kPa) at the system top is sufficient. It must also absorb the increase in system volume due to temperature. The concern here is not over the expansion between the initial fill and mean operating system temperatures, as the potential volume increase will be minimal. The concern is the expansion due to the ambient air temperature if the system isn't operating. A minimum sizing temperature of 100°F (38°C) is suggested. If the tank is to be installed in an application where 100°F (38°C) could be exceeded, use that higher temperature.

Glycol Solutions

Some hydronic system designs require the system fluid to have "anti-freeze" properties. Ethylene or Propylene glycol solutions are the most common choices for these applications. For a given temperature change, a glycol solution expands more than water. To properly size an air management tank for a glycol solution, size it for water and then multiply the water tank size by the appropriate factor from Figure T.

Tank Formulas

The basic relationship used for sizing a compression or pre-charged tank is derived from the ideal gas law and is expressed by equation (1):

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \tag{1}$$

Although in actual system operation, there may be some air temperature change in the tank, the equation above can be simplified considerably by assuming no temperature change ($T_1 = T_2$). The results of the calculation will be within acceptable accuracy for tank sizing purposes. Rewriting equation (1) with $T_1 = T_2$, it becomes Boyles' law:

$$P_1V_1 = P_2V_2 \tag{2}$$

Figure T – Aqueous Glycol Solution Correction Factors*

Temp. °F (°C)	Volume Percent - Ethylene Glycol					Volume Percent - Propylene Glycol				
	10%	20%	30%	40%	50%	10%	20%	30%	40%	50%
100 (38)	1.69	1.80	1.96	2.09	2.22	1.79	2.10	2.38	2.67	2.90
110 (43)	1.46	1.57	1.68	1.79	1.90	1.55	1.81	2.05	2.29	2.49
120 (49)	1.46	1.54	1.66	1.77	1.87	1.53	1.78	2.03	2.22	2.44
130 (54)	1.31	1.40	1.49	1.58	1.67	1.38	1.60	1.81	1.98	2.16
140 (60)	1.28	1.36	1.45	1.53	1.62	1.35	1.56	1.76	1.93	2.09
150 (66)	1.23	1.30	1.38	1.46	1.54	1.30	1.48	1.67	1.83	1.98
160 (71)	1.20	1.27	1.35	1.42	1.49	1.27	1.44	1.62	1.77	1.91
170 (77)	1.16	1.22	1.29	1.35	1.43	1.22	1.38	1.54	1.69	1.82
180 (82)	1.13	1.19	1.25	1.31	1.38	1.19	1.34	1.50	1.63	1.75
190 (88)	1.11	1.17	1.23	1.29	1.35	1.17	1.32	1.47	1.59	1.72
200 (93)	1.11	1.16	1.22	1.27	1.34	1.16	1.31	1.45	1.57	1.69
210 (99)	1.09	1.14	1.19	1.25	1.31	1.14	1.28	1.42	1.54	1.65
220 (104)	1.08	1.13	1.18	1.23	1.29	1.13	1.27	1.40	1.51	1.62
230 (110)	1.07	1.12	1.17	1.22	1.27	1.12	1.26	1.38	1.49	1.60
240 (116)	1.06	1.11	1.15	1.20	1.25	1.11	1.24	1.36	1.47	1.57
250 (121)	1.05	1.10	1.14	1.19	1.24	1.10	1.23	1.35	1.45	1.55
Approximate Freeze Temperature	25 (-4)	16 (-9)	4 (-16)	-13 (-25)	-35 (-37)	26 (-3)	19 (-7)	8 (-13)	-7 (-22)	-28 (-33)

*Multiply both the pre-charged tank volume and pre-charged tank acceptance volume with the above factor to correct tank size.
*Multiply the calculated compression tank volume with the above factor to correct tank size.

By proper substitution in equation (2), the basic formula for determining minimum tank size is:

$$(3) \quad V_t = \frac{V_1 - V_2}{\frac{P_a}{P_f} - \frac{P_a}{P_o}} = \frac{(E_w - E_p)V_s}{\frac{P_a}{P_f} - \frac{P_a}{P_o}}$$

Where:

V_t = Tank Size, Gallons (Liters)

V_s = Volume of System, Gallons (Liters)

$(E_w - E_p)$ = Net Water Expansion Factor (Ref. Figure F)

P_a = Pressure in Tank before Water Enters, psia (kPa)

P_f = Design Fill Pressure, psia (kPa)

P_o = Final Tank Pressure, psia (kPa)

$V_1 - V_2$ = Change of Tank Gas Volume, Gallons (Liters)

NOTE: P_a, P_f, and P_o are expressed in <u>absolute</u> pressures

Equation (3) applies to the selection of both compression and pre-charged air management tanks. The pre-charge tank application is unique, in that the pressure in the tank before filling, is not atmospheric (P_a). The tank must be charged in the field to the required system cold static fill pressure (P_f). Substituting P_f for P_a in equation (3), the minimum tank size for a pre-charged tank becomes:

$$(4) \quad V_t = \frac{(E_w - E_p)V_s}{\frac{P_f}{P_f} - \frac{P_f}{P_o}} = \frac{(E_w - E_p)V_s}{1 - \frac{P_f}{P_o}}$$

Due to the physical construction of the flexible membrane (diaphragm, bladder etc.) in a pre-charged tank, the full **tank volume**, V_t, may not be available for fluid expansion. The maximum amount of liquid a given tank can accept is known as the **acceptance volume**, A_c, or sometimes "acceptance allowance". For example, a 100 gallon (379 Liters) pre-charged tank may only have a 50 gallon (189 Liter) acceptance volume. This tank can be used if the system's total expected NET expansion of fluid volume is 50 gallons (189 Liters) or less. If the anticipated NET expansion of fluid volume is more than 50 gallons, then a revised tank selection must be made where the acceptance volume rating is equal to, or greater than, the correct value. In some cases, a single tank may not be capable of the capacity required, or may present a site access or installation issue due to physical dimensions. In this situation, multiple tanks may be used, piped in parallel, which meet or exceed the required acceptance volume.

Another term used in sizing pre-charged tanks is the **acceptance factor**, A_e, defined as:

$$(5) \quad A_e = 1 - \frac{P_f}{P_o}$$

Notice that the acceptance factor is the denominator of equation (4), which through substitution becomes:

$$(6) \quad V_t = \frac{(E_w - E_p)V_s}{A_e}$$

Selecting the correct pre-charged tank requires satisfying two conditions:

1. The volume of the tank, V_t, must be large enough to keep the change in pressure due to fluid expansion within the system's allowable pressure increase.
2. The tank's acceptance volume must be at least as large as the system's expansion volume.

Whereas the cold static fill pressure in a compression tank is set by fluid going into the tank and compressing the air inside, the cold static fill pressure setting for a Pre-Charged type tank must be done manually, using a separate air or nitrogen source, connected to the tank air charge valve. Factory pre-charge pressure is typically 12 PSI for HVAC applications, however the tank manufacturer's literature should be checked to confirm. The factory pre-charge setting must be modified up or down accordingly, on a job by job basis. This procedure must be done, in systems with lower cold static fill pressures, with no system fluid inside the diaphragm or bladder. Therefore, it is recommended the pressure adjustment be done prior to connecting the tank to the system piping. Consult manufacturer's literature for guidance on special charging instructions where higher cold static fill pressure requirements may exist. No fluid enters the tank during the system fill/vent/purge procedure.

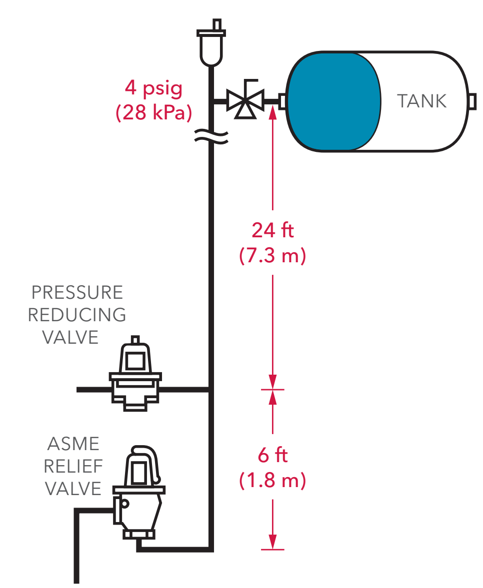
PRE-CHARGED (PRESSURIZED) TANKS

Sizing Pre-Charged Tanks

To calculate the required pre-charged air management tank size, obtain the rate of expansion from Figure F, then substitute the values for system volume, rate of expansion, cold fill pressure, and maximum tank pressure in equation (5) and solve. Select a pressurized tank that has an acceptance volume at least equal to the volume of expansion, and a tank volume at least equal to that computed. If a single tank isn't available to satisfy those two conditions, combine multiple tanks that will provide the required system acceptance and tank volumes.

In the following examples, assume the system is located close to sea level in a cold weather climate. Thus, atmospheric pressure is 14.7 psia (101 kPa), and the water temperature supplied from the municipality is approximately 40°F (4°C). Examples 1, 2 and 3 will illustrate that tank location in the system will affect the required tank size.

Example 1 – Tank Location at Top of System



- Water Only System
- 100 Gallons (379 Liters)
- 180°F (82°C) Average Design Temperature
- 190°F (88°C) Maximum Temperature
- 20°F (5.6°C) ΔT
- 4 PSI (28 kPa) Pressurization at System Top
- 30 psi (207 kPa) Rated ASME Safety Relief Valve

Step 1: ***Pressure Reducing Valve's Setting;***

The system's pressure reducing valve setting is job specific, and must be calculated to assure water completely fills the system to the top, and allows for air venting. Typically, 4 psi (28 kPa) minimum at the top provides adequate positive pressurization for good venting. First determine the vertical distance from the pressure reducing valve to the highest point in the system. In this example, the system's top is 24 feet (7.3 m) above the pressure reducing valve.

Static head at pressure reducing valve:
24 ft (7.3 m) / 2.31 ft/psi (0.1 m/kPa) = *10.4 psi (73 kPa)*

Pressurization at top of system: *4.0 psi (28 kPa)*

Pressure Reducing Valve setting: *14.4 psi (101 kPa)*

Adjust the pressure reducing valve setting to 14.4 psi (101 kPa) until a gauge at the same elevation as the valve reads 14.4 psi (101 kPa). If a gauge is at a different elevation, calculate the static head to add to, or subtract from, the final gauge reading. Example: If the gauge is 6 ft (1.8 m) higher than the pressure reducing valve, subtract 2.6 psi (18 kPa) [6 ft (1.8 m) / 2.31 ft/psi (0.1 kPa) = 2.6 psi (18 kPa)] from 14.4 psi (101 kPa). When the gauge reads 11.8 psi (83 kPa), the correct PRV setting has been reached. The system will be filled with water, and the top will be pressurized to 4 psi (28 kPa).

Step 2: ***Initial Tank Pressure;***

For this example, the tank's initial pressure is equal to 4 psi (28 kPa), since it is located at the highest point in the system, and there is no static head (building height) above the tank. The top is pressurized to 4 psi (28 kPa) to vent air from the system, and provide adequate pump pressurization.

(Ref. Figures C & D). Pre-charge tank to 4 psi (28 kPa) prior to installation.

Step 3: ***Maximum Tank Pressure;***

Maximum tank pressure will depend on the ASME safety relief valve rated pressure, and the tanks vertical orientation to this valve.

In this example, the ASME Safety Relief Valve has a 30 psi (207 kPa) pressure rating. To avoid the possibility of a nuisance valve discharge, derate the valve rating by 10%, or a minimum 5 psi (35 kPa), to determine the maximum tank pressure.

Derate ASME Safety Relief Valve: *25 psi (172 kPa)*

Static Head above ASME Safety Relief Valve:
30 ft (9 m) / 2.31 ft/psi (0.1 m/kPa) = 13 psi (90 kPa)

System Top Pressurization: *4 psi (28 kPa)*

Initial Total Pressure at ASME Safety Relief Valve: *17 psi (118 kPa)*

Maximum pressure increase at the ASME Safety Relief Valve:
25 psi (172 kPa) – 17 psi (118 kPa) = 8 psi (54 kPa)

Thus, the maximum pressure increase in the system, as well as the tank, is 8 psi (54 kPa).

Maximum tank pressure: Initial pressure + pressure increase: *4 psi (28 kPa) + 8 psi (54 kPa) = 12 psi (83 kPa)*

Step 4: *Acceptance Factor A_e (Equation (5));*

$$A_e = 1 - \frac{P_f}{P_o} \quad (5)$$

P_f = Design fill initial tank pressure = 14.7 + 4 = 18.7 psia (129 kPa)

P_o = Final tank pressure = 14.7 + 4 + 8 = 26.7 psia (184 kPa)

A_e = 1 – (18.7 psia (129 kPa) / 26.7 psia (184 kpa)) = 0.2996

Step 5: *Net Water Expansion Volume (Acceptance Volume);*
Based on 180°F (82°C) average design temperature and Figure F, the net water expansion factor (E_w-E_p) is 0.0279.

Net water expansion volume (E_w-E_p)V_s:
(0.0279)*(100 gal (379 Liters)) = 2.8 Gallons (10.6 Liters)

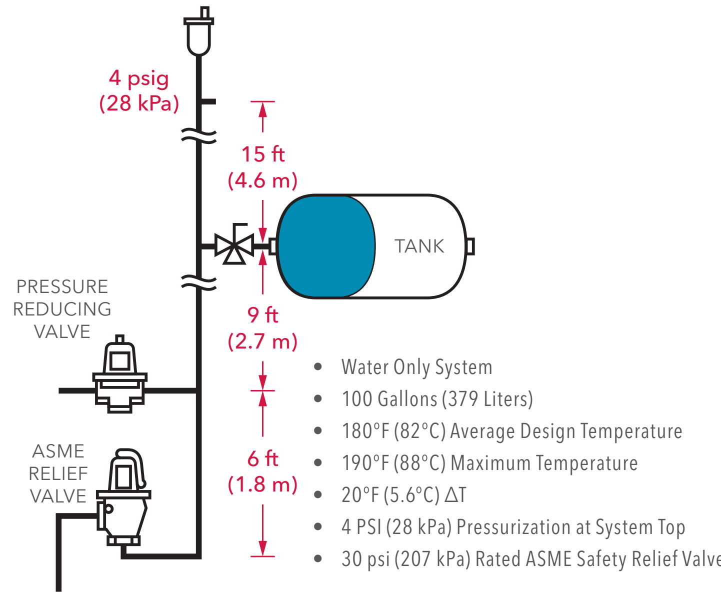
Step 6: *Tank Volume Size (Equation (6));*
V_t = 2.8 gal (10.6 Liters) / 0.2996 = 9.3 gallons (35.4 Liters)

$$V_t = \frac{(E_w - E_p)V_s}{A_e} \quad (6)$$

Step 7: *Select Pre-Charged Tank*
Minimum tank acceptance volume must equal to, or exceed, 2.8 gallons (10.6 Liters).

Minimum tank volume must equal to, or exceed, 9.3 gallons (35.4 Liters).

Example 2: Tank Location at Middle of System



Step 1: *Pressure Reducing Valve's Setting;*
The vertical distance from the pressure reducing valve to the highest point in the system is 24 feet (7.3 m).

Static head at pressure reducing valve:
24 ft (7.3 m) / 2.31 ft/psi (0.1 m/kPa) = 10.4 psi (73 kPa)

Pressurization at top of system: *4.0 psi (28 kPa)*

Pressure Reducing Valve setting: *14.4 psi (101 kPa)*

Adjusting the pressure reducing valve setting to 14.4 psi (101 kPa) will allow water to fill the system and pressurize the top to 4 psi (28 kPa).

Step 2: *Initial Tank Pressure;*
The initial pressure seen at the tank will include static head (building height above tank) plus the 4 psi (28 kPa) pressurization at the top.

Static head at tank:
15 ft (5 m) / 2.31 ft/psi (0.1 m/kPa) = 6.5 psi (45 kPa)

Pressurization at top of system: *4.0 psi (28 kPa)*

Initial tank pressure: *10.5 psi (73 kPa)*

Pre-charge tank to 10.5 psi (73 kPa) prior to installation.

Step 3: *Maximum Tank Pressure;*
Maximum tank pressure will depend on the ASME safety relief valve rated pressure, and the tank's vertical orientation to this valve.

In this example, the ASME Safety Relief Valve has a 30 psi (207 kPa) pressure rating. To avoid the possibility of a nuisance valve discharge, derate the valve rating by 10%, or a minimum 5 psi (35 kPa), to determine the maximum tank pressure.

Derate ASME Relief Valve: *25 psi (172 kPa)*

Maximum pressure increase at the ASME Safety Relief Valve:
25 psi (172 kPa) – 17 psi (118 kPa) = 8 psi (54 kPa)

Thus, the maximum pressure increase in the system, as well as the tank, is 8 psi (54 kPa).

Maximum tank pressure: Initial pressure + pressure increase: *10.5 psi (73 kPa) + 8 psi (55 kPa) = 18.5 psi (128 kPa)*

Step 4: *Acceptance Factor A_e (Equation (5));*

$$A_e = 1 - \frac{P_f}{P_o} \quad (5)$$

P_f = Design fill initial pressure = 14.7 + 4 + 6.5 = 25.2 psia (174 kPa)

P_o= Final tank pressure = 14.7 + 4 + 6.5 + 8 = 33.2 psia (229 kPa)

A_e = 1 – (25.2 (174 kPa) / 33.2 (229 kPa)) = 0.241

Step 5: *Net Water Expansion Volume (Acceptance Volume);*
Based on 180°F (82°C) average design temperature, and Figure F, the net water expansion factor (E_w-E_p) is 0.0279.

Net water expansion volume (E_w-E_p)V_s:
(0.0279)*(100 gal (379 Liters)) = 2.8 Gallons (10.6 Liters)

Step 6: *Tank Volume Size (Equation (6));*

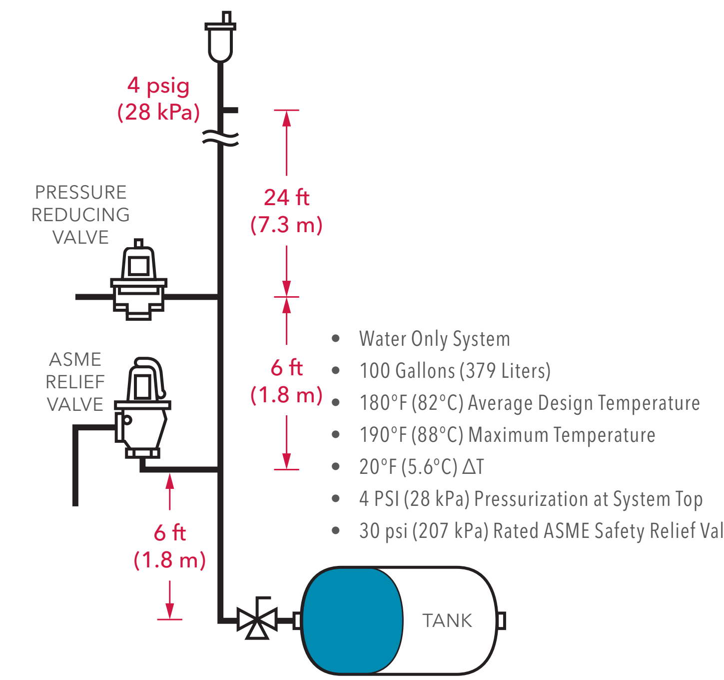
$$V_t = \frac{(E_w - E_p)V_s}{A_e} \quad (6)$$

V_t = 2.8 Gallons (10.6 Liters) / 0.241 = 11.6 gallons (43.9 Liters)

Step 7: *Select Pre-Charged Tank;*
Minimum tank acceptance volume must equal, or exceed, 2.8 Gallons (10.6 Liters).

Minimum tank volume must equal, or exceed, 11.6 gallons (43.9 Liters).

Example 3: Tank Location at Bottom of System



Step 1: *Pressure Reducing Valve's Setting;*
The vertical distance from the pressure reducing valve to the highest point in the system is 24 feet (7.3 m).

Static head at pressure reducing valve:
24 ft (7.3 m) / 2.31 ft/psi (0.1 m/kPa) = 10.4 psi (73 kPa)

Pressurization at top of system: *4.0 psi (28 kPa)*

Pressure Reducing Valve setting: *14.4 psi (101 kPa)*

Adjusting the pressure reducing valve setting to 14.4 psi (101 kPa) will allow water to fill the system and pressurize the top to 4 psi (28 kPa).

Step 2: *Initial Tank Pressure;*
The initial pressure seen at the tank will include static head (building height above tank) plus the 4 psi (28 kPa) pressurization at the top.

Static head at tank:
36 ft (11 m) / 2.31 ft/psi (0.1 m/kPa) = 15.6 psi (108 kPa)

Pressurization at top of system: *4.0 psi (28 kPa)*

Initial tank pressure: *19.6 psi (136 kPa)*

Pre-charge tank to 19.6 psi (136 kPa) prior to installation.

Step 3: ***Maximum Tank Pressure;***
Maximum tank pressure will depend on the ASME safety relief valve rated pressure, and the tank's vertical orientation to this valve.

In this example, the ASME Safety Relief Valve has a 30 psi (207 kPa) pressure rating. To avoid the possibility of a nuisance valve discharge, derate the valve rating by 10%, or a minimum 5 psi (35 kPa), to determine the maximum tank pressure.

Derate ASME Relief Valve: *25 psi (172 kPa)*

Maximum pressure increase at the ASME Safety Relief Valve:
25 psi (172 kPa) – 17 psi (118 kPa) = 8 psi (54 kPa)

Thus, the maximum pressure increase in the system, as well as the tank, is 8 psi (54 kPa).

Maximum tank pressure: Initial pressure + pressure increase: *19.6 psi (136 kPa) + 8 psi (54 kPa) = 27.6 psi (190 kPa)*

Step 4: ***Acceptance Factor A_e (Equation (5));***

$$A_e = 1 - \frac{P_f}{P_o} \tag{5}$$

P_f = Design fill initial pressure = 14.7 + 4 + 15.6 = 34.3 psia (236 kPa)

P_o = Final tank pressure = 14.7 + 4 + 15.6 + 8 = 42.3 psia (292 kPa)

A_e = 1 – (34.3 (236 kPa) / 42.3 (292 kPa)) = 0.1891

Step 5: ***Net Water Expansion Volume (Acceptance Volume);***
Based on 180°F (82°C) average design temperature, and Figure F, the net water expansion factor (E_w-E_p) is 0.0279.

Net water expansion volume (E_w-E_p)V_s: (0.0279)*(100 gal (379 Liters)) = 2.8 Gallons (10.6 Liters)

Step 6: ***Tank volume size (Equation (6));***

$$V_t = \frac{(E_w - E_p)V_s}{A_e} \tag{6}$$

V_t = 2.8 gal (10.6 Liters) / 0.1891 = 14.8 gallons (56 Liters)

Step 7: ***Select Pre-Charged Tank***
Minimum tank acceptance volume must equal, or exceed, 2.8 gallons (10.6 Liters).

Minimum tank volume must equal, or exceed, 14.8 gallons (56 Liters).

Figure U – Tank Size vs. Location Comparison

Tank Location in System	Top	Middle	Bottom
Pressurization at Top - psi (kpa)	4 (28)		
ASME Relief Valve Rating - psi (kpa)	30 (207)		
Pressure Reducing Valve Setting - psi (kpa)	14.4 (99)		
Initial Tank Pressure - psi (kpa)	4 (28)	10.5 (72)	19.6 (135)
Maximum Tank Pressure - psi (kpa)	12 (83)	18.5 (128)	27.6 (190)
Acceptance Volume - Gallons (Liters)	2.8 (11)		
Tank Volume - Gallons (Liters)	9.3 (35)	11.6 (44)	14.8 (56)

Figure U compares the results from examples 1, 2, & 3 and illustrates that the required tank volume deceases as it is installed higher in the system.

Example 4: 30% Propylene Glycol System

For a given temperature change, a glycol solution expands more than water. To properly size a pre-charge tank for a glycol solution, first size the tank for water, and then multiply the water tank volume, and acceptance volume, by the appropriate correction factor from Figure T.

Using the same design conditions and results as in examples 1, 2 and 3, multiply both the pre-charged tank volume, and pre-charged tank acceptance volume, with the appropriate correction factor from Figure T for 30% propylene glycol. For 180°F (82°C), and 30% propylene glycol, the correction factor is 1.5. Introducing glycol to the system increased the tank and acceptance volume by 50%. (Ref. Figure V).

Figure V – Glycol Expansion Comparison

30% Propylene Glycol System 180°F (82°C) Average Temperature			
Tank Location in System	Top	Middle	Bottom
Acceptance Volume - Gallons (Liters)	4.2 (16)		
Tank Volume - Gallons (Liters)	14 (53)	17.4 (66)	22.2 (84)

Example 5: Decrease the Average Design Temperature

Using the same design conditions as examples 1, 2, and 3, decrease the average temperature to 110°F (43°C). Based on the new temperature, and Figure F, the net water expansion factor (E_w-E_p) now becomes 0.0080. Completing Step 5 and Step 6 in the above examples, the required acceptance and tank volume decreased by 71%. Ref. Figure W below.

Figure W – Effect of Temperature Change

110°F (43°C) Average Temperature			
Tank Location in System	Top	Middle	Bottom
Acceptance Volume - Gallons (Liters)	0.8 (3)		
Tank Volume - Gallons (Liters)	2.7 (10)	3.3 (13)	4.2 (16)

Example 6: Increase System Total Water Volume

Using the same design conditions as examples 1, 2, and 3, increase the systems water volume to 865 Gallons (3274 Liters). Again Step 5 and Step 6 are used to complete the tank sizing with results in Figure X below.

Figure X – System Volume Increase

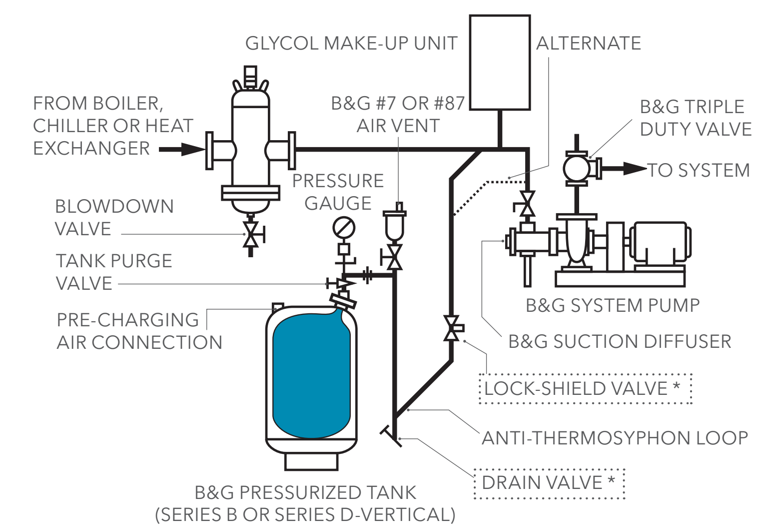
System Volume 865 Gallons (3274 Liters)			
Tank Location in System	Top	Middle	Bottom
Acceptance Volume - Gallons (Liters)	24.1 (91)		
Tank Volume - Gallons (Liters)	80.4 (304)	100 (379)	127.4 (482)

Pre-Charged Tank Installation
The tank to system piping in an application using a pressurized or pre-charged tank differs from that using a compression tank in several major respects:

1. Air from the system must be vented or purged to the atmosphere, and not allowed to enter the tank.
2. Tank to system piping must not be pitched-up to the tank.
3. A Tank Purge Valve, as shown in Figure AA, or separate shut-off and drain valves, must be installed in the tank to system piping to properly check, or re-charge, tank air pressure after the system has been filled with water.

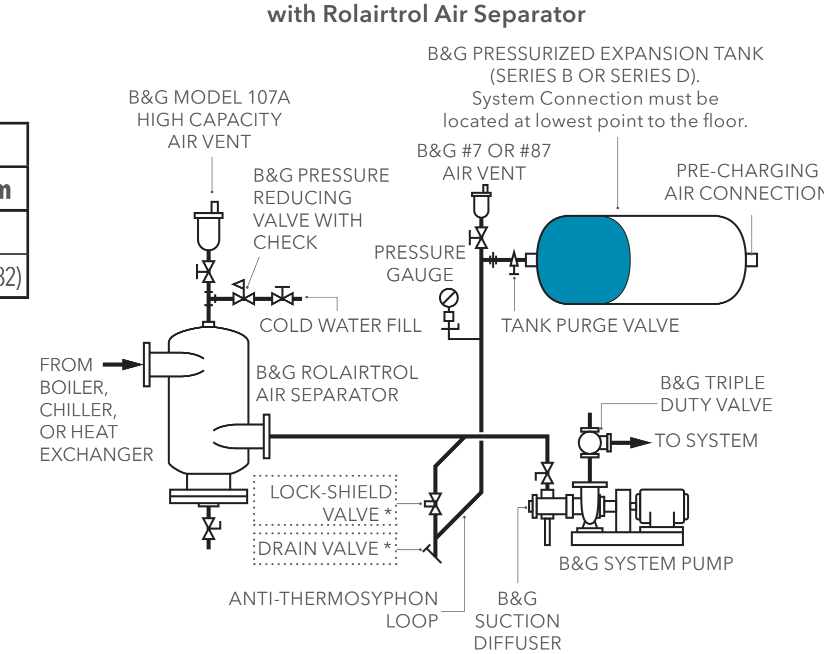
Typical tank to system and air vent piping details are illustrated in Figures Y & Z. General notes regarding this piping follow:

Figure Y – Vertical Tank Installation with Glycol Make-Up Unit and Coalescing Air Separator



** RECOMMENDED IF TANK PURGE VALVE NOT INSTALLED*

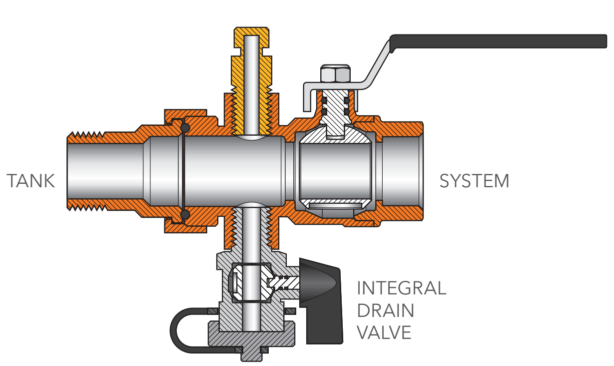
Figure Z – Horizontal Tank Installation with Rolairtrol Air Separator



** RECOMMENDED IF TANK PURGE VALVE NOT INSTALLED*

1. The connection point of tank to system is the point of no pressure change, just as it is when using a compression tank.
2. The piping connecting the tank to the system main should be attached to minimize the possibility of air and/or debris from entering the tank. If connected to a horizontal main, avoid bottom (6 o'clock) and top (12 o'clock) positions. If the connection must be made to the bottom of the main, install a dirt leg with a drain valve to trap and flush debris.
3. The pressurized tank pre-charge pressure is based on a dry (waterless) tank. In order to check, or change, the pre-charge pressure, the tank circuit must be isolated from the main system piping. A high quality, gate type, lock-shield valve or a combination isolation and drain Tank Purge valve (Ref. Figure AA) are recommended for this purpose. The lock-shield for the valve stem will reduce tampering with the valve which normally must be open during system operation.
4. In addition to the lock-shield or Tank Purge valve used to isolate the tank from the system, an automatic air vent, and a pressure gauge should be installed in this piping. The Tank Purge drain valve is for flushing, and to drain the water from the tank for proper air charging.
5. Since the tank sizing calculations are made on the basis of minimum temperature rise in the tank, if the tank system connection will be located above the top of the system piping after installation, an anti-thermosyphon loop must be included in the tank to system piping to minimize the effect of gravity circulation into the tank. A drop leg of twelve to twenty inches is usually sufficient. In addition, good practice dictates that the piping and the tank in a heating system not be insulated.

Figure AA – Tank Purge Valve



Pre-Charged Tank to System Pipe Sizing

Typically, air management tanks are sized such that the maximum pressure in the tank will prevent the pressure at the safety relief valve from exceeding 90% of the relief valve setting. When sizing pipe between the tank and system, keep pressure drops as low as possible to prevent a buildup of pressure in the heat generator, as the water is heated, expands, and flows towards the tank. If the pipe is too small, the resistance to flow can cause the pressure to increase enough to open the safety relief valve. The selected pipe size should never be smaller than the air management tank supplied fitting connection.

To properly analyze the required pipe size, the flow rate during the last 10°F (5.6°C) increase to the maximum temperature, can be calculated using the appropriate IP or SI equation (7). Then compare different pipe sizes, and friction loss rates based on resulting flow rate (GPM or M^3 / Hr), to establish a low back pressure that will prevent the safety relief valve from opening.

IP Version:

(7-IP)

$$GPM_{\text{(System to Tank Pipe)}} = \frac{(E_w - E_p) * q}{60 * \rho * c_p * \Delta T}$$

$(E_w - E_p)$ = Net Water Expansion Factor; (10°F (5.6°C) Increase to Maximum Temperature), (Ref. Figure F)

q = Heat Transfer Rate, Btu/h; (Heat Generator)

ρ = Density, lb / Gallon; (At Average Design Temperature)

c_p = Specific Heat, Btu / (lb .°F); (At Average Design Temperature)

ΔT = Temperature Difference, °F; (10°F (5.6°C) Increase to Maximum Temperature)

SI Version:

(7-SI)

$$M^3/Hr_{\text{(System to Tank Pipe)}} = \frac{(E_w - E_p) * q}{\rho * c_p * \Delta T}$$

$(E_w - E_p)$ = Net Water Expansion Factor; (10°F (5.6°C) Increase to Maximum Temperature), (Ref. Figure F)

q = Heat Transfer Rate, kWh; (Heat Generator)

ρ = Density, kg / m^3; (At Average Design Temperature)

c_p = Specific Heat, kW / (kg °C); (At Average Design Temperature)

ΔT = Temperature Difference, °C; (10°F (5.6°C) Increase to Maximum Temperature)

Example: Pre-Charged Tank to System Pipe Sizing

Water Only System

245°F (118°C) Average Design Temperature

250°F (121°C) Maximum Temperature

Density at 245°F (118°C): 7.88 lb / Gal (944 kg / m^3)

Specific Heat at 245°F (118°C): 1.01 Btu / (lb°F) (0.00118 kW / (kg°C)

Last 10°F (5.6°C) ΔT: 250°F (121°C) – 240°F (116°C)

Heat Transfer Rate: 20,000 MBH (5861 kWh)

From Figure F, the Net Water Expansion Factor for 250°F (121°C) and 240°F (116°C) is 0.0571 and 0.0523, respectively. The difference between the two factors shows the net expansion of water from 240°F (116°C) to 250°F (121°C) to be 0.0048 or 0.48%. Substituting numbers into equation (7-IP) results in:

$$GPM_{\text{(System to Tank Pipe)}} = \frac{0.0048 * 20{,}000{,}000}{60 * 7.88 * 1.01 * 10} = 20$$

Or equation (7-SI):

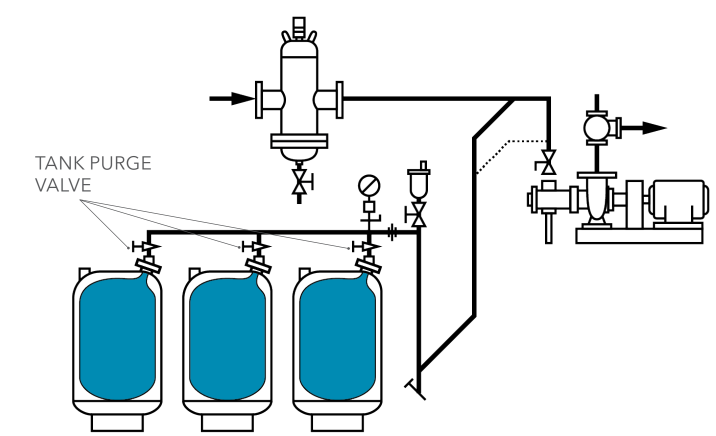
$$M^3/Hr_{\text{(System to Tank Pipe)}} = \frac{0.0048 * 5861}{944 * 0.00118 * 5.6} = 4.5$$

In this example, assume 40 ft(12 m) total equivalent length (TEL) of 2 inch (50 mm) copper pipe to the pre-charged tank, which has a 2 inch (50 mm) system connection. At 250°F (121°C), the friction loss rate is 0.71 ft (0.2 m) per 100 ft (30 m), which results in a 0.12 psi (0.8 kPa) pressure drop. [40 ft * 0.71 ft/100 ft *0.43 psi/ ft = 0.12 psi (0.8 kPa)]. In this example, the pipe size should remain 2 inch (50 mm), as the pre-charged tank system connection is 2 inch (50 mm).

Now, assume a 50 psi (345 kPa) safety relief valve, with a tank sized for a maximum pressure of 45 psi (310 kPa), and a pre-charged tank connection of 1.25 inch (32 mm). If 1.25 inch (32 mm) piping is installed from the system to the tank in the above example, there would be a 1 psi (7 kPa) back pressure in the pipe. This reduces the safety factor used for the relief valve when sizing the pre-charged tank. Using 1.5 inch (40 mm) pipe from the system to the tank would reduce the pipe pressure drop to 0.5 psi (3 kPa). The acceptable pressure drop is ultimately the designer's decision.

At times, installation of a single pre-charged tank is impractical, and therefore, two or more tanks with a total volume sufficient for the application, must be utilized (Ref. Figure BB). The same analysis can be accomplished using equation (7) for the manifold header. The manifold pipe size selected should produce a low pressure drop to avoid a large increase in system pressure. The header to tank pipe size would be determined by using the same equation (7), but dividing the total heat generator output by the number of pre-charged tanks that will be installed.

Figure BB – Multiple Pre-Charge Tank Manifold Piping



Automatic Air Vent Selection

Automatic air vents should be selected on the basis of their maximum operating pressure, and their venting capacity, at the initial system cold static fill pressure.

Nearly all of these vents will be float type, and therefore, may not operate properly if the system pressure exceeds the maximum design operating pressure of the vent.

The air discharge capacity of the vent, at the cold static fill pressure, is more critical than that at the operating pressure, because the greatest amount of air removal takes place during the filling and start-up procedures.

The rate at which air can be removed from the system depends on many factors, including:

1. System Pressure – The air vent discharge capacity increases as the pressure differential across the vent's seat increases.
2. Air Separator Efficiency – An efficient air separator can separate air from water at a very high rate, and the vent must release that air at the same rate, to prevent the air backing up, and being carried back out into the system, or creating a blockage.
3. Flow Rate – Generally, the greater the volume flowing through the separator, the greater the volume of air the vent must release. Therefore large flow rates require high capacity vents.
4. Temperature – Since warmer water has less soluble gas in solution than cold water, heating the water during the venting process increases the amount of air available for separation.

Since all of the air in a system cannot, and need not be removed during the first few passes through the air separator, the sizing of the automatic vent by capacity is not as important as selecting one with the proper maximum working pressure. A leaky vent is not only a nuisance, it may promote corrosion as a result of the oxygen contained within the required make-up water, added to maintain proper system pressurization.

Charging Procedure
Before the system is filled with water, check the tank pre-charge pressure. Unless otherwise noted, the tank is given a charge at the factory for testing. Typically this is not the correct pre-charge pressure for the job.

To determine the correct pre-charge pressure, first check the project engineered drawings and specifications for guidance. If nothing specific is indicated, either select it from Figure D or contact your local B&G representative for assistance. To pre-charge the tank:

1. Check the tank air pressure at the pre-charge connection with an accurate tire gauge.
2. If additional pressure is required, charge the tank with oil-free compressed air or nitrogen gas. Occasionally, check the pressure, as when filling a tire, to avoid the incorrect charge.
3. Check the air valve for leakage. If it leaks, relieve the pressure and replace the core with a Schraeder type tire core. Do not depend on the valve cap to seal the leak.

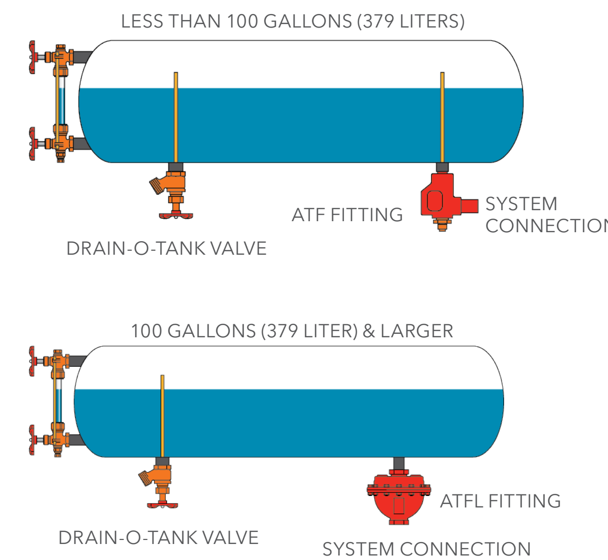
During system operation, and/or scheduled maintenance, it will be necessary to check the tank's pre-charge pressure. The following steps are recommended:

IMPORTANT: The tank cannot be properly air charged other than at the "fill" temperature.

1. Turn off the heat source and allow the system water to cool to ambient temperature.
2. Close the tank purge or lock-shield valve in the tank to system piping.
3. Open the Tank Purge Valve integral drain valve, or separate drain valve in piping, to empty water from the "wet side" of the tank. Check the tank air pressure at the pre-charge connection with an accurate tire gauge.
4. Charge the tank with nitrogen gas or oil-free compressed air. Again, occasionally check the tank air pressure.
5. Check the air valve for leakage. If it leaks, replace the core with a Schraeder type valve core. Do not depend on the valve cap to seal the leak.
6. Close the drain valve, open the tank purge or lock-shield valve and turn on the heat source.

COMPRESSION TANKS
Air control is the second strategy to manage air in a closed hydronic system. The air control method utilizes equipment to ensure the compression tank maintains an air cushion, while the system water is in direct contact with air. (Ref. Figure CC). During the initial system fill and pressurization step, all excess air is vented, and the only air in the system should be in the compression tank. Because of the change in solubility of air in water, due to the continual changes in system temperature and pressure, any air leaving the compression tank must be separated from the water, and returned back to the tank.

Figure CC – Compression Tank with Airtrol Fitting



Sizing Compression Tanks
If the minimum size standard tank is to be calculated, obtain the rate of expansion from Figure F, then substitute the values for system volume, net water expansion factor, fill pressure, maximum tank pressure and atmospheric pressure in equation (3) and solve. Select a compression tank equal to or larger than calculated. If a single tank large enough isn't available, use multiple tanks to provide the required volume.

If the system fluid is a glycol solution, the tank size determined above must be multiplied by the correction factor from Figure T. Again, select a compression tank equal to or larger than calculated, or if a single tank large enough isn't available, use multiple tanks to provide the required volume.

Example 1:

A 2000 gallon (7570 Liters) system has a mean design water temperature of 180°F (82°C). The compression tank will be installed at the top of the system with an initial pressure of 4 psi (28 kPa). The safety relief valve rating will be 30 psi (206 kPa). The initial pressure at the safety relief valve due to the static head (building height) plus the 4 psi (28 kPa) initial pressure at the tank will only allow an increase of 8 psi (55 kPa) without the danger of the valve weeping. Consequently the pressure in the tank can only rise 8 psi (55 kPa).

$$V_t = \frac{V_1 - V_2}{\frac{P_a}{P_f} - \frac{P_a}{P_o}} = \frac{(E_w - E_p)V_s}{\frac{P_a}{P_f} - \frac{P_a}{P_o}} \quad (3)$$

Example 1: Water System

Where:

V_t = Tank Size, Gallons (Liters)

V_S = Volume of System, Gallons (Liters)
2000 Gallons (7570 Liters)

$(E_w - E_P)$ = Net Water Expansion Factor (Ref. Figure F)
0.0279

P_a = Pressure in Tank before Water Enters, psia (kPa)
14.7 psia (101.4 kPa)

P_f = Design Fill Pressure, psia (kPa)
14.7 psia + 4 psi = 18.7 psia (128.9 kPa)

P_o = Final Tank Pressure, psia (kPa)
14.7 psia + 4 psi + 8 psi = 26.7 psia (184.1 kPa)

Using Equation (3) and substituting:

$$V_t = \frac{(0.0279) * 2000}{\frac{14.7}{18.7} - \frac{14.7}{26.7}} = 237.4 \text{ Gallons}$$

Or:

$$V_t = \frac{(0.0279) * 7570}{\frac{101.4}{128.9} - \frac{101.4}{184.7}} = 894.9 \text{ Liters}$$

Select a compression tank that meets, or exceeds, the 238 Gallon (895 Liters) requirement with an ATFL fitting.

Example 2: 30% Propylene Glycol System

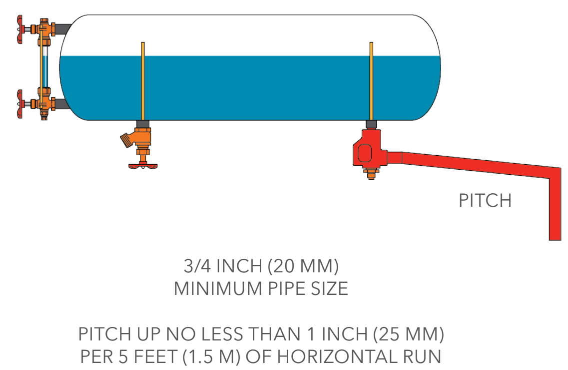
For a given temperature change, a glycol solution expands more than water. To properly size a compression tank for a glycol solution, first size the tank for water, and then multiply the water tank volume by the appropriate correction factor from Figure T.

Using the same design conditions and results as example 1 of this section, multiply the required compression tank volume by the appropriate correction factor from Figure T. For 180°F (82°C) and 30% propylene glycol, the correction factor is 1.5. The compression tanks size increased 50% to 356 gallons (1343 Liters).

Compression Tank Installation and Pipe Sizing
Efficient air separating equipment, and correctly sized and positioned compression tanks, require simple piping connections for proper performance. In an Air Control System, connecting piping need only be a riser pitched up to the tank. However, a number of variations exist that can have considerable influence on the overall efficiency of a system, and the size of the compression tank itself. As air bubbles are separated from a system, they must be allowed to rise into the compression tank. As that free air rises into the tank, an equal amount of water must return to the system. This means that the piping connection between the air separating device and the tank must always pitch up, and be large enough in diameter, to allow water and air to pass each other at the same time. Tests have shown that ¾ inch (20 mm) pipe is the smallest diameter pipe that should be used to allow simultaneous passage of water and air.

A reduced gravity head is a result of longer horizontal piping, which may make it necessary to use piping larger than ¾ inch (20 mm). Figure DD shows recommended pipe sizes to connect compression tanks to systems depending upon the horizontal length of pipe.

Figure DD – Compression Tank to Air Separator Piping

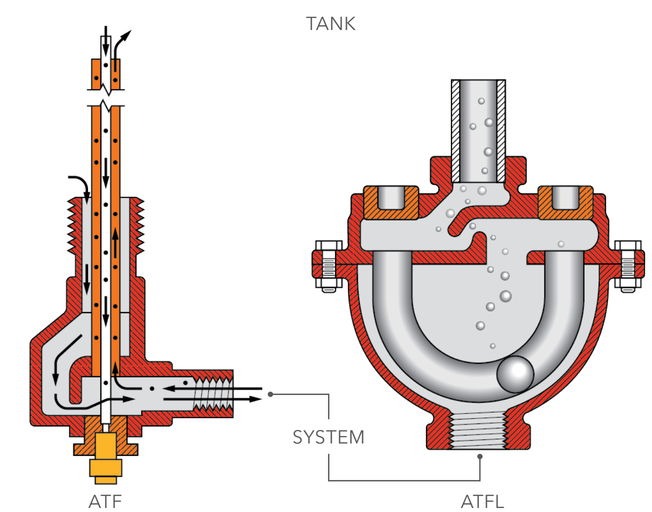


Tank Fitting	Tank Fitting Size	Total Length of Horizontal Pipe			
		≤ 7 ft (2 M)	≤ 20 ft (6 M)	≤ 40 ft (12 M)	≤ 100 ft (30 M)
		Pipe Size NPS (DN)			
ATF	3/4 inch (20 mm)	3/4 inch (20 mm)	1 inch (25 mm)	1.25 inch (32 mm)	1.5 inch (40 mm)
ATFL	1 inch (25 mm)	1 inch (25 mm)	1.25 inch (32 mm)	1.5 inch (40 mm)	2 inch (50 mm)

Since the piping to compression tanks should be no smaller than ¾ inch (20 mm), and at times even larger in diameter, a relatively large, direct pipe connection exists between the system and the tank. Water that has released air from solution, because of a change in pressure or temperature at some point in the system, will attempt to absorb free air, if the pressure or temperature changes put it in a state of less than saturation. Free air should be confined in the compression tank. Air leaving the tank, and the water going into the tank, will set up gravity circulation between the system and tank. This will cause the water temperature in the tank to approach that of the system water, and as a result, will increase the required compression tank size.

Free passage of air rising into the compression tank, while restricting gravity circulation between the tank and the system, is required. A B&G Airtrol Tank Fitting allows air to pass freely, but restricts the circulation of water between the tank and the system, reducing tank water temperature. As a result, the required tank size is smaller. The fitting selected depends upon the tank diameter (Ref. Figure EE).

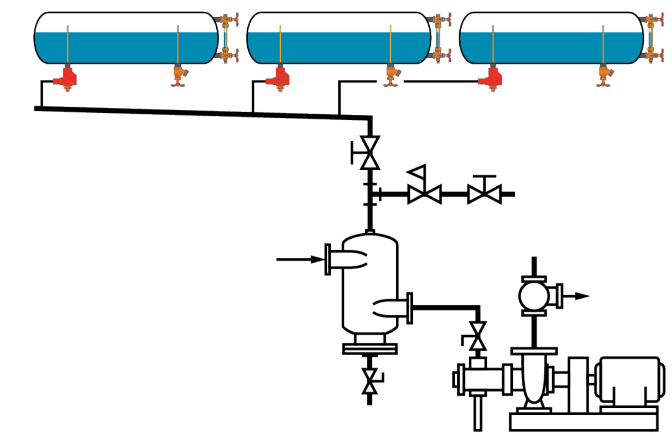
Figure EE – Airtrol Tank Fitting to Prevent Gravity Circulation



While it is impossible to prevent entirely the reabsorption of air from a compression tank, the Airtrol Tank Fittings are helpful in reducing circulation of water between the tank and the system. In addition, these fittings offer the ability to establish the initial water level in the compression tank when filling the system for the first time, as too much air can be trapped in the tank. A manual air vent is furnished, integral in the ATF model, separate in the ATFL design, consisting of a small diameter tube which extends up into the tank. The ATF models are selected for the tank diameter up to 80 gallons, and the vent tube length is pre-cut to the proper length for setting the initial ratio of water and air. The vent tube for the ATFL model, used on compression tanks 100 gallons (379 liters) and larger, must be cut to a length equal to two-thirds (⅔) the tank diameter. While filling the system, this vent tube is open, allowing excess air to escape. When the water level reaches the top of this tube, the vent should be closed. A liquid level gauge glass assembly should be installed on the compression tank to provide visual verification the correct water level has been established.

At times, installation of a single compression tank is impractical, and two or more tanks, with a total volume sufficient for the application, must be utilized. This may be the result of a low ceiling, limited opening size to access installation location, or a desire to use readily available stocked sizes. Figure FF lists the proper pipe size for the manifold as a function of the number of tanks to be used. All tanks should be installed with the top of the tanks at the same elevation.

Figure FF – Multiple Compression Tank Manifold Header Size



Tank Fitting	Tank Fitting Size	Manifold Header Size for Multiple Compression Tanks		
		Two Tanks	≤ 4 Tanks	≥ 5 Tanks
		Pipe Size NPS (DN)		
ATF	3/4 inch (20 mm)	1 inch (25 mm)	1.25 inch (32 mm)	1.5 inch (40mm)
ATFL	1 inch (25 mm)	1.25 inch (32 mm)	1.5 inch (40 mm)	2 inch (50 mm)

SYSTEM CLEANING, STARTUP AND INITIAL FILL PROCEDURE

System Cleaning
If a piping system could be installed in perfectly clean surroundings, using component parts that were also completely clean and free of all foreign material, it probably could be filled with water from the average city supply, started and operated satisfactorily ever after. However, this type of cleanliness in the assembly of a piping system is virtually impossible. The coatings normally used as rust preventive on pipe, the cutting oils used in threading pipe, the chips that result, the flux used in sweating copper fittings, sand, dirt of all types, etc. are all typical of the foreign matter commonly found in a newly completed piping system.

Consequently, every piping system should be thoroughly cleaned and flushed before startup. Various commercial cleaning compounds are available for this purpose. It is recommended that special flush pumps be used to circulate the fluid for several hours. After draining and flushing the system with fresh water, remove and clean any strainers, then refill the system with fresh water. To aid in speeding up the flushing operation, purge valves might be used.

System water should be maintained slightly on the alkaline side (pH above 7 but below 9). Once started in this manner, a properly designed system installed correctly, with a properly sized air management tank, will remain in operating condition indefinitely.

It is easy to see how a clean hydronic system is a necessity for efficient operation, circulation, and long life. In areas where water supplies are apt to be somewhat corrosive initially, even a thoroughly cleaned and flushed system, may need chemical treatment to raise the pH level into the 7 to 9 range. Obviously, any additive to a system, that is intended to give many years of trouble-free operation, must be selected with great care. Chemicals that aid in protection of some components may adversely affect others. These chemicals must be avoided. Silicates, borax based compounds, and various leak sealers are typical chemicals that are detrimental to certain parts of a circulating water system. Chemicals such as these destroy the sealing ability of the pump mechanical seals, valve glands, etc. due to erosion. When a chemical additive is required, it should be selected on the basis of its effect on the entire system.

One of the reasons tightly closed hydronic systems rarely require an additive to establish the desired pH level is that when a cleaning compound is used initially, some small amount adheres to the piping after the system is drained. This is usually enough alkaline material to raise the pH level to within the 7 to 9 range when the system is refilled. Open systems, however, continually exposed to the atmosphere, with fresh water being frequently added, usually require some form of chemical additive.

Start-Up

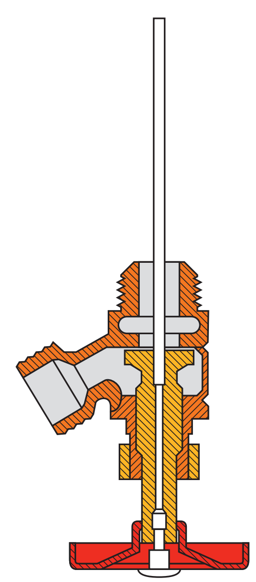
A properly designed and installed system, that is pressure tight, and thoroughly cleaned and flushed, is easily put into service. The system should be filled and the air managed properly. If the Air Control method is to be used, all excess air must be vented, or purged, and the proper ratio of water to air established in the compression tank. When using the Air Elimination method, all air must be vented or purged from the system continuously, as it has no active role in setting the cold static fill pre-charge pressure in the bladder or diaphragm type expansion tanks.

The type of piping system determines the method of initial air removal. Monoflo and two, three, or four pipe systems require an air vent on each piece of radiation. A series loop, or radiant panel (infloor or above floor) piping system, must be purged to eliminate the excess air after the initial fill.

Adequate pressurization at the top of the system is required. For best results the system should be circulated at full flow and full pump speed without the boiler firing for several hours. This will scavenge air bubbles that adhere to the surface of piping and system components. A final venting or purging at high points should then be repeated.

The initial air level in the compression tank should be established in accordance with the installation instructions. The Bell & Gossett Airtrol Tank Fitting is furnished with a manual vent tube to help set the proper initial water level in the compression tank. As mentioned previously, the ATF models are selected for the tank diameter and the vent tube is the proper length for setting the initial ratio of water and air. The ATFL model, used on a compression tank 100 gallons (379 Liters) or larger, has a separate vent which must be cut to the proper length for the tank diameter. Figure GG shows the DT-2 Drain-O-Tank fitting with integral air vent. When used in conjunction with an ATF model, it is provided separately, and is pre-cut to required length. When a larger ATFL model is required, the DT-2, with uncut copper tube, is included. Field verification of tank diameter is required, and then copper tube is cut to a length equal to two-thirds (⅔) the tank diameter.

Figure GG – Drain-O Tank Valve with Air Vent



Often, particularly on low static head buildings, too much air will be trapped in the compression tank when filling the system. The vent tube permits this excess air to escape and the proper water level to be established. The proper cold fill water level for a 12 psi (83 kPa) system is approximately two-thirds (⅔) of the compression tank diameter. Then, as the system is heated, additional air is released from solution, separated by the air separator, and directed to the compression tank. After the system's water has been de-aerated by heating, the Airtrol vent should not be opened unless, for some reason, the system must be drained.

To de-aerate the system water initially, apply heat before circulation is started, raising the temperature to 220°F (104°C), or within 10°F (-12°C) of the maximum water temperature the boiler is designed to produce without tripping the manual high limit setting. By starting the system pump when this temperature is reached, the water entering the system will be easily de-aerated. This procedure will quickly de-aerate most systems, but it is always recommended to verify all components in the system are rated accordingly. At a minimum, the water should be heated to the system design temperature. For chilled water systems not equipped with a heat source, thorough initial venting at the high points, and circulation at room temperature for a minimum of 12 hours, at full design flow, is recommended.

Initial Fill Procedure

Normally, a closed system need be filled only once. For some systems this can be a tedious, time consuming task, particularly on large, long circuited systems. However, the designer can simplify the problem considerably by incorporating a few simple design techniques in the initial plan.

Comment has been made previously that automatic air vents should not be used on Air Control Systems unless they can be shut off after the initial fill. Instead, manual air vents at the main high points are recommended. Automatic air vents are required in the Air Elimination System, since any free air must be vented to the atmosphere.

By selecting the system piping to maintain a minimum velocity of 2 ft/sec (0.6 m/sec), at full flow design flow, free air bubbles will be entrained by the water flow, and carried back to the separating point, where they can be directed to the compression tank, or vented, depending upon the air management system in use.

Purging may be another way to remove air from a system after the initial fill. Purging uses higher water pressure to force, or chase, free air from a piping circuit through an open drain. Often a system can be designed so that no manual air vents are required. Instead, purging can be used to free a system of most of the air trapped after the initial fill. A precaution, however, should be observed if purging is to be used. Often when a pressure reducing valve is used, the rate of fill possible is not adequate to produce the volume of water flow needed for large piping circuits. A manual bypass around the pressure reducing valve would provide the flow and pressure required for purging. Exercise caution when using higher water pressures, to ensure that the working pressures of all system components are not exceeded.

Filling a closed piping system with water and maintaining the correct water volume is normally a simple procedure. An automatic fill valve can be set to limit the system pressure during a fill cycle while the technician performs any necessary venting. Once the system is filled however, it is recommended that the water supply to the valve be shut off. Uncontrolled firing and overheating of the heat generator components may occur in a system that develops leaks or doesn't include a properly installed and operating air management system to compensate for thermal expansion. It's recommended to install a low water cutoff and/or alarm in the system to alert the operator to add makeup water when required. Manual fill by direct connection to the city water supply can be made using a positive shut-off type valve. When pressure reducing valves in hydronic systems are tied into the city water supply, typically back flow prevention is required. If city water pressure is lost, a device is required to prevent hydronic heat transfer fluid from entering the cities fresh water supply. Consult local codes for back flow prevention requirements.

Where adequate city water pressure is not available or to completely isolate a system from the main water supply system, filling may be done by means of an electrically driven pump, make-up unit or even a simple hand operated hydraulic pump.

If the designer is using an aqueous glycol solution, consideration must be given to proper initial filling procedures as well as supplying future make-up fluid. Extra caution should be taken when purging using glycol since many municipalities prohibit draining the solution into their system. Adding only water to a glycol solution system will dilute the concentration and change the physical properties of the fluid that were initially intended. Glycol make-up units are designed to store the correct concentration of an aqueous glycol solution while maintaining minimum cold fill pressure requirements. A Pressure Reducing Valve, whether integral to the package, or installed separately in the discharge piping, is used to set the desired system fill pressure. Figure HH shows a typical glycol make-up unit.

Figure HH – Glycol Make-Up Unit

The pressure created by the circulating pump affects system pressure at all points except one, the point of no pressure change. The point of no pressure change is where the air management tank connects to the system. In order to provide the necessary minimum initial pressure at the top of the system, the only point in a system where pump operation will not give an erroneous pressure indication on filling is at the point of no pressure change. Therefore, the best location to make the fill connection is to the line connecting the tank to the system. The fill connection at this point also serves to direct any free air entering with fresh water make-up into the compression tank or air elimination equipment without first entering the system. In the case of an Air Elimination System, any free air entering with make-up water has ready access to an automatic air vent. Cold water fill at any other point in the system, will be affected by the pump head at the point of entry. Dependent on the system pump, this can be an important consideration, often making fill impossible or undesirable while the pump is in operation.

SELECTING A PRE-CHARGED TANK TO REPLACE AN EXISTING COMPRESSION TANK

At times, it becomes necessary to replace an existing compression type tank, and the only tank sizing information available is the size of the existing tank itself. If the replacement tank will be a compression type tank, then most likely the same size would be selected. However, what if a more modern pre-charged type tank is preferred?

The first order of business is to make sure the existing tank performed properly. If it did, it can be assumed that it was correctly sized for the application. Next, confirm there will be no system modifications, such as additional piping and equipment, a change in fluid type, operating temperatures or pressures, made in conjunction with the tank replacement. Once these possibilities have been eliminated, sizing a replacement tank will be straightforward.

As shown earlier in this technical manual, sizing a compression type tank requires satisfying Equation (3) only. However, sizing a pre-charge tank involves additional considerations, and therefore Equation (3) must be modified, resulting in Equations (4), (5), and (6) also found in this manual, to size the pre-charge tank. Since the NET expansion of fluid volume remains the same regardless of tank type, to select a pre-charge tank when only knowing the existing compression tank size, we can reduce all equations to:

(8)

$$V_t \text{ (Pre-Charged)} = V_t \text{ (Compression)} * (P_a/P_f)$$

The relationship of pre-charge and compression tank sizes then depends only on the ratio of the absolute fill pressure (P_f) and the atmospheric pressure (P_a). A pre-charge type tank is available in two basic designs: Diaphragm and Bladder. Additionally, these tanks are characterized as "Full Acceptance" and "Partial Acceptance", which describes the amount of fluid volume that can be stored relative to the tank size in gallons (liters). If a "Full Acceptance" Bladder tank will be used, the storage volume will be equal to the actual tank size and therefore solving Equation (8) will be all that is necessary to size it.

If a "Partial Acceptance" Bladder tank or a Diaphragm tank will be used, only a portion of tank size will be available for storage, and thus the actual NET expansion of fluid volume for the system must be known. The existing compression tank was sized with this information, so if we go back to Equation (3) with the pressures involved, we can determine the amount of expansion in the application.

Example:

A compression type tank in Denver, Colorado needs to be replaced. The owner has decided the replacement tank will be a pre-charged type, and only knows that the existing tank operated fine with a system fluid of water at a fill pressure (P_f) of 12 psi (83 kPa), final tank pressure (P_o) of 30 psi (207 kPa), and that the physical size of the tank is 36 in. (0.9 m) diameter and 93 in. (2.4 m) long, which is a 400 gallon (1,514 Liters) capacity. There will be no changes to the existing system. The pressure in the tank before any water enters (P_a) is 12.2 psia (84 kPa) in Denver.

Using Equation (8):

V_t (Pre-Charged) = 400 Gal (1,514 Liters) * [12.2 psia (84 kPa) / (12.2 psia (84 kPa) + 12 psi (83 kPa))]

V_t (Pre-Charged) = 400 Gal (1,514 Liters) * 0.504 psia (0.504 kPa)

V_t (Pre-Charged) = 201.6 Gal (763.1 Liters)

To select a "Partial Acceptance" Bladder or Diaphragm type pre-charged tank, Equation (3) is solved for the system fluid expansion volume the tank must be capable of storing.

Using Equation (3):

$(E_w - E_p)\, V_s = V_t * [(P_a/P_f) - (P_a/P_o)]$

$(E_w - E_p)\, V_s$ = 400 Gal (1,514 Liters) * [(12.2 psia (84 kPa) / (12.2 psia (84 kPa) + 12 psi (83 kPa))] - (12.2 psia (84 kPa) / 12.2 psia (84 kPa) + 30 psi (207 kPa))]

$(E_w - E_p)\, V_s$ = 400 Gal (1,514 Liters) * [0.504 psia (0.504 kPa) - 0.289 psia (0.289 kPa)]

$(E_w - E_p)\, V_s$ = 400 Gal (1,514 Liters) * 0.215

$(E_w - E_p)\, V_s$ = 86 Gal (326 Liters)

The pre-charged tank to be selected can be either a "Full" or "Partial" Acceptance design with a minimum tank volume of 201.6 gallons (763.1 Liters) and a minimum acceptance volume of 86 gallons (326 Liters). When substituting a pre-charged type tank for an existing compression type tank, remember this also changes the type of air management system from Air Control to Air Elimination, and therefore some minor piping changes will be required as shown in either Figure B, Y, or Z of this technical manual. The changes will be dependent on the choice of tank and available installation space where the tank will be located.

SUMMARY AND KEY REMINDERS

Reliability, efficiency, and quiet operation are often considered the most important needs in a hydronic heating or cooling system. Properly designed, sized, and installed air management components will always be a major influence on the successful outcome to meet those requirements. This manual has given the reader a large quantity of facts, figures, and formulas, arranged to outline the recommended air management system design steps. Below are some key highlights, and a few field tips to remember:

Air Separation

- Most efficient at the point of highest fluid temperature and lowest system pressure
- When both conditions cannot be met at the same point in a system, locating the Air Separator at area of highest temperature is preferred.

System Pressurization

- Cold Static Fill Pressure is required for:
  - Ensuring system fluid fills the entire piping system to its highest elevation, and provides a minimum 4 psi (28 kPa) of additional pressure at the system top, for systems operating at 210°F (99°C) or lower.
  - Proper selection and field adjustment of set point on a Pressure Reducing Valve (PRV) or Glycol Make-up Package. Set point will be job specific.
  - Reference to assess minimum required safety relief valve set point.
- The system Pressure Range is defined by the minimum cold static fill pressure, and maximum allowable pressure increase at the air management tank inlet.

- The greater the pressure range, the smaller the required tank size.
- Safety relief valve set point must not exceed maximum allowable working pressure of any system component.
- The Total Net Expansion of a Fluid is a function of the type of fluid and pipe***** used, total volume within the system (*including any buffer tanks*) and largest expected temperature increase amongst filling, operating and static conditions.

***NOTE:** PVC and HDPE pipe will expand at a faster rate than water and most glycol solutions. Please consult your local Bell & Gossett Representative for assistance with proper air management tank sizing and selection.

- The "Point of No Pressure Change" is established where the air management tank connects to the system main piping.
  - This is the point where the pump cannot change the system pressure.
  - Maintain lowest possible pressure drop in piping between pump suction and the Point of No Pressure Change.

Pre-Charged Type Tank (Air Elimination System)

- Tank volume should be selected to meet both the acceptance volume and the total tank volumes required.
- System fluid and air separated by flexible membrane.
- Can use manual and automatic air vents.
- Pre-charge is job specific and equals the cold static fill pressure at the tank inlet.
- The tank charge must be checked periodically, with no system fluid in the tank.

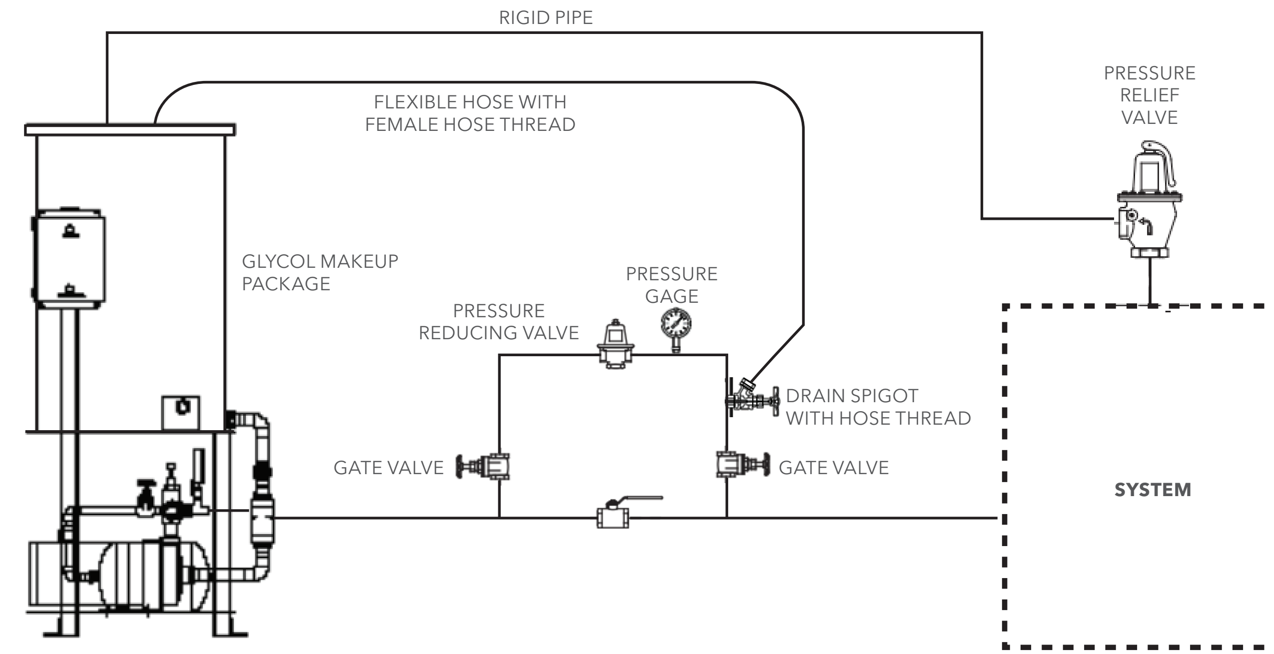
Compression Type Tank (Air Control System)

- System fluid and air in direct contact.
- Use manual air vents only.
- Proper air management tank fittings are required.
- Liquid level gauge glass assembly recommended.
- Compression tank must be located above, and should be connected to, the air separator.

Field Tips

- Size pipes to maintain a minimum fluid velocity of 2 ft/sec (0.6m/sec) to keep free air entrained and prevent formation of air pockets in system piping or terminal units.
- When using a Rolairtrol type air separator, the higher system connection port must be the inlet.
- For Pre-Charged tanks, consult manufacturer's literature prior to pressure adjustments, for maximum pre-charge pressure limit conditions and any special charging instructions.
- Check manufacturer's literature on all air management system components for required minimum service clearances (i.e. Strainer or Bladder removal) and proper installation procedures.
- If a replaceable bladder tank will be installed horizontally, be sure to have the system connection oriented at the bottom (6 o'clock) position.
- If a safety relief valve is discharging unexpectedly, possible causes are:
  - Dirt trapped in valve seat
  - Flooded air management tank
  - Undersized air management tank
  - Pre-charge in tank set incorrectly (*too high or too low*)
  - System operating temperature higher than expected
  - System operating pressure higher than expected
- When using a Glycol Make-up package, install a drain fitting with hose-bibb end in the discharge piping, prior to the package system isolation valve. This will provide a means to send glycol back into the reservoir during the startup calibration procedure. Ref. Figure II.

Figure II - Glycol Make-Up Piping



Air Control System Problems		
Complaint	**Possible Cause**	**Recommended Option**
Waterlogged Compression Tank	Gravity Circulation between system and tank	Install or Replace proper Airtrol Tank Fittings
	Leak in tank shell or welds	Check with soap solution - Replace components as required
	Leak/Crack in gauge glass tube	
	Leak/Dry Rot of gauge glass tube gasket (Usually Top)	
	Open or leaking Manual Air Vents in system piping	Close vent isolation valve or replace defective vent(s)
	Use of Automatic Air Vents in system piping	Remove and replace with manual air vents
		Close all vent isolation valves
	Leaks in system pipe joints or equipment coils	Repair all pipe and coil leaks
	Multiple tanks connected to system at different locations	Join tanks to properly sized and pitched common manifold
		Connect to Air Separator, which should be located close to pump suction
	Multiple air bound terminal units in the system	Bleed air from terminal units, check system Cold Static Fill Pressure
		Adjust Cold Fill to provide a minimum of 4 PSI at high point in system (210°F or less)
Waterlogged Pre-Charge Tank	Improper Pre-Charge air pressure setting	Isolate/Drain the tank of all fluid. Correct pre-charge pressure for site conditions
	Leak in diaphragm or bladder membrane	Consult IOM. Replace bladder when possible, otherwise replace entire tank
	Leak in tank shell or welds	Check with soap solution - Replace components as required
	Leak in tank drain plug area	
	Air migration through diaphragm or bladder membrane	1-2 PSI pressure loss per year is possible under normal operation
		Correct pre-charge pressure as needed for site conditions
	System allowable pressure rise less than design	Confirm actual system operating data, perform sizing calculations
	Undersized tank	Replace, or add extra tank, to meet acceptance and tank volume requirements
	Multiple tanks connected to system at different locations	Join tanks to properly sized common manifold, connect at suction side of pump

Air Control System Problems		
Complaint	**Possible Cause**	**Recommended Option**
Waterlogged Pre-Charge Tank (cont'd)	Multiple air bound terminal units in the system	Bleed air from terminal units, check system Cold Static Fill Pressure
		Adjust Cold Fill to provide a minimum of 4 PSI at high point in system (210°F or less)
Safety Relief Valve Discharge	Defective Safety Relief Valve	Replace
	Compression or Pre-Charge Tank Undersized	Confirm actual system operating data, perform sizing calculations
		Replace, or add extra tank, to meet acceptance and tank volume requirements
	Waterlogged Compression or Pre-Charge Tank	See prior Complaint for each, assess and implement corrective action
	Boiler or Heat Exchanger high discharge temperature	Check controls and high limit settings
	System operating pressure too high	Check cold static fill pressure and system operating temperature
		Check pressure reducing makeup valve setpoint
	Safety Relief Valve located close to pump discharge	Check Relief Valve setpoint against cold static fill pressure plus pump differential pressure.
		Relocate Relief Valve to pump suction piping
	Defective pressure reducing makeup valve	Clean or replace
	Pressure reducing makeup valve bypass valve leaking	Close or replace leaking valve
	Dirt or debris in valve seat	Lift "test" handle briefly to discharge dirt. If problem continues, replace valve
Pressure Reducing Makeup Valve Failures	Valve does not feed	Check if valve strainer has scaled. Clean or replace
		Check if valve adjustment screw scaled. Turn all the way down to free, or replace
		Check if setpoint is lower than actual system cold static pressure
	Valve does not reduce pressure	Municipal pressure is too high for valve. Check adjustment range and replace
		If so piped, insure bypass valve is closed
	Safety Relief Valve Discharge with Heat Source off	Reducing valve stuck open, see above for corrective action. Replace if needed

Xylem |'zīləm|

1) The tissue in plants that brings water upward from the roots;
2) a leading global water technology company.

We're a global team unified in a common purpose: creating advanced technology solutions to the world's water challenges. Developing new technologies that will improve the way water is used, conserved, and re-used in the future is central to our work. Our products and services move, treat, analyze, monitor and return water to the environment, in public utility, industrial, residential and commercial building services, and agricultural settings. With its October 2016 acquisition of Sensus, Xylem added smart metering, network technologies and advanced data analytics for water, gas and electric utilities to its portfolio of solutions. In more than 150 countries, we have strong, long-standing relationships with customers who know us for our powerful combination of leading product brands and applications expertise with a strong focus on developing comprehensive, sustainable solutions.

For more information on how Xylem can help you, go to www.xylem.com

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