

AWWA C904 SUBCOMMITTEE OF THE STANDARDS COMMITTEE ON POLYOLEFIN
PRESSURE PIPE AND FITTINGS

Committee Report: Design and Installation of Cross-linked Polyethylene (PEX) Pipe in Accordance with AWWA C904

THIS COMMITTEE REPORT
HAS BEEN ISSUED
TO PROVIDE BASIC
GUIDANCE AND REFERENCES
ON THE DESIGN AND
INSTALLATION OF PEX PIPING
MANUFACTURED
IN ACCORDANCE WITH
AWWA C904.

Cross-linked polyethylene (PEX) pipe described by AWWA C904 (2006a) is typically used for underground water service lines from a public water system. PEX pipe connects to standard compression joint valves and fittings and is corrosion-resistant.

PEX pipe has a history of successful use in Europe where it was extensively tested for durability and material performance. It was introduced in North America in 1984 when it was first used for radiant floor heating. More recently, PEX pipe has been used for residential water distribution systems (NAHB Research Center, 2006). It is approved for potable hot and cold water supply systems (ASTM, 2007) and hydronic heating systems in all model plumbing and mechanical codes in the United States and Canada (CSA, 2009).

This committee report has been issued to provide basic guidance and references on the design and installation of PEX piping manufactured in accordance with C904. This standard describes PEX pressure pipe made from material with a standard PEX material designation code of PEX 1006 as defined in ASTM F876 (2010a). The pipe described by C904 has a standard dimension ratio (SDR) of 9 and is primarily used for underground water service lines in sizes 0.5 in. (12 mm) through 3 in. (76 mm). This report does not supersede state and local building codes.

MATERIAL PROPERTIES

PEX is a cross-linked material formed by joining individual polyethylene (PE) molecules. The primary reason for cross-linking PE is to increase the material's elevated temperature internal pressure performance. Cross-linking

also improves the pipe's environmental-stress crack resistance, resistance to slow crack growth, chemical and corrosion resistance, toughness, and abrasion resistance (PPI, 2008b, 2004b).

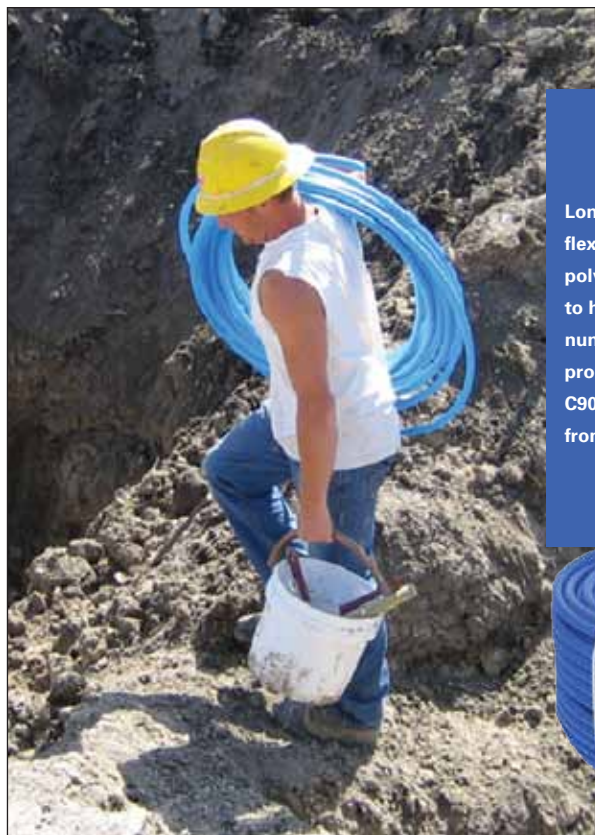
PEX cross-linking methodologies.

Polyethylene can be cross-linked using several technologies. The three most common methods of cross-linking polyethylene are peroxide, silane, and electron beam and are sometimes referred to as PEX-A, PEX-B, and PEX-C, respectively. The designations are not related to any performance rating system. PEX pipe produced by any of the methods must meet the material and performance requirements specified in C904 and other PEX standards.

Temperature and pressure capabilities. PEX pipe described in C904 has a pressure class (PC) of 160 psi at a service temperature of 73°F (23°C) or less. PC includes an allowance for surge pressure; refer to the section on pressure surge dissipation for additional information.

Flexibility. The flexibility of PEX pipe allows it to be bent around obstructions, and it can often be installed as one continuous run without fittings. Slight changes in direction can be made by bending the pipe by hand. See Table 1 for the minimum bend radius.

Pressure-surge dissipation. When water velocity in a piping system changes, the pipe, pipe fittings, and pipe supports must dissipate the energy. The resulting pressure surge is proportional to the piping material's modulus of elasticity: a high modulus of elasticity results in a lower amount of energy dissipation by the pipe and an increase in the magnitude of the resulting surge pressure. The flexibility (low modulus of elasticity) of PEX pipe allows the pipe to absorb and dissipate energy from pressure surges. A study by the NAHB Research Center titled *Surge Pressure in Plumbing Pipe Materials* (2009; <http://plasticpipe.org/pdf/nahbrc-surge-pressure.pdf>) concluded that while testing 0.5-in.



Long, light-weight coils and flexibility make cross-linked polyethylene (PEX) pipes easy to handle while minimizing the number of joints. PEX pipes are produced to comply with AWWA C904 in range of colors and sizes from ½ to 3 in.



pipe with “cold” water at a typical flow rate of 2.5 gpm, peak pressures were reduced by 30–37% for PEX pipes as compared with copper pipes.

Freeze resistance. PEX pipe retains its flexibility below freezing. If water-filled PEX pipe freezes, the elasticity of the material typically allows it to expand without cracking or splitting and to return to its original size on thawing (assuming the PEX pipe can expand evenly along its length). If installed within the frost zone, PEX pipe does not prevent water from freezing in the pipe, but it does resist damage if water freezes in the pipe. Care should be taken to ensure that PEX pipe is buried below the frost line to prevent freezing and to avoid interrupting the water supply.

Chlorine resistance. Most potable water in the United States and Canada is disinfected using free chlorine. The second-most common disinfectant is chloramines. PEX pipe is resistant to chlorine and chloramines. For additional information, refer to the Plastic Pipe Institute's (PPI's) state-

ment on oxidative aggressiveness of chloramines and free chlorine disinfectants used in treated potable water on PEX pipe (2007a).

C904 requires PEX pipe products to have a minimum extrapolated lifetime of 50 years when tested in accordance with method ASTM F2023 (2010b), Standard Test Method for Evaluating the Oxidative Resistance of Cross-linked Polyethylene (PEX) Tubing and Systems to Hot Chlorinated Water. Cold water conditions will result in longer extrapolated lifetimes. Consult with the pipe manufacturer for more information.

Corrosion resistance. PEX pipe has been tested extensively with aggressive potable water (chlorine = 4 mg/L, pH = 6.8) and has been found to be resistant to corrosion in this environment. The corrosion of metal fittings used to join PEX pipe to other pipe or in a PEX distribution system is dependent on the conditions of the soil and water. Appropriate fitting material should be selected based on environmental conditions.

Ultraviolet resistance. Most PEX pipe has some ultraviolet (UV) resistance, but PEX pipe should not be stored uncovered outdoors or installed in locations where the pipe will be exposed to UV radiation. Each PEX pipe manufacturer publishes a maximum recommended UV exposure limit, based on the UV resistance of the pipe when tested in accordance with ASTM F2657 (2007a). Do not allow PEX pipes to be exposed beyond these limits. For outdoor installation, PEX pipe should be buried in earth or properly protected from direct or indirect UV exposure. Refer to the ASTM F876 (2010a) section titled UV Labeling Guidelines for PEX Tubing and PPI Technical Note TN-32 (2004a), UV Labeling Guidelines for PEX Pipes for further details. The specifier can require a minimum UV resistance per ASTM F876.

Suitability for drinking water. PEX piping that is used to transport potable water must comply with federal regulations for public safety. C904 pipe is tested and certified for compliance with NSF/ANSI Standard 61, Drinking Water System Components—Health Effects (2007a) and Standard 14 Plastic Pipe System Components and Related Materials (2007b). The primary focus of NSF/ANSI Standard 61 is to establish minimum health-effect requirements for chemical contaminants and impurities that are indirectly imparted into drinking water from

products, components, and materials used in potable water systems. NSF/ANSI Standard 14 covers physical, performance, and health-effect requirements for plastic piping system components used in potable hot water and cold water distribution systems. Even though C904 only references NSF/ANSI Standard 61, the specifier can require NSF/ANSI 14 as described in the section on sample specifications at the end of this report.

Chemical resistance. To assist the designer in the selection of PEX for piping applications, chemical-resistance charts are available from PPI and manufacturers to provide guidelines regarding the suitability of PEX as a piping material in the presence of various chemicals. Additional information is available from PPI Technical Report TR-19 (2007c), Chemical Resistance of Thermoplastics Piping Materials. For specific chemical compatibility questions, users should consult the pipe manufacturer.

Erosion. PEX pipe has a smooth interior surface and good toughness and can withstand high velocities. Under the test conditions reported in PPI TN-26 (2005), Erosion Study on Brass Insert Fittings Used in PEX Piping Systems, no detectable erosion of the pipe surface occurred at water velocities in excess of 12 fps. Design velocities are generally restricted by factors other than the PEX pipe (i.e., valves, fittings).

Permeation. PEX systems, like other systems, can be susceptible to permeation of light hydrocarbon contaminants and solvents that may be present in the soil. With continued exposure the contaminants may permeate from the soil into the pipe. Special care should be taken when installing potable water lines through contaminated soils as noted in the section on Permeation (4.1) in C904.

The mechanism of hydrocarbon and solvent permeation through a pipe is complex. Some of the variables include: soil type and texture, type and concentration of contaminants, temperature, pipe diameter, wall thickness, and flow rates. When gross hydrocarbon contamination of soil surrounding pipe is a concern, there are several ways to address this issue, including:

- Surround the pipe with clean soil of Class I or Class II materials to allow the hydrocarbons that may have contacted the pipe's wall to dissipate into the atmosphere and in the envelope of the surrounding soil. The US Environmental Protection Agency guidelines prohibit the reuse of excavated hydrocarbon-contaminated soil in the envelope of bedding or backfill material.
- If the hydrocarbon contamination is relatively localized, sleeve the pipe in areas where hydrocarbon contamination exists.
- Reroute the pipe around the contamination plume.

Tuberculation. The potential for tuberculation of PEX pipe is minimal. Tuberculation 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 pipe has a smooth interior surface that provides minimal opportunity for the precipitation of minerals such as calcium carbonate.

Slow-crack-growth resistance. PEX piping is resistant to slow crack growth and environmental stress cracking when used in typical potable water systems. In rocky soils, PEX



A final assembly with cross-linked polyethylene pipe in a compression joint curb stop that is compliant with AWWA C800, Standard for Underground Service Line Valves and Fittings.

pipe is resistant to the effects of surface scratches.

Long-term properties. Long-term hydrostatic strength. The pressure capability of PEX pipe is based on extrapolation of stress-rupture data in accordance with ASTM D2837 (2011a). Using this protocol, the hydrostatic design basis (HDB) of a material is determined. The HDB is used to determine the pressure capability of a pipe under specific service conditions (refer to the subsequent section on design).

Fatigue and fracture properties. The fracture resistance of a given structure or material will depend on the level of stress applied to it, the presence and size of flaws, and the inherent resistance of the material to crack initiation and growth. Cross-linking improves PEX pipe's fatigue and resistance to slow crack growth.

Material designation. Because PEX is cross-linked, typical cell classifications that apply to PE materials do not apply to PEX. PEX does have material designation codes (MDCs) as defined in ASTM F876. The MDC of a PEX material is based on three properties: oxidative resistance (chlorine resistance), UV resistance, and long-term strength. C904 requires a PEX material with a minimum MDC of PEX 1006; the first digit refers to the chlorine resistance, the second digit refers to UV resistance, and the last two digits are the hydrostatic design stress. Refer to ASTM F876 (2010a) for additional information on these digits.

PEX piping dimensions and flow characteristics. PEX pipe for water distribution is required to conform to the dimensions specified in ASTM F876, as shown in Table 2. Table 3 shows the average inside diameter for flow calculations. Information on flow velocity and pressure loss for different flow rates and pipe sizes (AWWA, 2004) are available in Tables 4 and 5.

DESIGN

PEX pipe can safely withstand short-duration pressure surges even

if they exceed the pipe's PC. Concentrated loads are reduced by localized deformations. Stresses generated by bending or other forced deformation decrease with time through stress relaxation.

Pipe Selection. Pressure design. A PC of 160 psi (1.10 MPa) is recommended for general durability in handling and for use in typical water service installations. Refer to Eqs 7–11 for additional considerations.

PC is calculated as follows:

$$PC = \frac{2}{SDR - 1} \times HDB \times DF \quad (1)$$

in which PC is measured in psi, HDB is given for the applicable temperature in psi in accordance with ASTM D2837, and DF = design factor (0.5 for PEX water service). Refer to ASTM D2837 (2011a) for a discussion on DF.

For a SDR9 PEX pipe with a 1,250 psi HDB at 73°F and 0.5 DF:

$$PC = \frac{2}{9 - 1} \times 1,250 \times 0.5 \quad (2)$$

in which PC = 156 and psi = 160 (rounded).

Surge pressure. The wave velocity and surge pressure that result from abrupt changes in the velocity of a column of water moving through a restrained pipe may be calculated using the following formulas:

$$\alpha = 4,660/[1 + K(SDR - 2)/E_d]^{1/2} \quad (3)$$

$$P_s = \alpha \left(\frac{\Delta V}{A_2} \right) \quad (4)$$

in which α = wave velocity in fps, K = bulk modulus for water of 300,000 psi at 73°F, and E_d = dynamic instantaneous effective modulus of elasticity of pipe material.

For PEX 1006, E_d = 175,000 psi at 73°F, P_s = surge pressure in psi, ΔV = velocity change in fps occurring within the critical time $2L/\alpha$, A_2 = $2.31 \times g$ for in.-lb units, g = gravitational acceleration of 32.2 sq fps, and L = pipe length in ft.

For an SDR9 PEX pipe:

$$\alpha = \frac{4,660}{\left[1 + \frac{300,000(9 - 2)}{175,000} \right]^{1/2}} = 1,309 \quad (5)$$

$$P_s = 1,309 \left(\frac{1}{2.31 \times 32.2} \right) = 17.6 \text{ psi} \quad (6)$$

On the basis of these equations, the surge pressure from a 1-fps change in velocity is 17.6 psi for SDR9 pipe. Because the surge pressure is directly related to the change in velocity, other surge pressures can be calculated as multiples of the value shown (i.e., the estimated surge pressure for a velocity change of 5 fps is 88 psi if the velocity changes within $2L/\alpha$). A surge pressure wave does not occur if the velocity-change time exceeds $2L/\alpha$,

TABLE 1 Minimum recommended bending radii

Nominal Pipe Size—in.	Minimum Bending Radius (CTS)—in.
½	5
¾	7
1	9
1¼	11
1½	13
2	17
2½	21
3	25

CTS—copper tubing size

Minimum bending radius is based on 8 × outer diameter (see Table 2 for outer diameters).

If using pipe in coils and bending the pipe against the coil direction, the minimum bending radius is 3 × the radius given (e.g., ½ in. pipe = 3 × 5 = 15 in.)

in which L is the length of the line and α is the wave velocity per Eq 3.

Working pressure rating. Working pressure rating (WPR) is defined as the capacity to resist working pressure (WP) with sufficient capacity against the actual anticipated positive-pressure surges above WP. WP is defined as the maximum anticipated, sustained operating pressure applied to the pipe exclusive of transient pressures.

The PC is the maximum allowable sustained pressure and includes the maximum recurring and sustained surge pressures at operational temperatures through 73°F (23°C). Recurring surge pressures occur frequently and are inherent in the design and operation of the system; recurring surge pressure may be caused by normal pump start-up or shut-down and normal valve opening or closure. Occasional surge pressures are caused by emergency operations and are often the result of a malfunction, such as a power failure or system component failure, valve-stem failure, and pressure-relief valve failure. Where the operating temperature is above 73°F (23°C) or surge pressures are expected to be higher than those allowed by the PC definition, or if both conditions apply, the WPR must be reduced below the PC. The WPR can never exceed the PC. WP, WPR, and PC are related as follows:

$$WP \leq WPR \leq PC \quad (7)$$

When PEX pipe operates at 73°F (23°C) or less and the expected recurrent surge pressures (P_{RS}) or occasional surge pressures (P_{OS}) are within the limits established ($P_{RS} = 0.5 \times PC$ and $P_{OS} = 1.0 \times PC$, respectively), the WPR equals the PC:

$$WPR = PC \quad (8)$$

When PEX pipe operates at temperatures above 73°F (23°C), a temperature compensation multiplier, F_T , is used to reduce the PC and the allowance for pressure surges; to determine the WPR:

$$WPR = PC \times F_T \quad (9)$$

Temperature compensation multipliers, F_T , are shown in Table 6.

WPR must also be evaluated to account for the expected recurrent (P_{RS}) or occasional (P_{OS}) surges with the pipe system.

For recurring surges, WPR is one and a half times the pipe's PC adjusted for temperature, less the maximum pressure allowance resulting from recurring pressure surges (P_{RS}):

$$WPR = 1.5(PC)(F_T) - P_{RS} \quad (10)$$

For occasional surges, WPR is two times the pipe's PC adjusted for tem-

perature, less the maximum pressure allowance resulting from occasional pressure surges (P_{OS}):

$$WPR = 2(PC)(F_T) - P_{OS} \quad (11)$$

The WPR is the smallest number determined in accordance with Eqs 9–11.

Operating at a WP that is less than the pipe's PC provides additional capacity for surge pressure. However, surge allowance is applied exclusively for surge events and cannot be used to increase WP.

External loads. Earth loads. For properly installed small-diameter pipe, the effects of distributed earth loads can usually be disregarded. Also refer to the subsequent section on buried pipe.

Live loads. Pipe should be installed to avoid construction loads and subsequent traffic loads. If the installation is to be subjected to surface traffic, a minimum cover of 24 in. (610 mm) should be provided, and trench backfill in the pipe zone should be compacted to at least 90% of the laboratory maximum density of the backfill soil as determined in accordance with ASTM D698 (2007b).

Concentrated loads. Pipe systems should be designed and constructed to preclude localized concentrated loadings such as point contact with stones; the effects of differential earth settlement, particularly at

TABLE 2 Outside diameter, tolerance, and wall thickness for PEX SDR9 pipe (CTS)

Nominal CTS Pipe Size—in. (mm)	Average Outside Diameter—in. (mm)	Tolerance for Average Diameter in. (mm)	Out-of-roundness* in. (mm)	Minimum Wall Thickness—in. (mm)	Tolerance for Wall Thickness—in. (mm)
½ (13)	0.625 (15.88)	±0.004 (±0.10)	0.016 (0.40)	0.070 (1.78)	+0.010 (+0.25)
¾ (19)	0.875 (22.22)	±0.004 (±0.10)	0.016 (0.40)	0.097 (2.47)	+0.010 (+0.25)
1 (25)	1.125 (28.58)	±0.005 (±0.12)	0.020 (0.48)	0.125 (3.18)	+0.013 (+0.33)
1¼ (32)	1.375 (34.92)	±0.005 (±0.12)	0.020 (0.48)	0.153 (3.88)	+0.015 (+0.38)
1½ (38)	1.625 (41.28)	±0.006 (±0.16)	0.024 (0.60)	0.181 (4.59)	+0.019 (+0.48)
2 (51)	2.125 (53.98)	±0.006 (±0.16)	0.030 (0.76)	0.236 (6.00)	+0.024 (+0.61)
2½ (64)	2.625 (66.68)	±0.007 (±0.18)	0.038 (0.95)	0.292 (7.41)	+0.030 (+0.76)
3 (76)	3.125 (79.38)	±0.008 (±0.20)	0.045 (1.14)	0.347 (8.82)	+0.033 (+0.84)

CTS—copper tubing size, PEX—cross-linked polyethylene, SDR—standard dimension ratio

*The out-of-roundness tolerance applies only to pipe before coiling.

points of connection with rigidly anchored fittings and rigid pipes; and excessive bending as a result of the installation configuration. Refer to the section on penetrating foundation or basement walls.

Resistance to buckling. A pipe may be subject to net negative internal pressure as a result of internal transients, external loads (such as hydrostatic pressure exerted on a pipe buried below the water table), or a combination of the two. To resist the combined effect of internal and external loads, a pipe/soil system must offer adequate resistance to buckling. Refer to the section titled “Wall Buckling” in chapter 5 of AWWA Manual M55 (2005a).

Friction loss, pressure loss, and flow velocity. Standard engineering design procedures may be used to select the appropriate nominal diameter of PEX pipe. Friction loss calculations for PEX pipe may be computed using the Hazen-Williams Formula (Eq 12) and a *C* factor of 150 for water at ambient temperatures.

The Hazen-Williams Formula (for pressure pipes flowing full of water) is as follows:

$$H = 0.002083 \times L \times \left(\frac{100}{C}\right)^{1.85} \times \frac{Q^{1.85}}{D_i^{4.87}} \quad (12)$$

in which *H* = friction loss in feet of water, the Hazen-Williams pipe flow coefficient (*C*; dimensionless) = 150 for PEX, *Q* = volumetric flow rate in gpm, and *D_i* = inside diameter of the pipe in in.

From Eq 12, the pressure loss for the length of pipe *L* may be converted to psi by dividing the friction loss *H* by 2.31. Refer to Tables 4 and 5 for friction loss in psi per 100 ft for various PEX sizes.

The velocity of the fluid flow may be calculated from the rate of fluid flow and the pipe’s average inside diameter. A commonly used formula is as follows; refer to Tables 4 and 5 for tabulated results:

$$V = 0.4085 \frac{Q}{D_i^2} \quad (13)$$

in which *V* = average velocity of fluid flow in fps.

Friction losses that develop in piping components such as elbows and tees are generally expressed as loss of head in feet or as an equivalent length of straight pipe of the same size that would produce the same head loss at the flow conditions for which the pipeline is designed. For the various sizes of fittings and valves, test data indicate that the ratio of equivalent pipe length to inside pipe diameter tends to be a constant value. Representative values of equivalent pipe lengths are listed in Table 7. After the equivalents of all components in a pipeline are determined, they must be added to straight pipe length before computing the total head loss.

INSTALLATION

Storage and handling. PEX pipe should be stored in a way that prevents damage as a result of crushing or piercing, excessive heat, harmful chemicals, or exposure to sunlight for prolonged periods. See the previous section on UV resistance.

PEX pipe is not subject to breakage during normal handling. However, it is subject to damage from hard objects with sharp edges that could scratch, cut, or gouge the pipe during installation. Handling operations, trench installation, and backfill operations should be performed with rea-

sonable care to prevent scratches, nicks, and gouges in the pipe.

Avoid dragging pipe over rough ground and installing by pulling through auger or bored holes containing sharp-edged material to prevent damage by abrasion and cutting. Uncoiling and other handling should be done to avoid kinking. Remove and replace the damaged portion of the kinked pipe and pipe that is cut or scratched to a depth greater than 10% of its wall thickness.

Bending the pipe. Bends in PEX are not permitted closer than 10 pipe diameters from any fitting or valve. Do not bend PEX pipe tighter than the minimum recommended bending radii as shown in Table 7.

Joining methods and fittings. Fittings used on service line applications should be insert-stiffener type for use with C904 PEX pipe and complying with the material and performance requirements of AWWA C800 (2005b) or other standards identified subsequently and the manufacturer’s requirements for dimensions and tolerances. C800 covers valves, fittings, service saddles, and meter setters for use in service lines from the main through the meter valve or meter setting appurtenance. Valves, fittings, and meter setters described in this standard include ½ in. (12.5 mm) through 2 in. (50.8 mm). Service saddles described have outlet sizes ½ in. (12.5 mm) through 2 in. (50.8

TABLE 3 Average ID for PEX SDR9 Pipe (CTS)

Nominal CTS Pipe Size—in. (mm)	Average Inside Diameter*—in. (mm)
½ (13)	0.475 (12.07)
¾ (19)	0.671 (17.04)
1 (25)	0.865 (21.97)
1¼ (32)	1.055 (26.80)
1½ (38)	1.245 (31.62)
2 (51)	1.629 (41.38)
2½ (64)	2.011 (51.08)
3 (76)	2.399 (60.93)

CTS—copper tubing size, ID—inside diameter, OD—outside diameter, PEX—cross-linked polyethylene, SDR—standard dimension ratio

*Average ID is a calculated value used to estimate flow. It is not a specified dimension. Do not use average ID for sizing ID insert components. Average ID is calculated based on the average OD and the average allowable wall thickness: ID = average OD – 2 × (minimum wall thickness + ½ the tolerance).

mm), and they have fit mains of 2 in. (50.8 mm) through 12 in. (304.8 mm). Valves include corporation stops and curb stops. Fittings include various types of couplings and adapters. Service saddles include various types of devices circumferentially attached to the main. For other sizes, consult the manufacturer. Currently, PEX is not listed in C800; testing has been done with C800 fittings and PEX tubing and the test report is available from PPI upon request; the AWWA PEX Task Group will join the AWWA C800 Committee and recommend the addition of PEX.

PEX pipe can be joined to other PEX pipe or fittings or to pipe or appurtenances of other materials using one or more joining systems or transitional fittings. The purchaser should verify with the pipe and fittings manufacturer(s) that selected fittings are compatible with the pipe and capable of restraining PEX pipe from pullout, especially for larger-diameter products with thicker walls. Pressure classes for pipe and fittings

should be the same or compatible. Further information and specific procedures may be obtained from the pipe and fittings manufacturers.

Cold expansion fittings with PEX reinforced rings. Cold expansion fittings are available in a variety of configurations including couplings, tees, and adapters. ASTM F1960 (2011b) is applicable to fittings that use a PEX reinforcing ring.

Pipe ends should be prepared by cutting the pipe end square using a cutter tool designed for cutting plastic pipe. Connections are made by sliding a PEX ring over the PEX pipe and using a special tool to expand the ring and pipe simultaneously. The expanded pipe and PEX ring then slide over the cold expansion fitting. The connection is made as the PEX pipe and flex ring shrink over the inserted fittings. Do not install cold expansion fittings in temperatures below 5°F (15°C).

Cold expansion fittings with metal compression sleeves. Cold expansion fittings with metal com-

pression sleeves are available for PEX pipe in a variety of configurations including couplings, elbows, tees, and adapters. ASTM F2080 (2009a) is applicable to cold expansion fittings that use a metal compression sleeve.

The PEX pipe is inserted through the metal compression sleeve, then the end of the PEX pipe is expanded with a special expander tool. The fitting is inserted into the PEX pipe until the pipe is against the shoulder of the fitting, and the PEX is allowed to shrink over the fitting. A special tool is used to pull the metal compression sleeve over the PEX and fitting until the sleeve contacts the shoulder of the fitting.

Metal and plastic insert fittings. Metal and plastic insert fittings using a copper crimp ring are available for PEX pipe in a variety of configurations including couplings, tees, and adapters. This type of fitting uses a metal crimp ring that is compressed around the PEX piping to secure it to the fitting. Fittings can be made of

TABLE 4 Pressure loss and velocity versus flow rate for PEX SDR9 pipe (CTS)

Nominal Size gpm	½ in.		¾ in.		1 in.	
	Pressure Loss psi/100 ft	Velocity—fps	Pressure Loss psi/100 ft	Velocity—fps	Pressure Loss psi/100 ft	Velocity—fps
1	1.6	1.8				
2	5.8	3.6	1.1	1.8		
3	12	5.4	2.3	2.7	0.7	1.6
4	21	7.2	3.9	3.6	1.1	2.2
5	31	9.1	5.8	4.5	1.7	2.7
6	44	11	8.2	5.4	2.4	3.3
7	59	13	11	6.4	3.2	3.8
8			14	7.3	4.0	4.4
9			17	8.2	5.0	4.9
10			21	9.1	6.1	5.5
11			25	10	7.3	6.0
12			29	11	8.6	6.6
13			34	12	9.9	7.1
14			39	13	11	7.6
15					13	8.2
20					22	11
25					33	14

CTS—copper tubing size, PEX—cross-linked polyethylene, SDR—standard dimension ratio

Pressure loss at 60°F in psi/100 ft of pipe; CTS pipe manufactured per ASTM F876 (2010a) and F877 (2011g); calculations performed per information in section on Friction loss, pressure loss, and flow velocity and Table 3

copper, brass, bronze, stainless steel, or plastic. The fitting will typically have a barbed or ribbed annular end. Before making the connection, the metal crimp ring is slid over the PEX piping and away from the end of the pipe. The piping is pushed over the fitting, the crimp ring is aligned over the fitting ribs, and a tool is used to compress the crimp ring around the assembly forcing the pipe material into the annular spaces formed by the ribs of the fitting. ASTM F1807, F2159, F2434, and F2735 (2011c, 2011d, 2010c, and 2009b, respectively) are applicable to metal and plastic insert fittings.

Dezincification of copper alloy fittings. Under some conditions, dezincification selectively removes zinc from certain alloys, leaving behind a porous, copper-rich structure that has little mechanical strength. An in-service valve or fitting suffering from

dezincification has a white powdery substance or mineral stains on its exterior surface. The valve may exhibit water weeping from the valve body or stem/bonnet seal (NACE, undated).

The service conditions that are generally present where dezincification occurs include:

- Water with high levels of oxygen and carbon dioxide (uniform attack)
- Stagnant or slow-moving waters (uniform attack)
- Slightly acidic water, low in salt content and at room temperature (uniform attack)
- Soft, low-pH, and low-mineral water combined with oxygen, which forms zinc oxide (uniform attack)
- Waters with high-chloride-ion content (uniform attack)
- Neutral or alkaline waters, high in salt content and at or above room temperature (plug-type attack; NACE, undated)

These conditions should be avoided to minimize dezincification and potential copper alloy fitting leaks. Selection of appropriate fitting materials should be based on the water quality conditions. Qualify each fitting by independent third-party test results when necessary to determine whether the fitting is safe for the intended service.

Fusion fittings. PEX piping cannot be joined by solvent cementing or by socket or butt fusion. However, consult the pipe manufacturer to determine whether electrofusion is approved for the pipe; electrofusion fittings should comply with ASTM F1055 (2011e).

Connections to other materials. Solder copper-transition fittings onto the copper pipe and allow cooling before connecting to PEX pipe. High heat (greater than 180°F) may damage the PEX pipe. Do not use plastic male

TABLE 5 Pressure loss and velocity versus flow rate for PEX SDR9 pipe (CTS)

Nominal Size gpm	1¼ in.		1½ in.		2 in.		2½ in.		3 in.	
	Pressure Loss psi/100 ft	Velocity ft/sec	Pressure Loss psi/100 ft	Velocity ft/sec	Pressure Loss psi/100 ft	Velocity ft/sec	Pressure Loss psi/100 ft	Velocity ft/sec	Pressure Loss psi/100 ft	Velocity ft/sec
5	0.6	1.8	0.3	1.3						
10	2.3	3.7	1.0	2.6	0.3	1.5				
15	4.9	5.5	2.2	4.0	0.6	2.3	0.2	1.5		
20	8.4	7.3	3.7	5.3	1.0	3.1	0.4	2.0	0.2	1.4
25	13	9.2	5.6	6.6	1.5	3.8	0.5	2.5	0.2	1.8
30	18	11	7.9	7.9	2.1	4.6	0.8	3.0	0.3	2.1
35	24	13	11	9.2	2.8	5.4	1.0	3.5	0.4	2.5
40			13	11	3.6	6.2	1.3	4.0	0.6	2.8
45			17	12	4.5	6.9	1.6	4.5	0.7	3.2
50			20	13	5.5	7.7	2.0	5.1	0.8	3.5
60					7.7	9.2	2.8	6.1	1.2	4.3
70					10	11	3.7	7.1	1.6	5.0
80					13	12	4.7	8.1	2.0	5.7
90							5.8	9.1	2.5	6.4
100							7.1	10	3.0	7.1
120							10	12	4.2	8.5
140									5.6	9.9
160									7.2	11
180									8.9	13

CTS—copper tubing size, PEX—cross-linked polyethylene, SDR—standard dimension ratio

Pressure loss at 60°F in psi/100 ft of pipe; CTS pipe manufactured per ASTM F876 (2010a) and F877 (2011g); calculations performed per information in section on Friction loss, pressure loss, and flow velocity and Table 3

threads or nongasketed female threads when making a connection to metal threads. Use only manufacturer's recommended transition fittings. When making connections to chlorinated polyvinyl chloride pipe or fittings, use only approved transition fittings.

Expansion/contraction. Whenever possible, pipe should be "snaked" back and forth within the trench to provide additional stability against anticipated temperature fluctuations. Any additional expansion or contraction of the piping material that may result from temperature variation after the pipe has been placed in service is restrained by the friction between the pipe and its embedment.

Thawing PEX pipe systems. Several suitable methods exist to thaw water frozen inside PEX pipe. They include:

- pumping heated water through the pipe to the ice blockage and returning the cooled water for reheating,
- exposing the buried pipe and applying wet hot towels,
- exposing the buried pipe and applying hot water,
- exposing the buried pipe and using a hand-held hair dryer or electric heat gun, or
- exposing the buried pipe and applying low-wattage electrical heating tape.

PEX pipe systems should not be intentionally subjected to freezing. If water does freeze inside PEX pipes, do not use flames, open torch, or excessive heat to thaw the pipe. Pipe failure, injury, or damage can result. Heat must be applied directly and carefully to the frozen pipe section. Use one of the previously mentioned methods; do not use a torch. Tem-

perature on the pipe shall not exceed 180°F. Do not use high-pressure positive-displacement pumping equipment to clear an ice-blocked line. Doing so can force an ice plug down the line at extremely high velocity, and if the plug stops suddenly at a valve or fitting, the resulting surge pressure can burst the line.

Horizontal directional drilling. Horizontal directional drilling (HDD) uses trenchless directional drilling techniques to guide a drill string along a bore path around or under obstacles such as rivers or lakes or through congested underground infrastructure. HDD may be used to install a casing or to directly install long strings of C904 pipe. Information on HDD of PE pipe is available in ASTM F1962 (2011f), in chapter 12 of the PPI *Handbook of Polyethylene Pipe* (2008a), and in PPI TR-46 (2010). Consult the PEX manufacturer for assistance in applying this information to PEX pipe.

Buried pipe. In underground installations, PEX pipe should be installed in trench bottoms that provide continuous support and are free from rocks, stones, and debris (ASTM D2774, 2008). The initial backfill, from 3 in (76 mm) below the pipeline to 4 to 6 in (100 to 150 mm) above the pipe, should be sand or other granular materials, as required in ASTM D2774. To prevent freezing in water lines, the pipe should be installed below the frost line.

Penetrating foundation or basement walls. When PEX is run through a basement or foundation wall, it must be protected by a rigid sleeve that spans the distance from within the

wall out to the undisturbed soil in the pipe trench. The sleeve should start at least 12 in. away from the wall. The purpose of this protective sleeve is to prevent shearing of the PEX pipe at the wall in the event there is settlement in the backfill along the wall. At the point where the sleeve terminates inside the foundation or wall, the space between the PEX and the sleeve should be sealed with an approved compatible material to prevent leakage into the building. Refer to PPI TN-39 (2007b), specifically sections 3 and 4, for more information about sleeving PEX pipe. Also, use protective sleeves when PEX is joined to a rigid pipe that is not free to settle in the same way as the PEX pipe.

Petroleum-based caulks or sealants should not come in direct contact with PEX. Per PPI TN-39 (2007b), compatible sealants include latex caulk, latex foam, silicone sealant, and polyurethane expanding foam.

Slab-on-grade installation. *Laying and supporting piping within and under a slab.* Only continuously run lengths of pipe without fittings shall be used when installing PEX within or under a slab. All connections should be outside or above the slab. For under-slab installations, the pipe should be completely buried by a suitable, easily compacted, backfill material such as sand or pea gravel. For within-slab installations, PEX pipe should be installed under the rebar, remesh, or tensioning cables in the slab. PEX pipe should be covered or fastened to prevent the pipe from floating or being pulled up to the slab surface. PEX pipe does not have to be sleeved its entire length where it lies within or under a slab. PEX pipe should be protected with a nonmetallic sleeve where it comes through the slab. Because PEX is flexible, it may need support to keep it from falling back onto the slab once it exits the slab. To prevent this, PEX can be carefully tied to rebar, wood stakes, or a rigid drain pipe for support. This will serve to protect the PEX pipe as the slab is

TABLE 6 Temperature compensation multipliers, F_T

Maximum Operating Temperature—°F (°C)	Temperature Compensation Multiplier— F_T
Below 81 (28)	1.0
81–90 (28–32)	0.9
91–100 (33–38)	0.8
Above 100 (38)	Consult the pipe manufacturer

Source: AWWA, 2005a

poured, leveled, and smoothed and from subsequent framing and construction work. Protect PEX pipes from sharp edges. Refer to PPI TN-39 (2007b; sections 3 and 4) for more information.

Protection of pipe and fittings from UV exposure after the pour.

Because of the nature of slab-on-grade installations, pipe and fittings may be exposed to UV light for unspecified periods of time after the slab is poured and before the structure is framed and enclosed. To prevent damage from UV exposure, PEX pipe and fittings that are exposed above the slab shall be wrapped with an opaque covering such as black polyethylene bags or sheeting immediately after the pouring of the slab. This covering should extend down to the surface of the slab. For specific limitations on UV exposure, consult the PEX pipe manufacturer.

Consult with the pipe manufacturer before allowing adhesive tape to contact PEX pipes to prevent any issues with compatibility.

Disinfection. If required, disinfection for PEX water service tubes can be performed according to AWWA C651, Disinfecting Water Mains (2005c). PEX service tubes may be disinfected with potable water mains. All repairs and new installations should be disinfected before

using the line to transport water for the general public.

Prolonged exposure to pipe disinfection chemicals can be damaging to the pipe and is to be avoided. As soon as the pipe disinfection period is over, the disinfectant should be flushed with fresh water. Since chlorine residual is hazardous to fish and animals; the installer is cautioned to dispose of the chlorinated test and disinfection medium in a safe and environmentally acceptable fashion. All disposals should be in accordance with local, state, or federal codes.

The disinfection should take place after the initial flushing and after the completion of the pressure testing. Provisions should be made to avoid contamination of existing mains by cross-connection during flushing, testing, and disinfection of newly installed pipelines.

Filling and flushing. Filling and flushing are not commonly used for service tubes.

Filling. The pipe should be filled slowly, limiting the flow to low velocities that prevent surges and air entrapment. Air valves at high points should be open to allow air to escape as the water level increases inside the pipe. If permanent air valves are not required at all high points, the contractor should install temporary valves at these points to expel air during filling. Loosening connections

to bleed air from the system is not recommended. The critical filling rate for pipes with air vents is usually based on 5–15% of the pipe design flow. For air valves, the filling rate is limited by orifice size and the fact that the seat will blow shut when air passing through the valve reaches sonic velocity. A typical maximum filling rate for a pipe system with 2-in. air valves is 2 cu ft/s. However, the maximum filling velocity in the pipeline should never exceed the design velocity.

Flushing. To prevent damage to valves or other fittings from any foreign material left in the pipeline, the pipe should be thoroughly flushed before testing. Flushing can be accomplished by opening and closing hydrants, blow-offs, or drains with flow velocities sufficient to flush the foreign material from the pipeline. A minimum velocity of 3 fps is suggested. The initial flushing should be continued until the discharge appears clean; however, the minimum duration should be based on three changes of pipeline volume.

Pressure- or leak-testing and inspection of the completed system. Pressure- or leak-testing are required to verify system integrity. Conduct a hydrostatic pressure test or a hydrostatic leak test as follows:

Hydrostatic pressure test. Test the system hydrostatically with water.

TABLE 7 Representative equivalent pipe length of various piping components

Piping Component	Equivalent Length in Pipe Diameters (L_{eq}/D_i)	Nominal Pipe Diameter—in.							
		½	¾	1	1¼	1½	2	2½	3
		Pipe Inner Diameter (D_i)—in.							
		0.475	0.671	0.865	1.055	1.245	1.629	2.011	2.399
Equivalent Pipe Length—in.									
90° Molded elbow	40	19	27	35	42	50	65	80	96
Equal outlet tee, run/branch	80	38	54	69	84	100	130	161	192
Equal outlet tee, run/run	27	13	18	23	28	34	44	54	65
Insert couplings	12	6	8	10	13	15	20	24	29
Male–female insert adapters	18	9	12	16	19	22	29	36	43

Test pressure shall be at least equal to the expected working pressure (main pressure), but not less than 40 psi and not greater than 1.25 times working pressure at 73°F for a minimum duration of 15 minutes and maximum of two hours (refer to the previous section on working pressure rating). Check local codes.

Do not allow the water in the system to freeze.

Suitable precautions should be taken to eliminate hazards to personnel in the proximity of lines being tested in the event of a piping system rupture.

The system should be tested for leaks in accordance with the applicable code or engineering standards.

The critical leak rate for the pipeline system is usually specified in the contract documents. If any tests show leakage greater than that allowed, the installer is responsible for locating and repairing leaks and retesting until the test results are within the acceptance criteria. Retesting can be performed after depressurizing the pipeline and allowing it to “relax” for at least eight hours. All visible leaks must be repaired.

Never attempt to repair leaks while the system is under pressure. Always depressurize the system before repairing leaks.

Hydrostatic leak test. As an alternative to a hydrostatic pressure test, hydrostatic leak tests are conducted in accordance with ASTM F2164 (2010d) at a minimum pressure of 40 psi and a maximum pressure of 1.25 times the WP; the test time should not exceed the maximum total testing time specified in F2164. Currently, F2164 does not mention PEX; the AWWA PEX Task Group will initiate a project to update ASTM F2164 to include PEX.

Records. The test records should be provided by the contractor as required by the owner; in the absence of such requirements, the contractor shall provide the owner with test records for the pressure test or the ASTM F2164 leak test.

OPERATIONS AND REPAIRS

Disinfecting water mains. If required, disinfection for PEX water service tubes can be performed in accordance with AWWA C651 (2005c). Additional information is provided in the previous section on disinfection.

Cleaning. If required, clean new installations or lines after repair via the water-jet process or by forcing a soft pig through the line. Water-jet cleaning is available from commercial services. Cleaning usually uses water sprayed at high pressure from a nozzle that is drawn through the pipe system with a cable.

Operations. A good maintenance program for PEX water distribution and main piping systems will include the same elements used for other available piping materials. It is recommended that the system operator have:

- a means for locating pipes,
- records of system performance including:
 - unbillable water loss,
 - tests for system efficiency including flow coefficient,
 - tools required for installation and repair, and
 - repairs, downtime, and causes.

Repairs. Repairing PEX pipe is similar to repairing copper and high-density polyethylene water pipe. Couplings, as described in the previous sections on joining methods and fittings, may be used. The first step in making a repair is determining the problem.

A puncture can cause a small hole in the pipe. Punctures can be repaired using a standard repair coupling.

When a backhoe or other outside force ruptures, severs, or severely damages PEX pipe, the damaged section must be cut out and replaced. Refer to the previous section on joining methods and fittings and/or AWWA C800 (2005b). The pipe must be depressurized.

SAMPLE SPECIFICATIONS

Scope. This specification is for flexible cross-linked polyethylene

(PEX) municipal and utility water service pipe up to 3-in. nominal size.

Material. Service pipe shall be PEX piping manufactured in accordance with AWWA C904 (2006).

- Pipe shall be certified to AWWA C904 for water service by approved testing agencies.

- Pipe shall have a minimum chlorine-resistance designation code of 1 as tested in accordance with ASTM F2023 (2010b) and as specified in ASTM F876 (2010a).

- Pipe materials shall be listed in PPI TR-4 (2009).

- Pipe shall be certified to NSF/ANSI Standard 61 (2007a) for use with potable water.

- On request by the specifier, pipe shall also be certified to NSF/ANSI Standard 14 (2007b).

Markings. Piping shall be marked in accordance with AWWA C904 Section 6.1.

Shipping and delivery. Piping shall be shipped and delivered in accordance with AWWA C904 Section 6.2.

Affidavit of compliance. The Affidavit of Compliance shall be in accordance with AWWA C904 Section 6.3.

Installation. Pipe shall be installed according to manufacturer’s instructions and engineer’s specifications in accordance with AWWA C904 and local codes.

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<http://dx.doi.org/10.5942/jawwa.2012.104.0045>

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