GUIDE TO HIGH-TEMPERATURE APPLICATIONS OF NON-POTABLE PEX PIPE AND TUBING SYSTEMS

TN-52

2017

PLASTICS · PIPE · INSTITUTE®

THE VOICE OF AN INDUSTRY

105 Decker Court • Suite 825 • Irving, Texas 75062 • 469.499.1044 • www.plasticpipe.org

Foreword

GUIDE TO HIGH-TEMPERATURE APPLICATIONS OF NON-POTABLE

PEX PIPE AND TUBING SYSTEMS

This technical note was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute (PPI). These members have shown their commitment to developing and improving quality products by assisting standards development organizations in the development of standards, and also by developing design aids and reports to help engineers, code officials, specifying groups, contractors and users.

The purpose of this technical note is to provide information to the end user regarding the additional evaluation that is required for PEX pipes to show its suitability for an anticipated lifetime in specific high-temperature applications.

The PPI has prepared this technical note as a service to the industry. The information in this report is offered in good faith and believed to be accurate at the time of its preparation, but is offered "as is" without any express or implied warranty, including WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. Additional information may be needed in some areas, especially with regard to unusual or special applications. Consult the manufacturer or material supplier for more detailed information. A list of member manufacturers is available on the PPI website. PPI does not endorse the proprietary products or processes of any manufacturer and assumes no responsibility for compliance with applicable laws and regulations.

PPI intends to revise this technical note within 5 years or sooner if required, from the date of its publication, in response to comments and suggestions from users of the document. Please send suggestions of improvements to the address below. Information on other publications can be obtained by contacting PPI directly or visiting our website.

The Plastics Pipe Institute Inc.

www.plasticpipe.org

This Technical Note was first issued in June 2017.

GUIDE TO HIGH-TEMPERATURE APPLICATIONS

OF NON-POTABLE PEX PIPE AND TUBING SYSTEMS

1.0 SCOPE

The intent of this Technical Note is to give guidance to the end user for determining appropriate design life calculations of crosslinked polyethylene (PEX) pipe and tubing in high-temperature applications, defined as operating temperatures above 180°F (82°C) for the purpose of this document. Not all PEX manufacturers allow operating conditions above 180°F for their tubing. Applications with such high-temperature exposures may include commercial hydronic distribution systems such as high-temperature radiator/baseboard piping, district heating piping, and certain types of waste heat systems.

The **Background** information in this Technical Note is provided to explain how PEX pipe and tubing, conforming to standards such as ASTM F876, ASTM F2788 and CSA B137.5, are suitable for typical applications such as hydronic radiant heating/cooling, hydronic distribution, snow and ice melting, and geothermal ground heat exchangers at operating temperatures up to and including 180°F.

Note 1: For PEX materials, "tubing" refers to products whereby the actual outside diameter (OD) is 1/8 inch larger than the nominal size and is described as copper tube size (CTS). Product standards ASTM F876 and CSA B137.5 apply to PEX tubing. "Pipe" refers to products whereby the actual OD matches that of steel pipe of the same nominal size and is described as iron pipe size (IPS), or products where the actual OD matches the nominal size. ASTM F2788 applies to PEX pipe. The terms "pipe" and "piping", as well as "tube" and "tubing", are used interchangeably in this document.

Note 2: See PPI TN-53 GUIDE TO CHLORINE RESISTANCE RATINGS OF PEX PIPES AND TUBING FOR POTABLE WATER APPLICATIONS *for more information on the use of PEX tubing in hot chlorinated potable water applications.*

2.0 BACKGROUND

It is a basic requirement for most plastic pressure pipes[1] to undergo a hydrostatic pressure test or tests to prove their long-term hydrostatic strength (LTHS) at various temperatures. "Hydrostatic" simply means constant water pressure inside a pipe or tubing. Hydrostatic testing involves testing multiple pipe specimens to ductile failure at various temperatures and pressures; when a data-set of failure times at multiple temperatures and pressures is collected, a ductile failure curve is plotted and evaluated mathematically. This provides a method to predict pipe endurance at the specific operating pressures for each temperature.

---

[1] *The alternative to a long-term hydrostatic strength (LTHS) test is a long-term hydrostatic pressure-strength ($LTHS_p$) test, usually applied to multi-layer or composite piping products.*

Procedures for conducting long-term hydrostatic testing and evaluating the results were originally developed by PPI's Hydrostatic Stress Board (HSB) many decades ago. Today, these procedures are trusted to predict the long-term hydrostatic capabilities of crosslinked polyethylene (PEX) tubing, which achieves pressure ratings at various temperatures through extensive hydrostatic strength testing in accordance with the governing standards and policies such as ASTM D2837 and PPI TR-3.

The long-term hydrostatic strength of a specific PEX tubing is independent of any outside environmental factors which could cause tubing degradation or failure. Examples of environmental factors are oxidation of the tubing from excessive exposure to hot chlorinated water, excessive UV exposure or excessive thermal degradation. In North America, PEX tubing is required to establish its resistance to each type of oxidation through standardized testing and evaluation using test methods such as ASTM F2023 for hot chlorinated water oxidation, ASTM F2657 for UV exposure oxidation and mandatory requirements within ASTM F876 and ASTM F2788 for resistance to long-term high-temperature conditions.

This Technical Note will describe each of these test methods and evaluation techniques.

2.1 Evaluation Methods for Long-term Hydrostatic Strength (LTHS)

ASTM Test Method D2837 *Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products* (originally published 1969) contains a procedure for obtaining a long-term hydrostatic strength category based on stress, referred to herein as the hydrostatic design basis (HDB). According to D2837, "The HDB is a material property and is obtained by evaluating stress rupture data derived from testing pipe made from the subject material." "The LTHS is determined by analyzing stress versus time-to-rupture (that is, stress-rupture) test data that cover a testing period of not less than 10,000 hours and that are derived from sustained pressure testing of pipe made from the subject material. The data are analyzed by linear regression to yield a best-fit log-stress versus log time-to-fail straight-line equation."

This method utilizes tubing specimens tested at constant temperatures (e.g. 73 °F, 180°F, 200°F [23°C, 82°C, 93°C]) with the linear log stress—log time regression line extrapolated to 100,000 hours (11 years). This extrapolated value is called the long-term hydrostatic strength (LTHS) and the categorized value of the LTHS is called the Hydrostatic Design Basis (HDB).

When data is analyzed and approved by the PPI's Hydrostatic Stress Board, these HDB values are published in PPI TR-4 *PPI Listing of Hydrostatic Design Basis (HDB), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe*, which is available at www.plasticpipe.org. The hydrostatic design stress (HDS) is the product of the HDB and the design factor for water.

The HDB for a pressure pipe material must always be determined at 73°F. It is important to note that the Thermoplastic Pipe Material Designation Code, as shown in the applicable ASTM PEX standards (see Section 3.0), is ONLY determined using the HDB at 73°F.

If a material is also intended for use at higher temperatures (above 73°F), then an *elevated temperature HDB* should be established. The elevated temperature HDB method is discussed in more detail in PPI TR-9 *Recommended Design Factors and Design Coefficients for Thermoplastic Pressure Pipe*, along with a method for determining a temperature design factor (DF_T), to be applied if the service temperature exceeds the maximum established *elevated temperature HDB*. However, as stated in PPI TR-9, "*Temperature design factors should only be used when an established HDB is not available at the desired temperatures."*
The *elevated temperature HDB* establishes the Hydrostatic Design Basis for the specific material at chosen higher temperatures. The procedures of ASTM Test Method D2837 are still employed, using actual test temperatures of 140°F (60°C) or 180°F (82°C) or another test temperature as desired.

Elevated temperature HDB values are published in PPI TR-4 for PEX tubing materials which have been tested at those temperatures. Many plumbing codes require PEX tubing to be pressure-rated for 100 psig (gauge pressure) at 180°F, so this pressure rating is considered mandatory, and is based on hydrostatic testing as described above. PPI TR-3 also provides a method for determining the HDB at an intermediate temperature between 73°F and an elevated temperature (e.g. 180°F) by using the principles of mathematical interpolation.

Note 3: PEX listings within PPI TR-4 at 200°F should be considered within the context of this Technical Note.

2.2 Evaluation Methods for Oxidative Resistance to Hot Chlorinated Water

To ensure the reliability of PEX pipe or tubing systems in hot chlorinated potable water applications, product standards ASTM F876 and F2788 require that all PEX tubing intended for use with potable water have a minimum extrapolated time-to-failure when tested in accordance with ASTM Test Method F2023: *Standard Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Pipe, Tubing and Systems to Hot Chlorinated Water* (originally published in 2000). The minimum extrapolated time-to-failure is 50 years, when evaluated at various operating conditions.

Note 4: See PPI TN-53 GUIDE TO CHLORINE RESISTANCE RATINGS OF PEX PIPES AND TUBING FOR POTABLE WATER APPLICATIONS *for more information on the use of PEX tubing in hot chlorinated potable water applications.*

2.3 Evaluation Methods for Outdoor Weathering Exposure

Each PEX tubing manufacturer publishes a maximum recommended ultraviolet (UV) exposure time limit for its tubing based on the UV resistance of that tube as determined in accordance with ASTM Test Method F2657 *Standard Test Method for Outdoor Weathering Exposure of Crosslinked Polyethylene (PEX) Tubing* (originally published 2007) and the requirements published in ASTM F876.

This test method outlines the requirements for specimen size and preparation, exposure orientation, minimum UV exposure energy, post-exposure testing and reporting. Central Arizona is used as the basis of the natural exposure time limits, as it represents the worst case North American location for UV solar radiation energy.

For PEX tubing intended for use in plumbing applications, UV-exposed tubes are re-tested for chlorine resistance in accordance with ASTM F2023 and must show no significant reduction in the extrapolated time-to-failure. For tubing not intended for use in plumbing distribution (such as those intended for heating or geothermal applications), UV-exposed tubes are re-tested for stabilizer functionality[2] in accordance with ASTM F876 and must show no significant reduction in the resistance to long-term high-temperature conditions.

ASTM F2657 ensures that all manufacturer claims of UV-resistance are evaluated in a consistent manner which is empirically derived.

2.4 Stabilizer Functionality Test for Long-term Thermal Stability

Like all thermoplastic piping materials, PEX compounds include stabilizers to guard against various types of degradation. To ensure the reliability of the material in high-temperature applications, product standards require that PEX tubing undergoes the “stabilizer functionality” test to demonstrate each specific compound’s ability to withstand long-term high-temperature conditions.

This test requires a specific stress at a given temperature for a set amount of time. There are two (2) options for testing:

- 3,000 hour (125 day) test at 248°F (120°C) and hoop stress of 101.5 psi (0.7 MPa), or
- 8,000 hour (333 day) test at 230°F (110°C) and hoop stress of 406 psi (2.8 MPa)

[2] *See Section 2.4 for explanation of the stabilizer functionality test*

This is a single time-point pass/fail test that does not generate a regression curve. It is not necessary for manufacturers to test specimens to failure, which may take 1000s of hours beyond the minimum requirements. However, actual failure data points *are required* to evaluate the long-term performance of the compound at high temperatures in accordance with Section 4.0.

3.0 THE PEX THERMOPLASTIC PIPE MATERIAL DESIGNATION CODE

The PEX Thermoplastic Pipe Material Designation Code[3], per the applicable ASTM standard, is the abbreviation for the material - PEX - followed by four numerals.

The first numeral refers to chlorine resistance in one of four categories, when tested in accordance with ASTM Test Method F2023 and evaluated in accordance with the applicable ASTM product standard (e.g. F876):

- A digit “0” indicates that the PEX pipe or tubing either has not been tested for chlorine resistance or does not meet the minimum requirement for chlorine resistance.
- A digit “1” indicates the PEX pipe or tubing has been tested and meets the applicable ASTM PEX standard requirement for minimum chlorine resistance at the end use condition of 25% of the time at 140°F (60°C) and 75% at 73°F (23°C).
- A digit “3” indicates that the PEX pipe or tubing has been tested and meets the applicable ASTM PEX standard requirement for minimum chlorine resistance at end use condition of 50% of the time at 140°F (60°C) and 50% at 73°F (23°C).
- A digit “5” indicates that the PEX pipe or tubing has been tested and meets the applicable ASTM PEX standard requirement for minimum chlorine resistance at end use condition of 100% of the time at 140°F (60°C).

The second numeral refers to UV resistance in one of four categories, when tested in accordance with ASTM Test Method F2657 and evaluated in accordance with ASTM F876:

- A digit “0” indicates that the PEX tubing either has not been tested for UV resistance or does not meet the next category for UV resistance.
- A digit “1” indicates that the PEX tubing meets the requirements for 1 month UV resistance.
- A digit “2” indicates that the PEX tubing meets the requirements for 3 months UV resistance.
- A digit “3” indicates that the PEX tubing meets the requirements for 6 months UV resistance.

The third and fourth numerals of the PEX Thermoplastic Pipe Material Designation Code refer to the HDS for water at 73°F in hundreds of psi, with tens and units of measure omitted.

[3] *See ASTM F412 for full explanation of the Thermoplastic Pipe Material Designation Code*

4.0 DISCUSSION ON PREDICTING DESIGN LIFE AT HIGH TEMPERATURES ABOVE 180°F

In three of the test methods mentioned above (2.1 Long-term Hydrostatic Strength, 2.2 Oxidative Resistance to Hot Chlorinated Water and 2.3 Outdoor Weathering Exposure), tubing specimens are tested to failure, generating multiple data points which are placed into regression curves that can be extrapolated for a specific time to verify the test data or estimated design life of a particular PEX compound at a given set of operating conditions. However, for predicting design life at high temperatures above 180°F, the stabilizer functionality test is utilized.

The stabilizer functionality test is a single time-point test (3,000 hour or 8,000 hour, depending upon selected test temperature) that verifies the resistance to thermal degradation at a given time duration. Typical applications of PEX tubes are in systems that spend a limited amount of time at high temperatures (above 180°F) and the remainder of their lifetime at lower temperatures. Even a high-temperature radiator system does not likely operate 100% of the time, due to temperature cycling and intermittent heating demand.

This variation in operating temperature of the pipe's lifetime is accounted for by performing the stabilizer functionality test, then applying Miner's Rule to extrapolate the tubing's design life at project-specific or customer-specific operating conditions, including system temperature and pressure (see ASTM F2023 classification and Table 1 and Table 2 in Appendix A of this document for ISO 15875 and EN 15632 applied classifications, respectively). However, if PEX tubing is intended to be used in a non-potable application at a high temperature continuously, then further evaluation of the thermal oxidation of the tubing needs to be taken into consideration in accordance with Section 5.0. This is a design process that the tubing manufacturer can perform, based on specific test data for their tubing.

5.0 PROCEDURE FOR PREDICTING DESIGN LIFE FOR CONTINUOUS USE APPLICATIONS AT HIGH TEMPERATURES ABOVE 180°F

For non-potable hydronic applications of PEX tubing with continuous exposure to temperatures above 180°F, further evaluations are required to predict the tubing design life. The ASTM F876/F2788 stabilizer functionality test only verifies a single time point, and does not include guidance for properly using this data to extrapolate the design life of tubing when used in high-temperature conditions. Fortunately, the ISO 9080[4] standard has established a mathematical guideline for extrapolating the design life of a tubing material by evaluating the long-term high-temperature test data along with the activation energy of the material in the Arrhenius equation.

The ISO 9080 method for determining the design life of PEX requires the extrapolation of the failure time for the specific formulation through a long-term high-temperature test. In order to determine the failure time, PEX tubing must be tested at

[4] *ISO 9080 - Plastics piping and ducting systems - Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation*

230°F (110°C) in accordance with ISO 15875-2 Table 8 *Thermal stability by hydrostatic pressure testing* until brittle failure occurs. This test is similar to the ASTM stabilizer functionality test, with the exceptions that the hoop stress is 2.5 MPa (instead of 2.8 MPa) and the samples are tested to failure (not just 8,000 hours).

After the failure time has been established, the k_e extrapolation factor from ISO 9080 is used to determine the maximum extrapolation time limit of the tubing. The k_e extrapolation factor is a function of the difference between the test temperature (e.g. 230°F [110°C]) and the design temperature of the specific application, (e.g. 190°F [88°C]) in degrees Celsius. Table 3 of *Appendix A* shows the different extrapolation time limits for PEX tubing based on testing at 230°F and theoretical failure times of 8,000 hours, 12,000 hours and 16,000 hours.

This type of high-temperature evaluation is very specific to the test data of each PEX compound, which is proprietary information to the tubing manufacturer; all PEX tubing will not have the same estimated design life at a given operating condition. Therefore, each tubing manufacturer must do this calculation on their own, based on their own exclusive dataset.

Therefore, for continuous-use high-temperature applications (operating temperatures above 180°F) users should contact the specific PEX tubing manufacturer to determine whether such conditions are approved for use, and if so, what may be the effects on tubing design life.

6.0 SUMMARY

It is not uncommon to find PEX pipe and tubing systems employed in high-temperature, non-potable, applications such as commercial hydronics, high-temperature radiator/baseboard piping, district heating piping, and waste heating applications with occasional or frequent fluid temperatures above 180°F. When a PEX tubing system is operated in this manner, the tubing manufacturer should be contacted to evaluate the estimated design life of the tubing, based on their specific test data and the design criteria.

Some PEX manufacturers allow operating temperatures only up to 180°F (82°C) and not beyond, whereas other manufacturers may allow operation of their material at temperatures up to 200°F (93°C). For all PEX pipe and tubing, the maximum operating temperature is 200°F. No PEX should be operated at temperatures above 200°F for any length of time.

The use of crosslinked polyethylene (PEX) pipe and tubing in high-temperature applications with operating temperatures above 180°F may affect the tubing's design life. PEX users should contact the specific pipe or tubing manufacturer to determine whether such conditions are approved for use, and if so, what may be the effects on material design life.

The PPI Building & Construction Division and member companies may be reached through our website www.plasticpipe.org.

Appendix A

ISO 15875 *Plastics piping systems for hot and cold water installations-Crosslinked polyethylene (PE-X)* defines PEX pipe for hot- and cold-water installations. Identified within this ISO standard are multiple classes of PEX for specific applications, each having their own Miner's Rule calculation to justify the 50-year anticipated design life.

These classes may be thought of as "temperature profiles", based on the anticipation of the accumulated exposures within a pipe's lifetime. In other words, it is assumed that an installed PEX pipe will be exposed to combinations of temperatures exposures no worse than those indicated in the tables below for Class 1 to 5. For instance, a Class 5 pipe is anticipated to be exposed to the various temperatures shown in the table for the accumulated services time at each of those temperatures. This is based on how a "high-temperature radiator" piping systems would actually be used over a 50-year period.

ASTM Standards F876 and F2788 do not utilize such temperature profile assumptions. However, North American PEX manufacturers with full data sets for each of the tests described within this Technical Note can calculate expected design lives for their PEX tubing.

The tables below show the different classes and their accumulated service times at each temperature.

Table 1: ISO 15875 Classification Tables using Miner's Rule

Class 1: Hot water supply (140°F)	
Temperature °F	Accumulative Service Time Years
140	49
Followed by	
176	1
Followed by	
203	100 hours

Class 2: Hot water supply (158°F)	
Temperature °F	Accumulative Service Time Years
158	49
Followed by	
176	1
Followed by	
203	100 hours

Class 4: Underfloor heating and low temperature radiators	
Temperature °F	Accumulative Service Time Years
68	2.5
Followed by	
104	20
Followed by	
140	25
Followed by	
158	2.5
Followed by	
212	100 hours

Class 5: High-temperature radiators	
Temperature °F	Accumulative Service Time Years
68	14
Followed by	
140	25
Followed by	
176	10
Followed by	
194	1
Followed by	
212	100 hours

EN 15632 *District heating pipes-Pre-insulated flexible pipe systems* defines pre-insulated pipe for district heating applications. Identified within this EN standard is a class system using Miner's Rule calculation to justify a 30-year anticipated design life at higher operating temperatures than anticipated in ISO 15875.

The table below shows a summary of this class and the accumulated service time at each temperature.

Table 2: EN 15632 Classification Table using Miner's Rule

Temperature °F	Accumulative Service Time Years
176	29
Followed by	
194	1
Followed by	
203	100 hours

The examples in Table 3 show the maximum extrapolation time limits for different temperatures when testing has been performed at 230°F (110°C) for 8,000 hours, 12,000 hours and 16,000 hours. The test data shown below is a theoretical example that does not reflect the capabilities of any given PEX formulation. Each manufacturer is responsible for generating their own test data to predict design life in various applications.

Table 3: Extrapolation Factor (k_e) Applied for Multiple Test Times of PEX Tubing

	Test data for 8,000 hours		Test data for 12,000 hours		Test data for 16,000 hours	
Continuous Operating Temperature °F	Test Time (hours)	Maximum Extrapolated Design Life in Years	Test Time (hours)	Maximum Extrapolated Design Life in Years	Test Time (hours)	Maximum Extrapolated Design Life in Years
165	8,000	33.1	12,000	49.7	16,000	66.2
175	8,000	18.2	12,000	27.2	16,000	36.3
185	8,000	10.2	12,000	15.2	16,000	20.3
195	8,000	5.8	12,000	8.7	16,000	11.6
200	8,000	4.4	12,000	6.6	16,000	8.8

Note: The k_e extrapolation factors in Table 3 were derived using the Arrhenius equation in the same manner as Table 1 in ISO 9080. However, the values in Table 3 above were not categorized as they are in Table 1 of ISO 9080. Instead, the values shown in Table 3 were specifically calculated for the temperatures shown in the Table.

Examples of Predicting Design Life for Continuous Use Applications for a Theoretical PEX Material

Example 1: A university campus is installing an underground district heating system that will operate continuously at 195°F (90°C) to supply hot water for individual hydronic heating systems.

- PEX Manufacturer X has tested their pipe at 230°F (110°C) for 8,000 hours as required by the ASTM stabilizer functionality test, and then stopped the test without failures. Manufacturer X is able to extrapolate the design life of their pipe to 5.8 years at 195°F as test data is only available to 8,000 hours.
- PEX Manufacturer Y has tested their pipe at 230°F until failure, which happened to be at 16,000 hours (approximately 2 years). Manufacturer Y can extrapolate the design life of their pipe to 11.6 years at 195°F based on the test data and the ISO 9080 evaluation.

Example 2: A homeowner is installing a hydronic radiator baseboard heating system that will operate continuously at 165°F (74°C) to supply hot water for individual room heating.

- PEX Manufacturer W has tested their pipe at 230°F (110°C) for 8,000 hours as required by the ASTM stabilizer functionality test, and then stopped the test without failures. Manufacturer W is able to extrapolate the design life of their pipe to 33.1 years at 165°F as test data is only available to 8,000 hours.
- PEX Manufacturer Z has tested their pipe at 230°F until failure, which happened to be at 12,000 hours (approximately 1 1/2 years). Manufacturer Z can extrapolate the design life of their pipe to 49.7 years at 165°F based on the test data and the ISO 9080 evaluation.