Third Edition

# PEX

## Plumbing Distribution Systems Design and Installation Guide

Advantages | Material Properties | Codes & Standards

Joining Methods | PEX Plumbing Layouts | Optimizing Design

Installation Guidelines | Water Service Line | Other Applications


IAPMO®

PPI Plastics Pipe Institute
The Voice of an Industry.

Home Innovation RESEARCH LABS™

PPFA Plastic Pipe and Fittings Association

ES ICC EVALUATION SERVICE®

# PEX
# Plumbing Distribution Systems Design and Installation Guide
## Third Edition

Prepared for

Plastics Pipe Institute, Inc. (PPI)
105 Decker Court, Suite 825
Irving, TX 75062
www.plasticpipe.org

and

Plastic Pipe and Fittings Association (PPFA)
800 Roosevelt Road, Building C, Suite 312
Glen Ellyn, IL 60137
www.ppfahome.org

Prepared by

Home Innovation Research Labs
400 Prince George's Boulevard
Upper Marlboro, MD 20774
www.HomeInnovation.com

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# 3 Material Properties

Crosslinked polyethylene (PEX) is a polyethylene (PE) material, typically high-density polyethylene (HDPE), which has undergone a change in molecular structure using a chemical or a physical process whereby a majority of the polymer chains are chemically linked.

This crosslinking of the polymer chains results in improved performance properties such as elevated temperature strength, flexibility, chemical resistance, environmental stress crack resistance (ESCR), resistance to slow crack growth (SCG), toughness, and abrasion resistance. Crosslinking also makes PEX a "semi-thermoset" polymer, providing excellent long-term stability.

Polyethylene can be crosslinked using several technologies. All methods induce links between the single strands of HDPE to form a dense network or matrix through radical reactions. The number of links between the HDPE molecules determines the crosslink density and is an important factor in determining the physical properties of the material.

The three most common methods of crosslinking polyethylene are as follows:

**Peroxide –** This method employs organic peroxides that, when heated, generate reactive free radicals that splice PE chains together as the HDPE compound is extruded. This is sometimes referred to as the PEXa Process.

**Silane –** This method involves grafting a reactive silane molecule to the backbone of the polyethylene, which allows the HDPE compound to crosslink after extrusion as pipe when subjected to moisture and heat, such as with steam curing. This is sometimes referred to as the PEXb Process.

**Electron beam –** This method involves subjecting a dose of high-energy electrons to the extruded HDPE pipe. This is sometimes referred to as the PEXc Process.

Other crosslinking methods are also in commercial use. Although each method of crosslinking may produce slightly different characteristics, PEX tubing produced by any of the approved methods must meet the same qualification and performance requirements as specified in industry standards (e.g., ASTM F876, AWWA C904, CSA B137.5). The letter designations are not related to any type of rating system.

As required in any manufacturing process, procedures for each technology must be established and followed with stringent quality control checks in place to produce quality products.

## Industry Standards for PEX Tubing

As a widely-recognized product within the plastic piping industry, there are several industry standards that are commonly referred to when describing PEX tubing for plumbing applications. These industry standards define minimum material and performance requirements for all PEX tubing and systems and have been adopted into model plumbing codes for USA and Canada.

These are the most relevant industry standards for PEX systems:

**ASTM F876 *Standard Specification for Crosslinked Polyethylene (PEX) Tubing***
**Scope** (Partial): "This specification covers crosslinked polyethylene (PEX) tubing that incorporates an optional polymeric inner, middle or outer layer and that is outside diameter controlled, made in nominal SDR9 tubing dimension ratios except where noted, and pressure rated for water at three temperatures. Included are requirements and test methods for material, workmanship, dimensions, burst pressure, hydrostatic sustained pressure, excessive temperature and pressure, environmental stress cracking, stabilizer functionality, bent-tube hydrostatic pressure, oxidative stability in potable chlorinated water, UV resistance, and degree of crosslinking. Requirements for tubing markings are also given."

**ASTM F877 *Standard Specification for Crosslinked Polyethylene (PEX) Hot- and Cold-Water Distribution Systems***
**Scope** (Partial): "This specification covers requirements, test methods, and marking requirements for system components when tested with nominal SDR9 crosslinked polyethylene (PEX) tubing as a system. Systems are intended for 100 psi (0.69 MPa) water service up to and including a maximum working temperature of 180°F (82°C). Requirements and test methods are included for materials, workmanship, dimensions and tolerances, burst pressure, hydrostatic sustained pressure, excessive temperature and pressure, corrosion resistance, and thermocycling tests."

**ASTM F2023 *Standard Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Pipe, Tubing and Systems to Hot Chlorinated Water***
**Scope**: "This test method describes the general requirements for evaluating the long-term, chlorinated water, oxidative resistance of cross-linked polyethylene (PEX) pipe or tubing produced in accordance with PEX specifications, such as Specification F876 or Specification F2788/F2788M by exposure to hot, chlorinated water. This test method outlines the requirements of a pressurized flow-through test system, typical test pressures, test-fluid characteristics, failure type, and data analysis."

**ASTM F2657 *Standard Test Method for Outdoor Weathering Exposure of Crosslinked Polyethylene (PEX) Tubing***
**Scope**: "This test method describes the procedure for exposing crosslinked polyethylene (PEX) tubing produced in accordance with Specification F876 to natural (sunlight) ultraviolet (UV) radiation and evaluating the effects of the exposure. This test method outlines the requirements for specimen size and preparation, exposure orientation, minimum UV exposure energy, post exposure testing and reporting."

**CSA B137.5 *Crosslinked Polyethylene (PEX) Tubing Systems for Pressure Applications***
**Scope** (Partial): "This Standard specifies requirements for crosslinked polyethylene (PEX) tubing systems that comprise tubing and fittings. Tubing covered by this Standard is made

in Standard Dimensional Ratio 9 (SDR 9). Systems are pressure rated at three temperatures: 1105 kPa at 23°C, 690 kPa at 82°C, and 550 kPa at 93°C, with a maximum working pressure of 690 kPa at 82°C."

**AWWA C904** ***Crosslinked Polyethylene (PEX) Pressure Tubing, 1/2 in. Through 3 in. for Water Service***
**Scope**: "This standard describes crosslinked polyethylene (PEX) pressure tubing made from material having a standard PEX material designation code of PEX 1306, or higher, according to ASTM F876 and intended for use as underground potable water, reclaimed water, and wastewater service lines in sizes 1/2 in. through 3 in. that conform to a standard dimension ratio of SDR9. Tubing may include an optional polymeric outer layer. Included in this standard are criteria for classifying PEX plastic tubing materials, and a system of nomenclature, requirements, and test methods for materials and tubing. Methods of markings are given."

**IAPMO IS-31** ***Installation Standard for PEX Tubing Systems for Hot- and Cold-Water Distribution***
**Scope**: "This Standard specifies requirements for the installation of SDR 9 CTS crosslinked polyethylene (PEX) tubing and fittings, including cold-expansion, crimp, press, push-fit, and mechanical compression fittings, intended for hot- and cold-water distribution systems within buildings."

**NSF/ANSI 14** ***Plastics Piping System Components and Related Materials***
**Scope**: "This standard establishes minimum physical, performance, and health effects requirements for plastic piping system components and related materials. These criteria were established for the protection of public health and the environment."

**NSF/ANSI/CAN 61** ***Drinking Water System Components - Health Effects***
**Scope**: "This standard establishes minimum health effects requirements for the chemical contaminants and impurities that are indirectly imparted to drinking water from products, components, and materials used in drinking water systems. This standard does not establish performance, taste and odor, or microbial growth support requirements for drinking water system products, components, or materials."

**NSF/ANSI/CAN 372** ***Drinking Water System Components – Lead Content***
**Scope**: "This standard establishes procedures for the determination of lead content based on the wetted surface areas of products. This standard applies to any drinking water system component that conveys or dispenses water for human consumption through drinking or cooking."

## PEX Material Designation Code

Although PEX tubing is subjected to many performance tests during qualification testing, certification, and as regular quality control processes, three key performance measurements are categorized in the "PEX Material Designation Code" which is marked on the printline (i.e., markings) of all PEX tubing: chlorine resistance (minimum 50 years), UV resistance, and the hydrostatic design stress at 73°F (23°C) for sustained water pressure. The PEX Material Designation Code consists of the three letters "PEX" and four numeral digits where the first digit describes chlorine resistance, the second digit describes UV resistance, and the third and fourth digits describe the hydrostatic design stress (HDS) when tested using sustained water pressure at 73°F in units of 100 psi, with any decimal figures dropped (see **Figure 3.1**). This code is explained in detail within industry standards ASTM F876 and CSA B137.5.

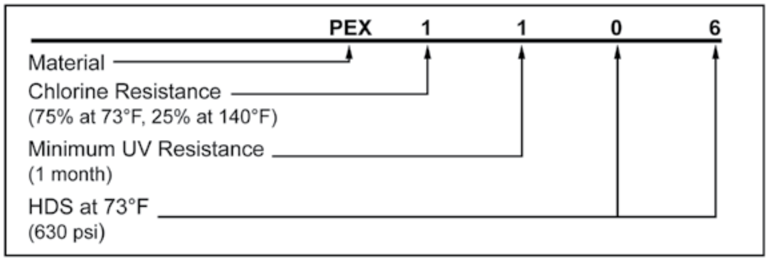



*Figure 3.1 Pictorial Explanation of the PEX Material Designation Code*

**First digit: Chlorine resistance**

The first digit of the PEX Material Designation Code is related to resistance to hot chlorinated water. PEX tubing for drinking water applications is required to have a minimum extrapolated time-to-failure of fifty (50) years when tested in accordance with ASTM F2023 for chlorine resistance and evaluated in accordance with ASTM F876 or CSA B137.5. Continuous recirculation, timed recirculation, and traditional domestic conditions are evaluated by ASTM F2023 and categorized within those standards as part of the PEX Material Designation Code.

- **0:** Not tested or not rated
- **1:** PEX tubing has been tested and meets the minimum requirements for chlorine resistance at the end use condition of 25% of the total time at 140°F (60°C) and 75% of the total time at 73°F (23°C). This is sometimes referred to as the Traditional Domestic application, with exposure to hot water (i.e., 140°F) up to 6 hours/day.
- **3:** PEX tubing has been tested and meets the minimum requirements for chlorine resistance at the end use condition of 50% of the total time at 140°F and 50% of the total time at 73°F. This is sometimes referred to as the Timed Recirculation application, with exposure to hot water (i.e., 140°F) up to 12 hours/day.
- **5:** PEX tubing has been tested and meets the minimum requirements for chlorine resistance at the end use condition of 100% of the total time at 140°F. This is sometimes referred to as the Continuous Recirculation application, with exposure to hot water (i.e., 140°F) up to 24 hours/day.

**Second digit: UV resistance**

The second digit of this code is related to resistance to outdoor weathering and ultraviolet (UV) light for the PEX material when tested in accordance with ASTM F2657 and evaluated in accordance with ASTM F876 or CSA B137.5.

- **0:** Not tested or not rated
- **1:** PEX tubing has been tested and meets the minimum requirements for UV resistance of 1 month.
- **2:** PEX tubing has been tested and meets the minimum requirements for UV resistance of 3 months.
- **3:** PEX tubing has been tested and meets the minimum requirements for UV resistance of 6 months.

**Third digit: Hydrostatic design stress (HDS) at 73°F (23°C)**
The hydrostatic design stress (HDS) is equal to a PEX material's hydrostatic design basis (HDB) value multiplied by the approved design factor (DF), which is currently 0.50 for PEX. These stress values are based on the hoop strength of the PEX material and not directly related to internal water pressure. See ASTM F876 and ASTM D2837 for additional details about HDS and HDB values.

- **06** = 630 psi HDS value
- **07** = 700 psi HDS value
- **08** = 800 psi HDS value

According to ASTM F876 and CSA B137.5, the minimum PEX material designation code for tubing intended for potable water is **PEX 1106**, which means:

- The first digit of "1" indicates that this material has been tested and meets the F876 requirement for minimum chlorine resistance at the end use condition of 25% of the total time at 140°F and 75% of the total time at 73°F.
- The second digit of "1" indicates that this material has been tested and meets the F876 requirement for minimum UV resistance of 1 month.
- The third and fourth digits of "06" indicates that this material has a 630 psi maximum recommended HDS using a 0.5 design factor at 73°F.

## PEX Tubing Dimensions

PEX tubing products are produced to strict dimensional controls, as found within the aforementioned industry standards with very tight tolerances on outside diameter (OD), wall thickness, and out-of-roundness. The dimensions within each industry standard are harmonized to be identical. See **Table 3.1** PEX Tubing Dimensions.

**Table 3.1 PEX Tubing Dimensions**

| Nominal Diameter | OD inches[A] | Wall inches[B] | ID[C] inches | Weight lb/ft | Volume[D] gallon/100ft |
|---|---|---|---|---|---|
| 3/8 | 0.500 | 0.075 | 0.350 | 0.04 | 0.5 |
| 1/2 | 0.625 | 0.075 | 0.475 | 0.05 | 1.0 |
| 5/8 | 0.750 | 0.088 | 0.574 | 0.07 | 1.3 |
| 3/4 | 0.875 | 0.102 | 0.671 | 0.10 | 1.9 |
| 1 | 1.125 | 0.132 | 0.862 | 0.17 | 3.2 |
| 1 1/4 | 1.375 | 0.161 | 1.054 | 0.25 | 4.7 |
| 1 1/2 | 1.625 | 0.191 | 1.244 | 0.35 | 6.5 |
| 2 | 2.125 | 0.248 | 1.629 | 0.60 | 11.1 |
| 2 1/2 | 2.625 | 0.307 | 2.011 | 0.92 | 16.5 |
| 3 | 3.125 | 0.363 | 2.399 | 1.29 | 23.5 |
| 4 | 4.125 | 0.478 | 3.169 | 2.24 | 41.0 |

[A] Average Outside Diameter (OD) from ASTM F876
[B] Average Wall thickness from ASTM F876
[C] Inside Diameter (ID) is calculated from OD and wall thickness
[D] Typical tubing volumes in US gallons

In the piping industry, the term "tubing" refers to products where the actual outside diameter (OD) is 1/8 inch larger than the nominal size, the same as copper tubing. Products with an OD that matches copper tubing are sometimes referred to as "copper tube size" (CTS) or "nominal tube size" (NTS). PEX products used for hot- and cold-water plumbing distribution are CTS.

The term "pipe" refers to products whereby the actual outside diameter matches that of steel pipe of the same nominal size, or products where the actual OD matches the nominal size. Those products are sometimes referred to as "iron pipe size" (IPS) or "nominal pipe size" (NPS).

Within this Guide, the terms "tubing" and "pipe" may be used interchangeably, although the technically-accurate term for the PEX described in this Guide is "tubing."

## Color

PEX tubing is available in natural (translucent) or colors such as red, white, and blue. Tubing may be pigmented with color throughout or coated with a pigmented layer to apply the color, or not pigmented at all. Some installers prefer to use red and blue PEX for hot- and cold-water distribution piping, respectively, while others prefer to have one uniform color, such as white, throughout the system.

Model plumbing codes do not dictate the use of any particular color for hot- and cold-water distribution piping. PEX tubing of all colors must meet the same technical requirements.

## Corrosion Resistance

Corrosion, an electrolytic process, requires the presence of electrically conductive materials such as lead, iron, steel, or copper. PEX is a dielectric material which is electrically non-conductive and does not pit or corrode like metal pipes.

Corrosion factor adjustments, commonly used with metal piping systems, are not needed when sizing a PEX system.

### Erosion Corrosion

Erosion corrosion is defined as the degradation of a surface due to mechanical action coupled with a secondary corrosion element. Erosion is often caused by abrasion from suspended solids, cavitation, or turbulent fluid flow wearing away the passivation layer protecting an underlying material and causing rapid damage to the material through both physical wear of the material and further chemical attack.

PEX tubing has a smooth interior surface and can withstand high velocities without erosion. Under the test conditions reported in **PPI TN-26 *Erosion Study on Brass Insert Fittings Used in PEX Piping Systems***, PEX tubing and brass fittings were subjected to extraordinarily high water velocities in excess of 12 ft/sec using hot chlorinated water for months of continuous flow testing. This test utilized potable water with corrosive pH levels between 6.5 and 6.7, much lower and more aggressive than levels found in common potable water systems. At the conclusion, no detectable erosion of the tubing surface occurred despite the very high flow velocities of aggressive water.

In PEX plumbing systems, design velocities are generally restricted by factors other than the capabilities of the PEX tubing or fittings (e.g., pressure drop, energy conservation, water hammer).

### Tuberculation

Tuberculation is a type of scaling build-up that occurs within pipes that can be a result of bacteria feeding on iron within pipe walls. It typically occurs in response to the deposition of minerals onto the surface of the pipe and subsequent corrosive action with the base material of the pipe. PEX tubing has a smooth interior surface, which provides minimal opportunity for the precipitation of minerals such as calcium carbonate, and contains no iron content. The potential for tuberculation of PEX tubing is minimal, which means that PEX tubing resists mineral build-up.

## Drinking Water Safety

The plastic piping industry is highly regulated within USA and Canada with systems of standards, codes, and third-party certifications which are extremely rigorous with regards to pipe materials (ingredients), production controls, and finished products.

To ensure drinking water safety, plastic pipe, tubing, and system components (e.g., fittings) must comply with federal regulations. **NSF/ANSI/CAN 61 *Drinking Water System Components – Health Effects*** is the legally-recognized national standard in the United States and Canada for evaluating the human health effects of drinking water materials, components, and devices, and ensuring that approved materials are safe for drinking water. All PEX components must be tested and certified to this standard.

In addition, plastic pipe, tubing, and system components must also be tested and certified to **NSF/ANSI/CAN 372 *Drinking Water System Components – Lead Content*** to demonstrate that they are lead-free.

Finally, plastic pipe, tubing, and system components must also comply with **NSF/ANSI Standard 14 *Plastic Pipe System Components and Related Materials*** which focuses on other aspects of performance and quality control.

As part of these certification processes, certifiers know exactly what materials are used in each pipe, tubing, or fitting formulation, and the safety of these products is repeatedly verified through frequent unannounced plant inspections.

PEX tubing systems for potable water are tested at water pH levels from 5.0 to 10.0, both extreme acidity and alkalinity beyond typical levels encountered in potable water systems, and at both cold and hot water temperatures.

PEX tubing does not contain lead, harmful volatile organic compounds (VOCs), or BPA (Bisphenol A).

## Flexibility

Crosslinked polyethylene remains a flexible material even at temperatures well below freezing. In fact, PEX tubing remains flexible and can still be bent at temperatures below -40°F (-40°C).

The flexibility and low stiffness of PEX allows it to be bent gently around obstructions and installed as one continuous run without fittings, if desired. Slight changes in direction are made easily by cold-bending the tubing by hand; snap-on bend supports can hold the tubing in 90-degree sweeps in place of elbow fittings (see **Figure 3.2**). Minimizing joints and connections can result in quicker installations, less potential for leaks at fittings, and less resistance by reducing pressure drop through fittings. Bend supports should be used to facilitate rigid bends and to alleviate stress on PEX joints when bends are needed in close proximity to such joints.

The free (unsupported) bending radius for PEX tubing, measured at the mid-point of the bend, shall be not less than (i.e., no tighter than) six times the actual outside diameter of the tubing, unless otherwise specified by the PEX manufacturer (see **Figure 3.3**).

Refer to **Table 3.2** for a list of minimum bend radii based on tubing diameter.

*Figure 3.2 Examples of Snap-on Bend Supports for PEX Tubing*

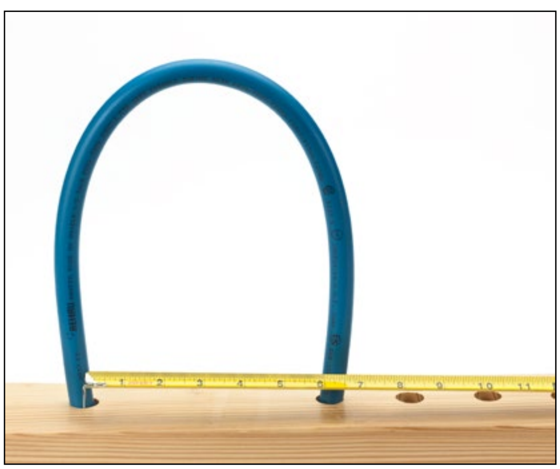


*Figure 3.3 PEX Tubing Bent at a Radius of 6 Times the Outside Diameter*

**Table 3.2 Minimum Bend Radii of PEX Tubing**

| Nominal Tubing Size | Tubing OD (Actual) in. | 6 times Bend Radius in. |
|---|---|---|
| 3/8 | 0.500 | 3.0 |
| 1/2 | 0.625 | 3.8 |
| 3/4 | 0.875 | 5.3 |
| 1 | 1.125 | 6.8 |
| 1 1/4 | 1.375 | 8.3 |
| 1 1/2 | 1.625 | 9.8 |
| 2 | 2.125 | 12.8 |
| 2 1/2 | 2.625 | 15.8 |
| 3 | 3.125 | 18.8 |
| 4 | 4.125 | 24.8 |

## Noise and Water Hammer (Surge Pressure) Resistance

As water flows through pipes, pressure in the system gives moving water energy, known as kinetic energy. Kinetic energy increases with the speed of water and with the mass of flowing water. When the flow of water is suddenly stopped, such as when a fast-acting valve or faucet is closed, this kinetic energy must be dissipated in the system and a short-term surge in water pressure will result.

The surge pressure that can result from fast-closing valves (e.g., washing machines, ice makers, irrigation systems) can produce instantaneous pressure spikes of 300 to 400 psig, which can, over time, cause damage to rigid pipes, fittings, fixtures, valves, and hot water tanks.

The ability of a plumbing pipe to absorb and dissipate energy due to surges in water pressure is based on the pipe's modulus of elasticity, a measure of material stiffness. A higher modulus of elasticity means the material is more rigid. Copper tubing is approximately 180 times more rigid than PEX tubing, and less capable of absorbing pressure spikes.

Ultimately, this means that with rigid piping systems, pressure surges can produce noticeable banging sounds as energy is dissipated through the piping network, thus causing what is known as "water hammer."

**Note:** Other audible "water hammer" noise can also be caused by a moving column of water cavitating as pressure waves reverberate within pipes. This noise is typically not related to excessive surge pressures and is not damaging to plumbing system components. This effect may be more likely in low water-pressure systems. Even the most flexible pipe cannot prevent all noises in certain situations.

### Surge Pressure Performance Testing

In a research project conducted at Home Innovation Research Labs (formerly known as NAHB Research Center), a test apparatus was constructed and operated such that pressurized flowing water in 20-foot straight lengths of pipe was abruptly interrupted by a fast-acting solenoid valve with a closing speed estimated at approximately 25 milliseconds. Several rigid and flexible, metal and plastic, nominal tubing size 1/2 materials were subjected to a test regime that included flow rates of 2, 2 1/2, 3, 4, and 6 gallons per minute using cold (54°F) and hot (130°F) test water. Pipes were mounted at hanger intervals according to the International Plumbing Code (PEX and CPVC at 32 inches, copper at 72 inches). The system was pressurized to a static pressure of 60 psig.

Results of the pressure measurements taken at the location of the fast-acting valve showed that plastic tubing materials exhibited significantly lower peak pressure measurements than Type L copper tubing at all flow rates and water temperatures.

For example, test results using nominal 1/2 tubing with 54°F (12°C) "cold" water at a typical flow rate of 2.5 GPM showed that peak pressures were reduced by up to 37% for PEX tubing as compared with copper. Test results using nominal 1/2 tubing with 130°F (54°C) "hot" water at the same flow rate of 2.5 GPM showed that peak pressures were reduced by up to 33% for PEX tubing as compared with copper. Results are shown in **Tables 3.3** and **3.4**.

At higher flow rates, the percentage of the surge pressure reduction increases.

**Table 3.3 First Peak Pressure for Each Piping Material and Flow Rate**

| Flow Rate, GPM | 2 | 2.5 | 3 | 4 | 6 | 2 | 2.5 | 3 | 4 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|
| Pipe Material (NTS 1/2) | Maximum Measured Pressure, psi | | | | | | | | | |
| | 54°F Water | | | | | 130°F Water | | | | |
| 1/2 Type L Copper | 194 | 239 | 266 | 318 | 422 | 149 | 181 | 204 | 250 | 306 |
| 1/2 CPVC | 155 | 173 | 201 | 222 | 296 | 142 | 157 | 174 | 203 | 252 |
| 1/2 PEX-1 | 143 | 168 | 177 | 212 | 274 | 108 | 113 | 124 | 141 | 175 |
| 1/2 PEX-2 | 136 | 150 | 169 | 193 | 244 | 113 | 122 | 123 | 141 | 174 |

Note: Pressure response measurements include 60 psi static pressure.

Note: Two types of PEX, indicated as "PEX-1" and "PEX-2" were tested.

**Table 3.4 Peak Pressure Comparison – 2.5 GPM**

| Pipe Material (NTS 1/2) | 54°F Water | | 130°F Water | |
|---|---|---|---|---|
| | Pipe Peak 1 (psig) | % Difference | Pipe Peak 1 (psig) | % Difference |
| 1/2 Type L Copper | 239 | 0 | 181 | 0 |
| 1/2 CPVC | 173 | 28 | 149 | 18 |
| 1/2 PEX-1 | 168 | 30 | 113 | 38 |
| 1/2 PEX-2 | 150 | 37 | 109 | 40 |

In summary, the flexibility of PEX tubing material allows it to absorb energy from pressure surges and eliminate or reduce the occurrence of water hammer and the potentially harmful surge pressures that may damage other plumbing systems components such as faucets, toilets, etc.

**Note:** For full details of this testing, see the report ***Surge Pressure in Plumbing Pipe Materials*** available on the PPI website.

Refer to the PPI **Plastic Pipe Design Calculator** (www.plasticpipecalculator.com) for Hydraulic Shock calculations.

## Resistance to Freeze Damage

The material properties of PEX tubing provide it with inherent benefits when subjected to freezing conditions.

First, PEX materials have lower thermal conductivity than metallic piping materials, which reduces the thermal exchange rate and can extend the time required to freeze the water within the system.

Second, the flexibility of PEX allows it to be installed with fewer fittings than other piping materials, reducing the potential for ice blockage events at transition locations, thus allowing the increased pressure that can build up in a freezing piping system to be distributed throughout the piping system.

Third, if the freezing of water within PEX *does* occur, the elastic nature of PEX materials at temperatures even below -40°F (-40°C) enable for circumferential and axial expansion of the tubing that correlates to the increase in volume of the fluid during a freezing event, usually preventing breakage. If an unintended freeze event does occur, then the properties of PEX tubing are such that, in many instances, the tubing will not burst when the fluid inside is frozen.

There are situations where freezing fluid can damage or burst PEX tubing, and this should be prevented through proper planning and installation of PEX systems. See **PPI TR-52 *Resistance of PEX Pipe and Tubing to Breakage when Frozen (Freeze-Break Resistance)*** for more details on this topic.

## Temperature and Pressure Capabilities

Consensus standards published by ASTM International and CSA Group specify temperature and pressure capabilities of and requirements for PEX systems and components.

A pressure rating is the estimated maximum pressure that the fluid in the pipe can exert continuously with a high degree of certainty that failure of the pipe will not occur. Pressure ratings are always given at a specified temperature. PEX tubing and systems are pressure-rated at multiple temperatures, related to operation in cold- and hot-water systems. The minimum pressure ratings for PEX according to industry standards are 160 psig at 73°F (1,100 kPa at 23°C) and 100 psig at 180°F (690 kPa at 82°C). Some PEX tubing is also rated for 80 psig at 200°F (550 kPa at 93°C).

Pressure ratings for plastic pipes and tubing are based on an extrapolated time-to-failure prediction as defined in **ASTM Test Method D2837 *Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products***. Pressure ratings are calculated using the hydrostatic design basis (HDB) and hydrostatic design stress (HDS) values. These values are recommended by The Plastics Pipe Institute (PPI) or other certification bodies.

One example of these test requirements is the Hydrostatic Sustained Pressure Strength test. This laboratory test is performed at several temperatures and results are used to demonstrate the pressure ratings which will be marked on PEX tubing. Each PEX tubing manufacturer must subject its PEX tubing material(s) at multiple temperatures and multiple pressures for thousands of hours of hydrostatic testing to satisfy the qualification requirements as found within ASTM D2837, ASTM F876, AWWA C904, CSA B137.5, PPI TR-3, and other industry standards.

PEX tubing and fitting systems must also be subjected to the excessive temperature and pressure test found within the standards. In the event of a water heating system malfunction, PEX systems are designed to accommodate short-term conditions 150 psig at 210°F (1,034 kPa at 99°C) until repairs can be made to the water heating system. This requirement is based on the most commonly used Temperature & Pressure (T&P) Relief valves which activate (open) at either that temperature or pressure condition (i.e., 150 psig or 210°F) in case a water heater does not deactivate when it reaches its temperature setpoint. All PEX systems must be tested to withstand this condition (i.e., 150 psig or 210°F) for a minimum of 720 hours (30 days) to ensure that safety requirements are met. As such, PEX systems DO NOT require the use of a special T&P relief valve.

## Thermal Conductivity / R-Value

PEX material has a low thermal conductivity as compared to metal piping materials such as copper which reduces heat transfer through the tubing wall. This means that condensation is less likely to form on cold-water PEX tubing in humid environments and less heat is lost to the environment in hot-water applications. This can also delay the freezing of water within PEX tubing, potentially preventing freezing events.

For similar material thickness, PEX is approximately 68 times less conductive than copper, which will delay heat transfer into or out of the contained fluid. According to **PPI TR-48 *R-Value and Thermal Conductivity of PEX and PE-RT Tubing***, the normalized thermal conductivity (K-factor) for PEX is **2.86 (BTU·in)/(ft²·hr·°F)**. This compares with a thermal conductivity (K-factor) for copper tubing material of **196 (BTU·in)/(ft²·hr·°F)**, a factor of 68 times.

Another way of expressing the relatively low thermal conductivity of PEX is to convert this to an R-value expressed with the units ft²·°F·h/BTU. The higher the Resistance value, the slower the rate of heat transfer through the insulating material.

The wall thickness of each diameter of PEX tubing varies, based on a standard dimension ratio (SDR) of 9, with the wall getting increasingly and proportionally thicker as diameter increases. In fact, in all diameters, the wall thickness of PEX tubing is higher than that of copper tubing, so a direct comparison of R-values is not linear. See **Table 3.5** for the R-value of PEX tubing by nominal diameter.

**Table 3.5 R-value of PEX Tubing by Nominal Tubing Size (i.e., diameter)**

| Property | Nominal Tubing Size (NTS) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3/8 | 1/2 | 3/4 | 1 | 1 1/4 | 1 1/2 | 2 |
| Wall Thickness (in) | 0.070-0.080 | 0.070-0.080 | 0.097-0.107 | 0.125-0.138 | 0.153-0.168 | 0.181-0.200 | 0.236-0.260 |
| R-Value (ft²°F-h/BTU) | 0.028 | 0.028 | 0.038 | 0.049 | 0.060 | 0.072 | 0.093 |

**Note:** Normalized R-values are based on standardized material thickness of 1.00 inch

## Resistance to Disinfectants

The U.S. Environmental Protection Agency (EPA) recommends that all drinking water be disinfected, typically using free chlorine, chloramines, or other less common methods.

Currently, the majority of potable drinking water in the United States and Canada is disinfected using free chlorine while the second most common method of disinfection is chloramines. For water treated with free chlorine or chloramines, the EPA sets a maximum disinfectant level of 4.0 parts per million (ppm) within a public water distribution system.

### Chlorine and Chloramines

To ensure the reliability of PEX tubing systems in hot chlorinated water applications, it is a requirement of the PEX product standard specification ASTM F876 that all PEX tubing intended for use with potable water have a minimum extrapolated lifetime of fifty (50) years when tested in accordance with **ASTM Test Method F2023** ***Standard Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Tubing and Systems to Hot Chlorinated Water***.

The test conditions of ASTM F2023 require that the test fluid has a minimum oxidative reduction potential (ORP) of 825 mV. ORP is a measure of how likely a solution is to give or receive electrons given the right circumstances. To produce test fluid with such an elevated ORP, third-party test laboratories typically use reverse osmosis-purified water with a free chlorine concentration of 4.3 +/- 0.3 ppm (4.3 mg/L) and pH of 6.8 +/- 0.2, resulting in an ORP of 825 mV or higher. This represents a very aggressive water quality which gives conservative results in terms of expected pipe lifetime. This test procedure is designed to extrapolate the life expectancy of a hot-water plumbing pipe when used at a pressure up to 80 psig at a water temperature up to 140°F. Continuous recirculation, timed recirculation, and traditional domestic (i.e., intermittent) conditions are evaluated by ASTM F876.

All PEX tubing intended for potable water applications must be tested and certified by qualified third-party certification agencies to meet the requirements of ASTM F876, including chlorine resistance. The minimum performance requirement applies to traditional domestic applications; F876 states "PEX tubing intended for use in the transport of potable water shall have a minimum extrapolated time-to-failure of 50 years and comply with the requirements for a first digit of "1" or higher in the PEX Material Designation Code." See the previous section ***PEX Material Designation Code*** for more details about chlorine resistance requirements. For more information about chlorine resistance of PEX tubing, please see **PPI TN-53** ***Guide to Chlorine Resistance of PEX Pipes and Tubing for Potable Water Applications***.

Fittings used with PEX tubing must comply with ASTM standards and are made from brass, copper, or high temperature engineered polymers that are also chlorine resistant.

According to the U.S. EPA, chloramines are disinfectants used to treat drinking water, and are formed when ammonia is added to chlorine. To evaluate the resistance of PEX tubing to chloramines, a research project coordinated by the PPI examined the relative oxidative aggressiveness of both free chlorine and chloramines.

According to the study, published as **PPI Statement A** ***Relative Oxidative Aggressiveness of Chloramines and Free Chlorine Disinfectants on Crosslinked Polyethylene (PEX) Pipes used in Treated Potable Water***, it is the position of PPI that chloramines are less aggressive than free chlorine to PEX tubing. Testing of oxidative resistance using free chlorine, in accordance with ASTM F2023, will provide a conservative estimate of the time-to-failure for PEX tubing when used with the disinfectant chloramines.

In summary, PEX tubing has shown itself to be resistant to attack from chlorine and chloramines under a wide range of conditions and has performed reliably in all regions of North America.

### Chlorine Dioxide

While chlorine dioxide ($ClO_2$) is a far less common water disinfectant that is rarely used as a secondary (i.e., residual) water disinfectant in public potable water systems, in certain types of large facilities such as hospitals, nursing homes, hotels, apartment buildings, and office buildings, it is sometimes added to plumbing distribution systems to treat or control outbreaks of harmful bacteria such as Legionella.

In such facilities, specialized chlorine dioxide generation devices can be added to inject $ClO_2$ in measured doses directly into the piping system before hot water is delivered throughout the building. Chlorine dioxide is a dissolved gas and is highly volatile and efficient as an oxidizing agent for disinfection. It is used in different concentrations than free chlorine or chloramines and has a different mechanism of attack on the various materials and substances to which it is exposed.

**PPI TN-67 *Chlorine Dioxide and Plastic Hot- And Cold- Water Plumbing Distribution Pipes*** addresses this topic. Based on data that has been analyzed regarding the effects of chlorine dioxide on piping materials in hot- and cold-water plumbing systems, it is apparent that this compound can be very aggressive to materials such as crosslinked polyethylene. PPI recommends caution when considering the use of $ClO_2$ as a chemical disinfectant to treat water for the control of Legionella or other pathogens and recommends contacting each piping system supplier for guidance on the use of their pipe and fitting material(s) in circumstances where chlorine dioxide has been selected as the disinfection chemical.

## Outdoor Weathering / Ultraviolet (UV) Resistance

Like most plastics, the long-term performance of PEX will be affected by ultraviolet (UV) radiation from sunlight. Although most PEX tubing has good UV resistance, PEX tubing should not be stored outdoors where it is exposed to the sun. PEX tubing should not be installed outdoors unless buried in earth or properly protected from UV exposure, either direct or indirect.

Indirect (diffused) and reflected sunlight also emit UV energy. If PEX will be exposed to sunlight continuously after installation, such as in an unfinished basement, installers should cover the pipe with a UV-blocking sleeve or pipe insulation as approved by the PEX manufacturer.

To ensure the reliability of PEX tubing systems when exposed to sunlight, it is a requirement of the industry standards ASTM F876 and CSA B137.5 that all PEX tubing intended for use with potable water has a minimum UV resistance of 1 month when tested in accordance with **ASTM Test Method F2657 *Standard Test Method for Outdoor Weathering Exposure of Crosslinked Polyethylene (PEX) Tubing***. ASTM F876-25 states, "PEX tubing intended for use in the transport of potable water shall comply with the requirements for a second digit of "1" or higher in the PEX Material Designation Code." See the previous section "PEX Material Designation Code" for more details about UV resistance requirements.

Each PEX tubing manufacturer publishes the maximum recommended UV exposure time limit based on the UV resistance of each type and color of PEX tubing, as determined in accordance with ASTM F2657 and the requirements published in ASTM F876. Central Arizona is used as the basis of the exposure time limits as it represents the worst-case North American location for UV energy. As part of the test procedure, exposed pipes are then re-tested for chlorine resistance in accordance with ASTM F2023 and must show no significant reduction in pipe lifetime.

**PPI TN-32 *UV Labelling Guidelines for PEX Pipe and Tubing*** suggests the following information be labelled on all PEX packaging to clearly inform the user on the form of a NOTICE label:

- Keep PEX stored indoors in the original packaging prior to installation for protection against UV/sunlight and other potential hazards.
- Do not store unprotected PEX outdoors.
- The long-term performance of PEX will be compromised by excessive UV radiation from sunlight.
- To prevent UV damage, ensure that exposure to sunlight during installation does not exceed the maximum allowable UV exposure time of **X**[1] days.
- UV damage is not visible to the naked eye, and may degrade the material and reduce its service life.

## Fitting Materials Used with PEX Tubing

The following materials for construction of PEX fittings are approved in one or more of the ASTM or ASSE fitting standards listed in **Chapter 5 *Joining Methods***. Each of these industry standards describes exactly which fitting material or materials may be used for the manufacturing of that particular fitting design.

### Brass and bronze fittings

Many of the fitting systems listed in **Chapter 5 *Joining Methods*** are produced using lead-free brass or bronze materials. Multiple alloys with various combinations of copper and other elements, suitable for manufacturing processes such as casting, forging, and machining, are approved within those industry standards. Each of these materials is selected to provide the required strength, forgeability, machinability, and resistance to corrosion as required for potable water applications.

It is a requirement of the Uniform Plumbing Code (UPC) that fittings and valves produced from copper alloys containing more than 15% zinc by weight shall be resistant to dezincification and stress corrosion cracking in compliance with the test outlined in **NSF/ANSI 14**.

According to the US EPA, Section 1417 of the Safe Drinking Water Act (SDWA) establishes the definition for "lead free" as a weighted average of 0.25% lead calculated across the wetted surfaces of a pipe, pipe fitting, plumbing fitting, and fixture and 0.2% lead for solder and flux. The Act also provides a methodology for calculating the weighted average of wetted surfaces.

The Act prohibits the "use of any pipe, any pipe or plumbing fitting or fixture, any solder, or any flux, after June 1986, in the installation or repair of (i) any public water system; or (ii) any plumbing in a residential or non-residential facility providing water for human consumption, that is not lead free."

1 The allowed UV exposure time of "**X** days" shall be recommended by the tubing manufacturer. Additionally, the third-party testing of the product is according to ASTM Test Method F2657 and requirements which are published in standards such as ASTM F876, AWWA C904, and CSA B137.5

All brass and bronze fittings for PEX tubing systems intended for use in potable water applications must be tested and certified to **NSF/ANSI/CAN 372** to ensure compliance with the ≤0.25% maximum weighted average lead content requirement and must be tested and certified to **NSF/ANSI/CAN 61** to ensure safety for drinking water.

### Polysulfone (PSU) and Polyphenlysulfone (PPSU)

Many of the polymeric fitting systems listed in **Chapter 5 *Joining Methods*** may be produced using polysulfone (PSU) and/or polyphenylsulfone (PPSU) materials, typically produced via injection molding. These engineered plastic materials are tough and rigid to ensure tightness, durability, and dimensional stability. These materials are resistant to corrosion and bacterial deposits and are free of heavy metals.

### Polyphenylene sulfide (PPS)

Some of the fitting systems listed in **Chapter 5 *Joining Methods*** may be produced using polyphenylene sulfide (PPS) materials. Polyphenylene sulfide is a type of engineered plastic known for its mechanical strength, high melting point (>275°C), excellent heat resistance, excellent chemical resistance against both organic and inorganic substances, low water absorption, and dimensional stability. It is suitable for the fitting systems for the above characteristics especially chemical resistance, low water absorption and high dimensional stability.

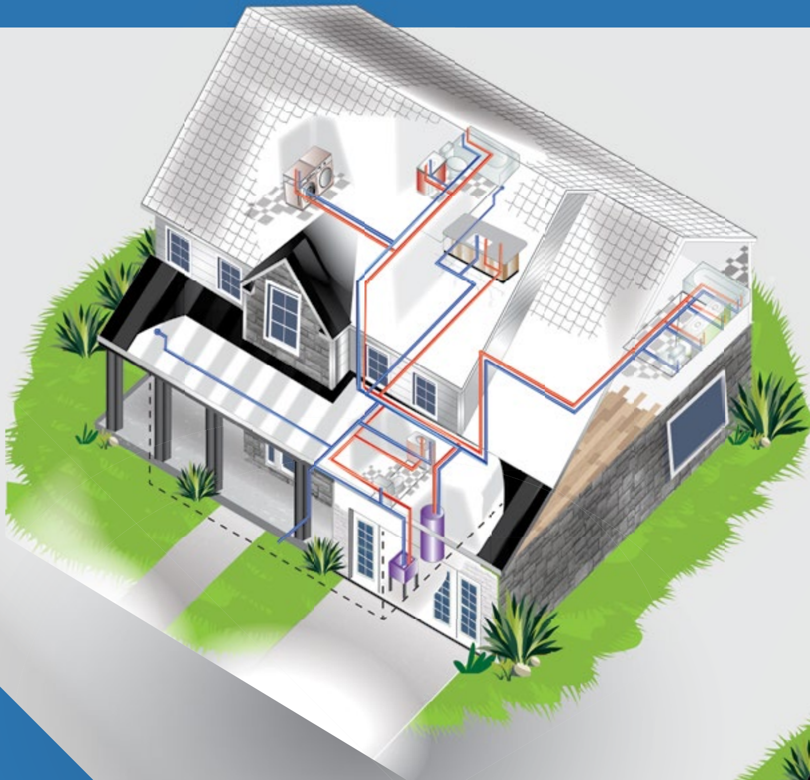
### Polyvinylidene fluoride (PVDF)

Some of the fitting systems listed in **Chapter 5 *Joining Methods*** may be produced using polyvinylidene fluoride (PVDF) materials. Polyvinylidene fluoride is a type of engineered plastic known for its mechanical strength, excellent heat resistance, excellent chemical resistance against both organic and inorganic substances, purity, low water absorption, and dimensional stability. It is suitable for the fitting systems for the above characteristics especially chemical resistance, low water absorption and high dimensional stability.

## PEX Tubing Markings

Per requirements of standards ASTM F876 and CSA B137.5, PEX tubing shall have the following markings on the print line, spaced at intervals of not more than 5 ft:

- Nominal tubing size and "SDR 9"
- Manufacturer's name or trademark
- Production code indicating date of production
- PEX material designation code (e.g., "PEX xxxx")
- "F876" and other standard designations (e.g., "CSA B137.5")
- Pressure ratings at 73°F and 180°F (e.g., 160 psi at 73°F, 100 psi at 180°F)
- Seal or mark of the laboratory certifying the tubing for use with potable water
- Standard designation(s) of the fitting system(s) for which the tubing is recommended for use by the tubing manufacturer (e.g., "F1807", "F1960") – see **Chapter 5 *Joining Methods***



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