Provisions for Expansion and Contraction in Plastic Pressure Piping Systems

Published by the
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Scope

This PPFA User Bulletin provides information for users to understand the basics of thermal expansion and contraction in pressurized plastic piping systems that are nominal size 4 inches or less and installed above ground.

Introduction

Plastic pressure piping systems expand and contract with temperature changes more than metallic piping systems. Plastic systems are, however, less rigid than metal systems and in most cases can absorb repeated flexing. In fact, plastic pipe will develop less force than metal pipe when exposed to a temperature change.

Thermal expansion is generally not an issue in single family or low-rise residential construction. Special provisions, however, may be required in some cases involving extreme temperature ranges, high-rise applications, long, straight pipe runs, or in installations where pipe is restrained.

Important issues to consider include making the calculations for thermal expansion where you have long piping runs and layouts to compensate for expansion and contraction. Users should also consider referencing the ASPE Plumbing Components and Equipment Volume 4, Chapter 11, Thermal Expansion, other PPFA installation and design guides for specific materials as well as manufacturer instructions.

Temperature Ranges

Plumbing systems can be exposed to temperatures below freezing to over 100°F during installation, or when a building is left unconditioned for extended periods. Some installations, such as hot-water distribution systems, may be subjected to continually changing temperatures. Installations in attics, manufacturing facilities, or chemical plants can also be exposed to higher temperatures.

While there is a tendency to focus on expansion due to an increase in temperature, it is equally important to consider contraction due to a temperature decrease. This contraction can cause pulling forces on connections between the pipe and fitting, which could cause a pipe pull-out or joint failure.

Construction Codes

Installation shall be done in accordance with all applicable construction codes and the manufacturer's instructions.

Comparative Example of Thermal Expansion and Contraction

As an example representative of plastic piping compared with steel piping, the coefficient of linear expansion for polyethylene is about 9 to 12 x 10-5 in./in./ºF compared to steel at about 1 x 10-5. The typical method to determine this value is described in ASTM D696, Standard Test Method for Coefficient of Linear Expansion of Plastics. This means that an unconstrained polyethylene pipe will expand or contract at least ten times the distance of steel pipe of the same length. The main concern to the piping engineer is the amount of internal stress generated during expansion and contraction movements. For constrained polyethylene pipe, the stresses developed due to this movement are substantially lower than that of a steel line. This is due to the lower modulus of elasticity of polyethylene as compared to steel. Plastic pipe that is properly anchored should not be adversely affected by normal expansion or contraction.

The equation to calculate expansion or contraction is:

$$\Delta L = \alpha * L * \Delta T$$

Where:

ΔL = Change in length

L = Original length

ΔT = Change in temperatureα

α= Coefficient of linear expansion

A 10ºF rise or fall in temperature will cause a 100-foot length of an unconstrained polyethylene pipe to move 1.0 to 1.2 inches. The same length of steel pipe will move about 0.10 inch but will generate larger internal stresses than the polyethylene pipe.

Expansion Coefficients

This table lists the "free body" coefficient of thermal expansion, and other physical factors, for commonly used piping materials and the theoretical stress in a restrained pipe with a 70-degree temperature change.

FACTORS FOR COMMON PIPING MATERIALS

• Piping Material	• Coefficient of Thermal Expansion (ASTM D696) in/in x degree F (a)	• Increase inches per 10 degrees F for 100 feet of pipe	• Young's Modulus of Elasticity (E) lbf/in² (psi)	• Stress (psi) delta +70 oF (S)
• ABS	• 5.2 to 6 x 10-5	• 0.62 to 0.72	• 0.30 x 106	• 1,092-1,260
• CPVC	• 3.4 x 10-5	• 0.41	• 0.42 x 106	• 1,000
• HPDE	• 9.0 to 12.0 x 10-5	• 1.10 – 1.47	• 0.12 x 106	• 756-1,008
• PERT	• 9.0 to 12.0 x 10-5	• 1.10 – 1.47	• 0.12 x 106	• 756-1,008
• PEX	• 9.5 x 10-5	• 1.20	• 0.13 x 106	• 865
• PP	• 4.3 x 10-5	• 0.50	• 0.17 x 106	• 512
• PVC	• 3.5 x 10-5	• 0.42	• 0.42 x 106	• 1,029
• PVDF	• 7.8 x 10-5	• 0.93	• 0.21 x 106	• 1,147
• Steel	• 6.7 x 10-6	• 0.08	• 30.0 x 106	• 14,070

Abbreviations for plastics: ABS - acrylonitrile-butadiene-styrene; CPVC – chlorinated polyvinyl chloride; HDPE – polyethylene, high density; PERT – Polyethylene raised temperature; PEX - crosslinked polyethylene; PP – Polypropylene; PVC - polyvinyl chloride; PP - polypropylene; PVDF - polyvinylidine difluoride

Expansion/Contraction of Piping

For any selected temperature range the theoretical expansion or contraction can be readily calculated using the proper coefficient of expansion.

Installed piping, however, hardly ever attains the theoretical "free body" condition because all surface contact would have to be free of friction and there could be no end or branch connections. In addition, while installed pressure piping can be expected to reach temperature equilibrium, this takes time and will most likely stabilize near the middle of the temperature range rather than at the extremes produced under the condition of continual flow of hot or cold fluids. Therefore the selection of a "temperature range" and the recognition of the normal amount of restraint that results as part of every installation is the challenge in this process.

A design using the "free body" coefficient and the extremes of the fluid temperature will be conservative and is recommended unless there are space limitations that require minimizing the size of offsets or expansion loops.

Double Containment Piping

For double containment piping systems (pipe in pipe) you have to consider both the primary and secondary materials when dealing with expansion/contraction. The manufacturer of these systems should be consulted for more information.

When Provisions may Not be Required

Consideration for thermal expansion or contraction may not be required where only short runs of piping exist, or piping systems that will not encounter significant temperature changes. Flexible piping systems, such as PEX, PE-RT, and PE in nominal sizes 1 and smaller typically do not need any special allowance for expansion and contraction as long as you allow 1/8 inch per foot of movement when installing. This extra length will be sufficient to allow for the contraction that will occur when the pipe cools to some temperature less than the installation temperature. For plastic pipe that is flexible, any expansion that occurs when the pipe is warmed to a temperature above the installation temperature is typically compensated for with a slight additional amount of sag between supports.

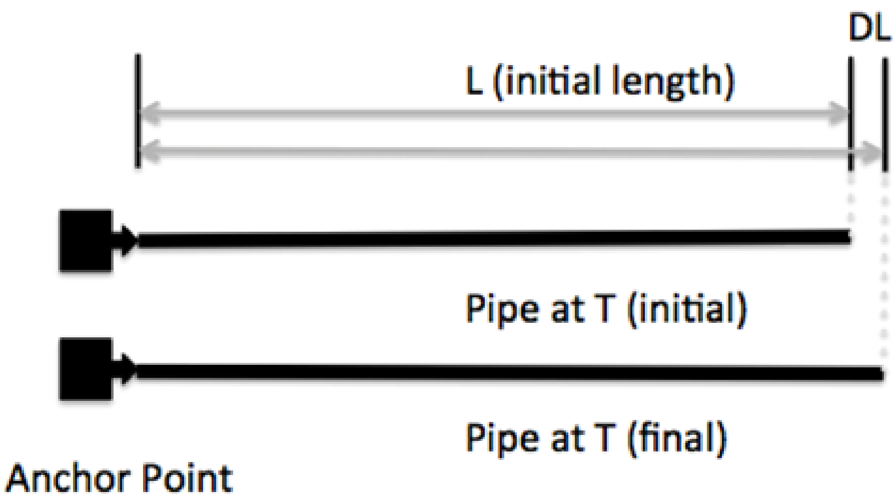
Providing for Expansion/Contraction

Where required, compensation for thermal expansion in a piping system must be addressed by the engineer of record or qualified installing contractor. Compensation for thermal expansion may be accomplished by the installation of offsets, changes in direction, loops, and expansion joints, or in some circumstances by properly restraining the system.

A pipe anchored at one end can freely expand in the axial direction if increase in temperature occurs. A decrease in temperature would cause the pipe to contract. The following equation calculates the expansion/contraction of a fully unrestrained pipe that occurs due to a given change in temperature:

DL = a * L* DT

Where:
DL = change in pipe length
L = initial pipe length, in
DṬchange in pipe temperature in °F
a = coefficient of linear expansion/contraction, in/in °F



Thermal Expansion of Pipe

Note that the larger coefficients of thermal expansion/contraction for plastic results in a larger change in length for the same temperature change for metallic piping. One hundred feet of PVC with a temperature increase of 50 feet could therefore be:

DL = 3 x 10-5 in/in/°F * 100 feet *12 inch/foot * 50 °F = 1.8 inches

The measured change in pipe length due to a change in temperature may be somewhat less than determined by this equation, as installed pipe experiences some resistance to movement in the axial direction due to friction. Such restraint may be relatively minor, such as the small frictional drag of pipe guides and supports; or major, as when a pipe is continuously constrained by embedment.

While rare, it is possible for the combined thrust due to thermal expansion to approach the axial strength of a plastic pipe. Some pipe joints have relatively low resistance to pipe pullout; and some piping components, such as plastic pipe flanges, may have a relatively low strength in the axial direction. If the total anticipated axial thrust is too high for a pipe joint or a piping component, then it must either be controlled or engineered to an appropriate value by adding additional flexibility into the piping layout so as to transform any potentially excessive thrust into a more tolerable bending force; or by isolating all vulnerable piping components from excessive axial thrust by means of properly placed anchors or other devices.

Joints of plastic piping made by a heat fusion process are characterized by high axial strength – properly made, they can be as strong as the pipe. Heat-fusion and solvent cement welded connections using the bell-spigot (or, socket-spigot) design are similarly strong in nominal pipe sizes up to NPS 4. In the larger diameters, where socket depth tends to decrease with increasing pipe diameter, the user should contact the pipe or fitting supplier to determine axial thrust limitations.

The thrust tolerance, or joint strength of mechanical fittings can vary widely depending on fitting design. Certain mechanical fittings have been designed to offer axial strength that is equal to or greater than that offered by the plastic pipe for which they are intended. Other connectors, like many of the rubber-gasket bell and spigot joints, are designed primarily for pressure sealing and less so for holding the pipe within the joint. Consequently, such fittings are almost always used in under-ground installations in which the piping can readily be restrained against excessive axial and lateral movement.

Mechanical fittings intended for use in aboveground systems, such as for flexible plastics piping, are generally designed to withstand the total anticipated axial thrusts that can result from internal pressure and other causes. Because of the wide array of designs of mechanical fittings, however, it is the responsibility of the specifier and installer to make sure that the axial, or the pullout strength, of a mechanical fitting is adequate for the intended application and service conditions.

Above ground piping systems are often designed to include a number of changes in direction. In such systems thermal pipe expansion/contraction induces bending stresses that need to be limited so as not to risk a structural damage to a piping component. A layout that produces excessive localized bending stresses should be avoided. Piping runs should be designed as to reduce the possibility of developing excessive bending stresses, particularly in fittings that may have a significantly lower tolerance to bending forces than does pipe.

There is a beneficial aspect of changes in direction in a piping system. Directional changes create a spring-like effect in flexible piping that can be used to safely absorb the thermal expansion or contraction that occurs when a long piping run is subjected to thermal expansion.

Above ground piping undergoes more temperature changes and thermal expansion than underground piping because of atmospheric temperature changes, potential exposure to sunlight, and the greater temperature variations of the fluids being conveyed.

Two examples of systems with significant temperature changes include hot- and cold-water service pipes that carry hot water intermittently with cold water in between, and chemical transfer lines through which a hot fluid may flow intermittently. However, in many such applications the effect of such wide swings in temperature are often satisfactorily offset because in most such installations the piping consists of relatively short runs – generally, under 20 feet in length – with changes in direction which endow the system with a natural flexibility. Typically, in such cases, no special precautions are required in the piping runs to offset minor expansion or contraction reactions. However, where this flexibility is employed the pipe extra length should not be constrained by placing an elbow or other bend too closely to a wall or similar object. Excepting at points at which the pipe is deliberately anchored, pipe must be free to move in guides and hangers.

Care should always be taken to ensure that the pipe layout, including the placement of anchors1 and guides2 adequately isolates joints, fittings or connections from high tensile thrust or bending forces. As previously discussed, certain compression joints may have relatively low pullout resistance.

Some piping components such as fabricated fittings, saddles and flanges may have very significantly lower axial and bending strength then the pipe. Care should be taken to properly isolate these fittings against excessive pullout and bending stresses.

In situations where the piping makes relatively long runs or where it may be exposed to large temperature swings the higher resultant expansion or contraction will usually have to be absorbed by additional means. When the piping is dark colored – as in the case of black PE piping which has been made sun-light resistant by the addition of finely divided carbon black particles – direct exposure to the sun may result in pipe surface temperatures as high as 140°F, which in some locations may also drop to subzero values at nighttime. In such cases, the larger potential expansion/contraction can be safely absorbed by built-in added flexibility, and some times by the use of expansion joints.

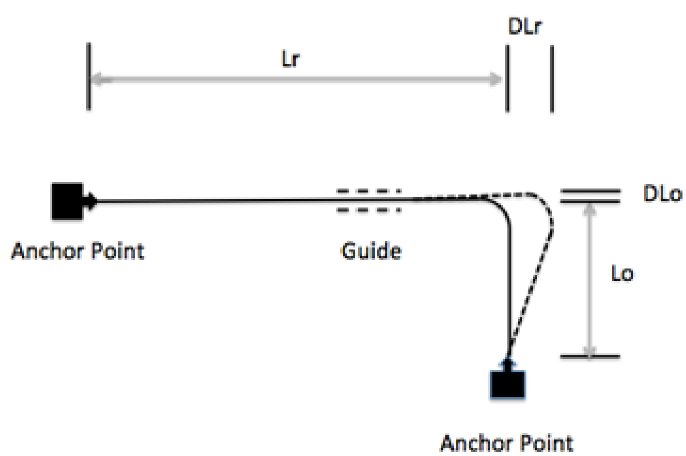
Two kinds of expansion joints have been used with plastics: the packless kind, which consists of a bellows design wherein the bellows are made from a fatigue resistant material; and a slip-joint type that is kept leak-tight by the use of a packing that can consist of a rubber gasket or other appropriately chemically resistant material.

Mechanical Expansion Joints, both packless (bellows) and packed (slip-joint) types, require special considerations. Follow the manufacturer's recommendations.

Excepting for some low-pressure or pressureless applications, such as for drain, waste and vent piping, expansion joints are not often used. When subjected to a compressive thrust plastic pipe, because of its relatively lower stiffness as compared to metal pipe, tends to deflect laterally rather than generate the reactive thrust necessary to close the expansion joint. In the case of the slip-joint kind of expansion joint, it is difficult to achieve a design that allows return at a low axial compressive thrust while simultaneously providing a seal that remains tight under a broad range of operating temperatures and pressures. In pressure service expansion joints readily expand, but do not always fully return, which causes further pipe deflection. Furthermore, because expansion joints do not transmit thrust they need to be used with carefully located thrust absorbing pipe anchors, a requirement that may tend to complicate piping layout and supporting structure design. Expansion joints, however, are the preferred solution for certain situations such as when it may not be as practical to configure added flexibility into a piping system. Expansion joints are commercially available, principally for PVC and CPVC, in up to about nominal size 12.

The more common solution for the absorbing of thermal expansion or contraction in plastic pipelines is to build-in flexibility. There are two ways this may be done: the first is by the addition of offsets or expansion loops; and the second is by allowing controlled lateral deflection. Offsets and expansion loops are primarily used with pipes that are supported periodically, such as by hangers. Lateral deflection is employed with pipes that have continuous support such as by racks or when installed on grade, which could be either above or below water.

Offset and Expansion Loop Calculation



Pipe Offset

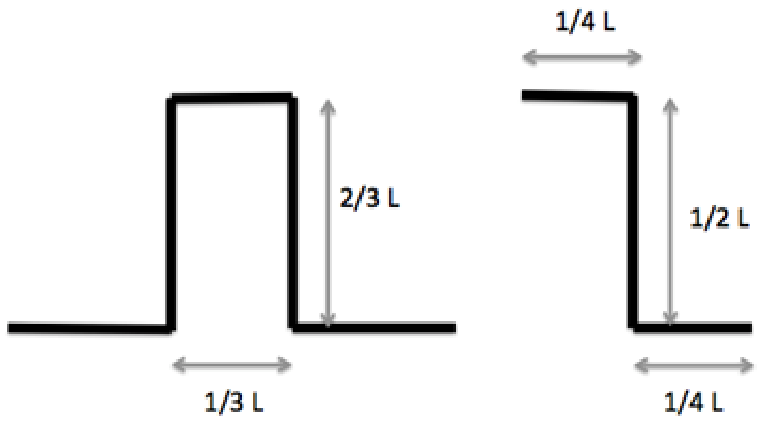
A pipe offset relieves thermal expansion forces by transforming it into a moderate bending stress. A compressive or tensile axial stress in a straight run of pipe may be relieved by transforming it to a bending stress at an offset. As illustrated by the figure above, the offset length (Lo) acts as a cantilevered beam to the long pipe run (Lr). Under thermal expansion, length Lr increases by DLr, which forces offset Lo to bend, and thereby absorb the expansion stress.

The minimum length of offset, Lo, that will safely absorb the thermal expansion in a long straight length of pipe, Lr, may be calculated

After the minimum length L is determined, these same equations may be used to determine whether the guide in the main run is sufficiently away from the ninety-degree directional change to ensure that the bending stresses in this section of the main run are also below the limiting value. To conduct this calculation, one will first have to calculate directional change to ensure that the bending stresses are not excessive.

It should be noted that in the figure, the bending in the offset begins at a guide and not at an anchor point. As already mentioned, some fittings have relatively low tolerance to bending, particularly when the bending is repetitive which can lower strength through fatigue. Accordingly, connections of offsets to rigidly held fittings should be isolated from bending stresses by means of guides, clamps or other devices.

Relief of expansion/contraction reactions may be accomplished by other configurations than offsets, such as loops and changes in direction, so long as: 1) the developed length in these configurations is as least as long as that required for a simple offset; and 2) the length of each segment of the configuration is sufficiently long to preclude the development of excessive bending stresses. Guidelines for the achieving of these objectives have been developed and are illustrated in the figure below.



Pipe Loop and Change in Direction

Thermal Expansion & Expansion Loop Length Formulas

$$L = [1.5\, E/s]\ \tfrac{1}{2}\ \ [D\Delta L]\ \tfrac{1}{2}$$

Lo = Loop Length (in)
E = Modulus of elasticity (psi)
S = Stress (psi)
D = Pipe OD (in)
Δ L = Pipe Expansion (in)

$$L = [1.5\, 1/\in]\tfrac{1}{2}\ \ [D\Delta L]\ \tfrac{1}{2}$$

Lo = Loop Length (in)
∈= Strain (in/in)
D = Pipe OD (in)
Δ L = Pipe Expansion (in)

Modulus of Elasticity (E), Stress (S) and Strain (∈) are related by the formula E= S/ ∈.

Conclusions

The change in length of pipe with temperature variation should always be considered when installing pipe and provisions made to compensate for this change in length.

Based on all available information, PPFA recommends that the above provisions be considered in addition to all specific requirements of the local plumbing code and manufacturer's installation instructions. All these methods have been found to be effective when properly utilized based on the job site conditions encountered.

NOTE: This PPFA User Bulletin is designed to provide guidance in achieving the efficient, effective and proper use of plastic piping systems. The suggestions and advice contained in the Bulletin are offered merely to provide plastic pipe users with a general frame of reference. Because specific situations may and often do require special treatment, the suggestions and advice are obviously not universally applicable. Therefore, the user should carefully assess the requirements of his specific situation before making practical application of anything contained in this publication.

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