Designation: F2023 – 15

Standard Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Pipe, Tubing and Systems to Hot Chlorinated Water[1]

This standard is issued under the fixed designation F2023; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 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.

NOTE 1—Other known disinfecting systems (chlorine dioxide, ozone, and chloramines) are also used for protection of potable water. Free-chlorine is the most common disinfectant in use today. A PPI research project examined the relative aggressiveness of free chlorine and chloramines on PEX pipes, both at the same 4.0 ppm concentration and the same test temperatures. The results of the testing showed pipe failure times approximately 40% longer when tested with chloramines compared to testing with free chlorine, at the tested conditions. Based on these results, the data suggests that chloramines are less aggressive than free chlorine to PEX pipes.

1.2 Guidelines and requirements for test temperatures, test hoop stresses, and other test criteria have been established by prior testing of PEX pipe or tubing produced by the three most common commercial methods of cross-linking: silane, peroxide, and electron-beam (see Note 2). Other related system components that typically appear in a PEX hot-and-cold water distribution system can be evaluated with the PEX pipe or tubing. When testing PEX pipe or tubing and fittings as a system, it is recommended that the anticipated end-use fitting type(s) and material(s) be included in the test circuit since it is known that some fitting types and materials can impact failure times. Specimens used shall be representative of the piping product(s) and material(s) under investigation.

NOTE 2—The procedures described in this test method (with some modifications of test temperatures or stresses, or both) have been used to evaluate pipes manufactured from polybutylene (PB), polyethylene (PE), polypropylene (PP), multilayer (polymer-metal composite), copper, and stainless steel.

1.3 This test method is applicable to PEX pipe or tubing and systems used for transport of potable water containing free-chlorine for disinfecting purposes. The oxidizing potential of the test-fluid specified in this test method exceeds that typically found in potable water systems across the United States.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.5 The following precautionary caveat pertains only to the test method portion, Section 12, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1600 Terminology for Abbreviated Terms Relating to Plastics

D2122 Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings

F412 Terminology Relating to Plastic Piping Systems

F876 Specification for Crosslinked Polyethylene (PEX) Tubing

F2788/F2788M Specification For Metric and Inch-sized Crosslinked Polyethylene (PEX) Pipe

2.2 *ISO Standards:*

ISO 9080 Thermoplastic Pipe for Transport of Fluids—Methods of Extrapolation of Hydrostatic Stress Rupture Data to Determine the Long Term Strength of Thermoplastic Pipe

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[1] This test method is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.40 on Test Methods.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard

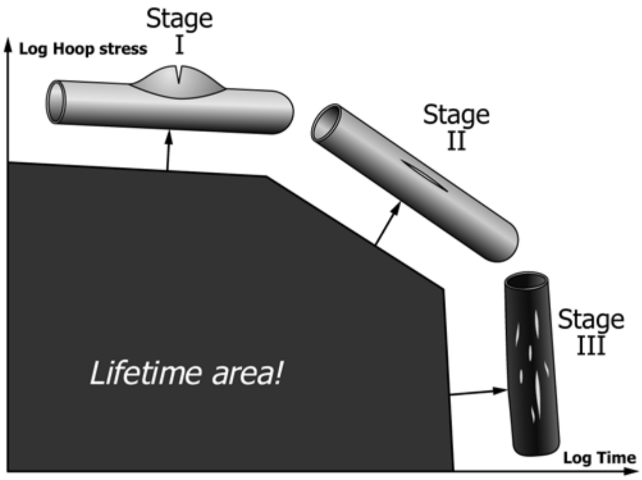

FIG. 1 Pictorial Illustration of Failure Types

ISO 13760 Plastic Pipe for the Conveyance of Fluids Under Pressure—Miners Rule—Calculation Method for Cumulative Damage[3]

2.3 *Plastics Pipe Institute (PPI) Document:*

TN-16 Rate Process Method for Projecting Performance of Polyethylene Piping Components[4]

2.4 *American Water Works Association (AWWA) Document:*

1996 WATER:\STATS Survey[5]

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions are in accordance with Terminology F412 and abbreviations are in accordance with Terminology D1600, unless otherwise indicated.

3.1.2 *brittle failure (Stage II), n*—failure in the pipe or tubing wall that is characterized by little or no material deformation in the failure area and is the result of a single crack emanating from the interior of the pipe or tubing to the outside surface typically resulting in a pinhole leak, see Fig. 1. Brittle failures produced with this test method shall not be used for data analysis.

3.1.3 *ductile failure (Stage I), n*—failure in the pipe or tubing wall that is characterized by obvious localized deformation of the material visible with the unaided eye, see Fig. 1. Ductile failures produced with this test method shall not be used for data analysis.

3.1.4 *environmental or oxidative failure (Stage III), n*—failure in the pipe or tubing wall characterized by a large number of cracks emanating from the interior surface of the pipe or tubing wall, see Fig. 1.

3.1.4.1 *Discussion*—Stage III failures may also be identified by a color shift in the failure area (typically brown or reddish-brown). Identification of environmental or oxidative failure, when not obvious by inspection with the unaided eye, can be performed with a 25× microscope or other similar device yielding the same level of magnification. Only Stage III environmental or oxidative failures shall be used for data analysis.

3.1.5 *hot-and-cold water distribution system, n*—a combination of components such as pipe or tubing, fittings, valves, and so forth, that when installed as a complete system, make up the interior water supply system of a commercial or residential structure.

3.1.6 *long-term oxidative resistance, n*—the extrapolated time-to-failure prediction as determined by analysis of time-to-failure test data by multiple linear regression utilizing the rate process method of PPI TN-16 or Model Q of ISO 9080. Where applicable, application of Miners Rule in accordance with ISO 13760 can be used to estimate time-to-failure at several differing conditions of temperature or stress, or both.

3.1.7 *multiple linear regression, n*—a three or four coefficient mathematical model used to analyze time-to-failure data from different temperatures and stresses to extrapolate projected time-to-failure at selected temperatures or stresses.

3.1.8 *Miners Rule, n*—a mathematical method for estimating the cumulative, irreversible damage that results from exposure to each of several differing conditions of stress or temperature, or both.

3.1.9 *oxidation reduction potential (ORP), n*—a measure of the total oxidizing power of a solution by means of a platinum-redox electrode. For a further explanation of ORP see Appendix X2.

3.1.10 *unaided eye, n*—observable without visual enhancement beyond correction for normal vision.

4. Summary of Test Method

4.1 The PEX pipe or tubing or pipe/tubing/fitting assemblies are exposed to pressurized test-fluid until failure. All time-to-fail data used for analysis shall be the result of oxidative degradation (Stage III). A minimum number of test temperature and hoop stress conditions are required to allow accurate data analysis and time-to-failure extrapolations.

5. Significance and Use

5.1 Environment or oxidative time-to-fail data derived from this test method, analyzed in accordance with Section 13, are suitable for extrapolation to typical end-use temperatures and hoop stresses. The extrapolated value(s) provides a relative indication of the resistance of the tested PEX pipe or tubing or system to the oxidative effects of hot, chlorinated water for conditions equivalent to those conditions under which the test data were obtained. The performance of a material or piping product under actual conditions of installation and use is dependent upon a number of factors including installation methods, use patterns, water quality, nature and magnitude of localized stresses, and other variables of an actual, operating hot-and-cold water distribution system that are not addressed in this test method. As such, the extrapolated values do not constitute a representation that a PEX tube or system with a given extrapolated time-to-failure value will perform for that period of time under actual use conditions.

[4] Available from Plastics Pipe Institute (PPI), 105 Decker Court, Suite 825, Irving, TX 75062, http://www.plasticpipe.org.

[5] Available from American Water Works Association (AWWA), 6666 W. Quincy Ave., Denver, CO 80235, http://www.awwa.org.

6. Apparatus

6.1 *Pressurized Flow-Through Test System*—A system comprised of the necessary pump(s), fittings, piping, heaters, sensors, and meters that is capable of maintaining the required test pressures within the tolerance specified in 9.1.3, the required test temperatures within the tolerance of 9.1.2, and flow the test-fluid through the specimens continually at a flow rate within the tolerance specified in 9.1.4. Cyclic pressure variations, such as those produced by some pumping systems, shall not produce pressure excursions that exceed the tolerance stated in 9.1.3.

6.1.1 *Recirculating Test System*—A flow-through test system that repeatedly reconditions the test-fluid and passes it through the specimens. For purposes of this test method, the test-fluid shall be monitored at a sufficient frequency to ensure that it continuously meets the test-fluid parameters and water quality criteria. A portion of the total system volume shall be purged and replaced with fresh test-fluid continually.

6.1.2 *Single-Pass Test System*—A flow-through test system that passes the test-fluid through the specimens only once and is discarded.

6.2 *Specimen Holders*—Test specimens shall be supported to minimize or eliminate externally induced stresses. Specimens shall be allowed to freely expand bi-directionally.

7. Sampling, Test Specimens, and Test Units

7.1 *Sampling*—Select at random, a sufficient amount of pipe or tubing to satisfy the specimen requirements of this test method. When testing as a system, randomly select a sufficient quantity of fittings.

7.2 *Test Specimen Size*—The PEX pipe or tubing specimens shall be 12 to 18 in. (300 to 460 mm) in length between fitting closures or between fitting joints.

7.2.1 *Dimensions Measurement*—Measure and record the critical dimensions for pipe or tubing and fittings. For pipe or tubing, measure the average outside diameter and wall-thickness in accordance with Test Method D2122. For fittings, measure those dimensions critical to the function of the joint, as well as minimum body wall thickness.

7.3 *Testing as a System*—When testing PEX pipe or tubing and related system components (such as fittings) as a system, the other components shall be attached to the PEX pipe or tubing in the same manner as in actual service. For fittings, the particular fitting style shall be installed in accordance with the manufacturer's instructions or the ASTM specification when applicable.

7.4 *Minimum Required Test Units*—A minimum of six test units is required. A test unit is comprised of two or more individual time-to-failure data points at the same temperature and hoop stress condition. Statistical reliability of the analysis of the resultant data will be benefited by obtaining additional data points at each temperature/hoop stress condition.

7.4.1 *Test Unit Distribution*—Time-to-failure data points shall be obtained at 2 test hoop stresses at each of a minimum of 3 test temperatures for a minimum of 12 data points. As an alternate, obtain time-to-failure data for the temperature/hoop stress combinations of the three-temperature matrix of PPI TN-16, see Note 3. Hoop stresses shall be separated by a least 80 psi (0.55 MPa).

NOTE 3—When using the PPI TN-16 matrix, Temperature T_3, which requires testing at only one stress, refers to the lowest test temperature.

7.4.2 *Test Temperature Selection*—Temperatures of 239°F (115°C), 221°F (105°C), and 203°F (95°C) have been utilized in prior testing of PEX, see Note 4. Adjacent test temperatures shall be separated by at least 18°F (10°C). Other test temperatures may be used, but the maximum test temperature shall not exceed 239°F (115°C).

NOTE 4—Prior testing indicates that for the test temperatures stated in 7.4.2, hoop stresses to yield Stage III failures within reasonable testing times are between 160 psi (1.10 MPa) and 400 psi (2.76 MPa). For a true SDR9 tube, those hoop stresses correspond to test pressures of 40 psig (275.9 kPa) to 100 psig (689.7 kPa). If a selected test hoop stress produces Stage I or Stage II failures, the stress will need to be reduced to produce Stage III failures at all temperatures.

7.4.2.1 *Relationship of Internal Pressure to Hoop Stress*—The hoop stress in the pipe or tubing wall is calculated by the following expression, commonly known as the ISO equation:

$$2S/P = DR - 1 \quad (1)$$

or

$$2S/P = (D_o/t) - 1 \quad (2)$$

where:

S = stress in the circumferential or hoop direction, psi (MPa),
P = internal pressure, psig (kPa),
t = minimum wall thickness, in. (mm),
DR = dimension ratio, DR, and
D_o = average outside diameter, in. (mm).

8. Calibration and Standardization

8.1 *Measuring Equipment*—All measuring and testing equipment having an effect on the accuracy or validity of the calibrations or tests shall be calibrated or verified, or both, before being put into service.

9. Test Fluid

9.1 *Internal Test Fluid*—The test fluid shall be reverse osmosis (RO) or deionized (DI) water prepared in accordance with 9.1.1.

9.1.1 *RO or DI Water Test-Fluid Preparation*—Test fluid prepared from RO or DI water shall have a pH in the range from 6.5 to 8.0 and contain 2.5 ppm to 5 ppm (milligrams per litre) of free-chlorine. The chosen pH shall be maintained to ±0.2 and the chosen free-chlorine concentration shall be maintained to ±0.2 ppm. The pH and free-chlorine concentration combination shall yield a minimum ORP of 825 mV for the test fluid, see Note 5. Testing shall be conducted with the same nominal pH and free-chlorine concentration for all test units.

NOTE 5—It is anticipated that use of RO or DI water may improve interlaboratory reproducibility; however, RO or DI water does not generally exist in real service. Since tap water (locally available potable water) quality can vary from location to location, and considering the international application of this test method, it seems prudent to utilize RO or DI water to minimize possible disparities of results obtained from laboratories in different geographical locations. Prior data obtained with test-fluid having an ORP of 750 mV or higher still provides a conservative extrapolation for potable-water conditions found in most areas of the United States.

9.1.2 *Test Fluid Temperature Control*—The test fluid entering each specimen shall be maintained to ±1.8°F (±1°C) of the test temperature.

9.1.3 *Pressure Control*—The pressure of the test fluid shall be maintained to ±3 psig (±20.69 kPa).

9.1.4 *Test Fluid Flow Rate*—The flow rate of the test fluid shall yield a minimum velocity of 0.12 fps (0.04 mps). For the nominal size ½ in., SDR9 pipe or tubing, this corresponds to a flow rate of 0.06 gpm (0.23 LPM). The formula used to calculate the flow rates for other sizes and DRs is as follows:

$$\frac{\pi(id/2)^2 * FPS * 720}{231} = gpm \quad (3)$$

where:

id = measured inside diameter of the pipe or tubing, in.

9.2 *Test Fluid Instrument Accuracy:*

9.2.1 *pH*—The pH measurement and control instruments shall have an accuracy of 0.1 pH or better.

9.2.2 *Free-Chlorine*—Free-chlorine content measurement and control instruments shall have an accuracy of 0.1 ppm or better.

9.2.3 *ORP*—The ORP measurement and control instruments shall have an accuracy of ±10 mV or better.

10. External Environment

10.1 The exterior environment shall be air and shall be maintained at the target temperature of the test fluid temperature ±4.5°F (±2.5°C). Direct, forced-air heating of the specimens shall not be used.

11. Specimen Positioning

11.1 The specimens can be positioned vertically or horizontally. Horizontal positioning requires special attention to insure that all entrapped air has been removed prior to starting the test. For vertically positioned specimens, the test fluid shall flow into the specimens from the lower end.

12. Procedure

12.1 Perform the test procedure in accordance with 12.2 – 12.4 for the test units specified in 7.4 with a test fluid as specified in Section 9.

12.2 After connecting the specimens to the flow-through apparatus, purge the specimens of all entrapped gas and start the flow of the test-fluid through the specimens at a temperature or pressure, or both, 40 to 50 % less than the test condition. Over the next 1 to 3 h, gradually increase the temperature and pressure of the test fluid to the test condition. When the test fluid reaches the test condition temperature, pressure, and flow rate, and the external environment has reached the test temperature in accordance with Section 10, register the start time.

12.3 Maintain the test condition until all of the specimens have failed. Any loss of fluid through the wall of the pipe or tubing or assembly constitutes a failure. Record the time-to-failure for each failed specimen within ±1 % of the test time for the specimen. When multiple specimens are connected end-to-end, remove each failed specimen and continue the test until all remaining specimens at the conditions have failed.

12.4 Record the time in hours and a description for each failure. The description of each failure shall include: linear location from flow inlet, circumferential position, and initiation point (inside or outside of tube). For accurate test life extrapolation, all of the failures must be the same type. Mixed mode failures and failures initiated from the outside of the tube shall not be used for data analysis, see Note 6.

NOTE 6—Numerous failures occurring predominantly in approximately the same position on the tube circumference should be examined carefully. When there is an indication that the failures are attributable to the design or operation of the test, these values should be discarded unless it can be demonstrated that the testing provided a more conservative estimate of the oxidative resistance.

13. Calculation

13.1 *Regression Analysis*—Perform a multiple linear regression on the time-to-failure data in accordance with the rate process method PPI-TN-16 or Model Q of ISO 9080. The correlation coefficient (R^2 value) of the data shall be greater than 0.9 to ensure accuracy of the time-to-failure extrapolations. If it can be demonstrated that the four-coefficient regression equation in Model Q of ISO 9080 provides a better fit to the data set, then the coefficients, correlation (R^2 value), and extrapolated times-to-failure from that model shall be used and reported.

13.2 *Time-to-Failure Extrapolations* —Using the coefficients from 13.1, calculate the estimated time-to-failure at a hoop stress corresponding to a sustained internal pressure of 80 psig (551.7 kPa) for the DR of the tested specimens at temperatures of 180°F (82°C), 140°F (60°C), and 73°F (23°C).

NOTE 7—Calculations of the estimated time-to-failure may also be made at other temperatures up to the highest rated temperature.

NOTE 8—It may be convenient to also report the extrapolated time-to-failure in years by dividing hours by 8760.

13.3 *Application of Miner's Rule*—Calculate the estimated time to-failure for a hoop stress corresponding to a sustained internal pressure of 80 psig (551.7 kPa) for the DR of the tested specimens at temperature exposure conditions of 25 % of the total time at 140°F (60°C) and 75 % of the total time at 73°F (23°C) in accordance with ISO 13760. An example is shown in X1.2.

14. Report

14.1 *Report Content*—Report the minimum information as required in 14.2 – 14.9.

14.2 Laboratory name and location and starting and ending dates of the test.

14.3 Chlorine source (that is, chlorine gas, hypochlorite, and so forth)

14.4 Identification of the PEX pipe or tubing in the report shall include: pipe or tubing nominal size and DR or wall thickness specification; average outside diameter and minimum wall thickness of each specimen; pipe or tubing manufacturer's name, trade designation and pipe or tubing lot number (if applicable); resin manufacturer's name, compound designation, and lot designation (for in-plant compounded materials, resin manufacturer's name may be omitted); cross-linking process; and gel count.

14.5 Identification of fitting(s) tested with the PEX pipe or tubing (if applicable) shall include: manufacturer's name and model or designation, fitting type, material, and ASTM standard designation (if applicable).

14.6 All test conditions, including: test fluid temperature/internal pressure combinations; specimen external air temperature; test fluid free-chlorine concentration and pH; test fluid ORP; water type (tap, RO or DI); flow rate; and specimen position (horizontal or vertical). Where applicable, report the minimum, maximum, and average values for each parameter.

14.7 A table of the test temperatures, hoop stresses, and failure times for all specimens tested.

14.8 A description of each failure in accordance with 12.4.

14.9 A summary of the regression analysis including: coefficients; correlation coefficient (R^2 value); estimated time-to-failure at 140°F (60°C); estimated time-to-failure at conditions of 25 % at 140°F (60°C) and 75 % at 73.4°F (23°C); estimated time-to-failure at 180°F (82°C).

15. Precision and Bias

15.1 *Precision*—For a single laboratory, the intra-laboratory standard deviation reproducibility from 23 test runs having 2 to 4 specimens per run, at temperatures of 95°C, 105°C and 115°C, and covering 14 grades of polyolefin materials were:

±5% for 50% of test runs

±10% for 70% of test runs, and

±15% for 90% of test runs.

15.1.1 A round robin study was conducted on ½ in. SDR 9 PEX pipes under the test conditions shown in Table 1.

TABLE 1 Round Robin Testing Conditions

Pressure	50 ± 1 psig
Chlorine Concentration	4.2 ± 0.2 ppm
Temperature	115 ± 1°C
pH	6.8 ± 0.2
ORP	860 ± 35 mV

15.1.2 The two laboratories who participated in the round robin study placed six pipes on test and reported the failure times and type failures. Results of the testing are shown in Table 2.

TABLE 2 Round Robin Testing Results

Type Failures	Brittle
Average Mean Failure Time	1098 h
Failure Time Range	871 to 1490 h
Standard Deviation	165 h
Standard Deviation/Mean	15 %

TABLE 3 t-Test

Lab Identification	Lab A	Lab B
Average Mean Failure Time	1043 h	1153 h
Failure Time Range	871 to 1185 h	986 to 1490 h
Standard Deviation	115 h	198 h
Standard Deviation/Mean	11%	17%
t-statistic, two sample, 0.05 sig. level	-1.17	
t-critical, 2–tail, equal variance	±2.23	
Probability T ≤ t, 2-tail	0.27	

NOTE 9—The t-test performed indicates that at the 95 % confidence level (0.05 level of significance), the difference in mean failure times of the samples as determined by the two laboratories is not significant. The probability associated with this determination is 0.27. In other words, the means of similar 6-specimen tests performed in accordance with this method can be expected to differ by an amount equal to or greater than the Lab A vs. Lab B results about 27 % of the time due to random variation. (See Table 3)

15.2 *Bias*—No information can be presented on the bias of this test method because no material having an accepted reference value is available.

ANNEX

(Mandatory Information)

A1. METHOD FOR ESTABLISHING OXIDATIVE RESISTANCE EQUIVALENCY

When it is required to establish oxidative resistance equivalency of a product, the method described in this annex shall be used. The referring product standard shall define when equivalency in accordance to this annex is applicable.

A1.1 *Testing* —The following testing shall be performed:

A1.1.1 Test a minimum of five specimens from the same lot to failure at the highest temperature condition used for the original F2023 data set.

A1.1.2 Three of the five specimens shall be tested at one stress condition (Condition 1). Two of the specimens shall be tested at a lower stress condition (Condition 2). The difference in the stresses of Condition 1 and Condition 2 is defined as per 7.4.1.

NOTE A1.1—It is recommended to test at or near the test stresses of the original F2023 data set.

A1.1.3 Testing shall be performed in accordance with Sections 6 through Section 12.

A1.2 *Calculations* —Perform the following calculations:

A1.2.1 Calculate the Lower Prediction Limit (LPL) of the 95 % Prediction Interval of the original F2023 data set at the tested temperature/stress conditions. The 95 % LPL is (See a statistics text for details):

$$Log_{10}ft = A + \frac{B}{T} + \frac{C(Log_{10}S)}{T} - t_{0.025,n-3} \cdot \sqrt{s^2 + s^2_{A+\frac{B}{T}+\frac{C(Log_{10}S)}{T}}} \quad (A1.1)$$

where:
n = number of data points in the original F2023 data set
s^2 = variance associated with an individual failure times
$s^2_{A+\frac{B}{T}+\frac{C(Log_{10}S)}{T}}$ variance associated with the predicted failure time based on the model.

A1.2.2 Calculate the A, B, and C parameters of the RPM equation by multiple linear regression on the combined data in accordance with Section 13 using the results of the testing in A1.1 combined with the data of the original F2023 data set.

A1.2.3 Calculate the estimated time-to-failure extrapolations as per the referenced product standard specification or at the following conditions:

A1.2.3.1 The estimated time-to-failures at a hoop stress corresponding to a sustained internal pressure of 80 psig (551.7 kPa) for the DR of the tested specimens at temperatures of:
180°F (82°C)
140°F (60°C)
73°F (23°C)

A1.2.3.2 Using Miner's Rule and the estimated time-to-failures calculated in A1.2.3.1, calculate the estimated time-to-failure in accordance with X1.2at temperature exposure conditions of:
25 % of the total time at 140°F (60°C) and 75 % of the total time at 73°F(23°C)
50 % of the total time at 140°F (60°C) and 50 % of the total time at 73°F(23°C).

A1.3 *Determination of Equivalency* —The sample shall be considered to have equivalent oxidative resistance to the original F2023 sample based on the following requirements:

A1.3.1 The R^2 value of the regression analysis performed in A1.2.2 is greater than 0.9.

A1.3.2 The failure time of each of the tested specimens tested in A1.1 meets or exceeds the 95% LPL value of the specimen as calculated in A1.2.1.

A1.3.3 The estimated time-to-failure extrapolation calculated in A1.2.3 meets the same or higher categorized requirement as the original F2023 data set in the referenced product standard specification.

APPENDIXES

(Nonmandatory Information)

X1. SUMMARY OF FORMULAS

X1.1 *Multiple Linear Regression*—The three-parameter, rate process equation from PPI TN-16 and ISO 9080 is expressed as follows:

$$Log_{10}ft = A + B/T + C(Log_{10}S)/T \quad (X1.1)$$

where:

ft = time to failure, h,
T = absolute temperature K°,
S = hoop stress, psi (MPa), and
A, B, and C = coefficients derived from a particular data set.

X1.1.1 The four-parameter, multiple linear regression equation from ISO 9080 is expressed as follows:

$$Log_{10}ft = c_1 + c_2/T + c_3Log_{10}S + c_4(Log_{10}S)/T + e \quad (X1.2)$$

where:

$c_1 - c_4$ = coefficients derived from a particular data set, and
e = an error variable, having a Laplace-Gauss distribution with zero mean and constant variance.

X1.2 *Miner's Rule Calculations*—The Miner's Rule equations are expressed as follows:

$$TDY = \%_a/t_a + \%_b/t_b + ...\%_x/t_x \quad (X1.3)$$

and

$$t_s = 100/TDY \quad (X1.4)$$

where:

TDY = total damage per year,
$t_a, t_b \ldots t_x$ = time-to-failure at different conditions, *a, b,* and so forth, years,
$\%_a, \%_b \ldots \%_x$ = percentage of time at each condition, *a, b,* and so forth. (Total of percentages must equal 100), and
t_s = time-to-failure prediction from cumulative damage, years.

X2. OXIDATION REDUCTION POTENTIAL (ORP)

X2.1 *ORP Background*—ORP is a monitoring/control method that provides a measurement of the total oxidizing potential of a solution. For chlorinated water, ORP provides a measurement of the equilibrium of the free-chlorine as a function of pH. It is widely used as a disinfection control in effluent treatment, and DIN standards 19643 and 19644 specify a minimum ORP level of 750 mV for pools and spas. In 1972, the World Health Organization recognized that an ORP of 650 mV provides disinfection and viral inactivation almost instantaneously. For reference, pure water has an ORP of about 200 mV and typical tap water rarely, if ever, exceeds 850 mV.

X2.2 *ORP Instrument*—The measuring instrument resembles a pH probe except that electron transfer from the solution to a platinum band is compared to an internal silver/silver-chloride reference electrode. The output of the probe is measured in millivolts. A higher millivolt reading indicates a greater oxidizing potential of the solution.

X2.3 *ORP Relationship to pH*—Free-chlorine is defined as both the hypochlorous acid (HClO) and hypochlorite ions (OCl) that form equilibrium in solution and is pH dependent. Fig. X2.1 shows the relationship between pH/free-chlorine and ORP in a deionized water solution. The specific ORP/pH/chlorine relationship is dependent on specific water quality. Fig. X2.1 should, therefore, be considered directional only.

X3. AWWA SURVEY

X3.1 The 1996 WATER:\STATS Survey conducted by the American Water Works Association (AWWA) of 3200 water purveyors across the United States indicates that 98.2 % of responding utilities reported pH and free-chlorine conditions that correspond to a DI-water ORP value of 825 mV or less. It has been previously demonstrated that at the ORP specified in this test method, typical tap water (due to the presence of various salts and other elements) prepared to a specific pH and free-chlorine has an ORP about 4 % less than the value attained with DI water prepared to the same pH and free-chlorine conditions.

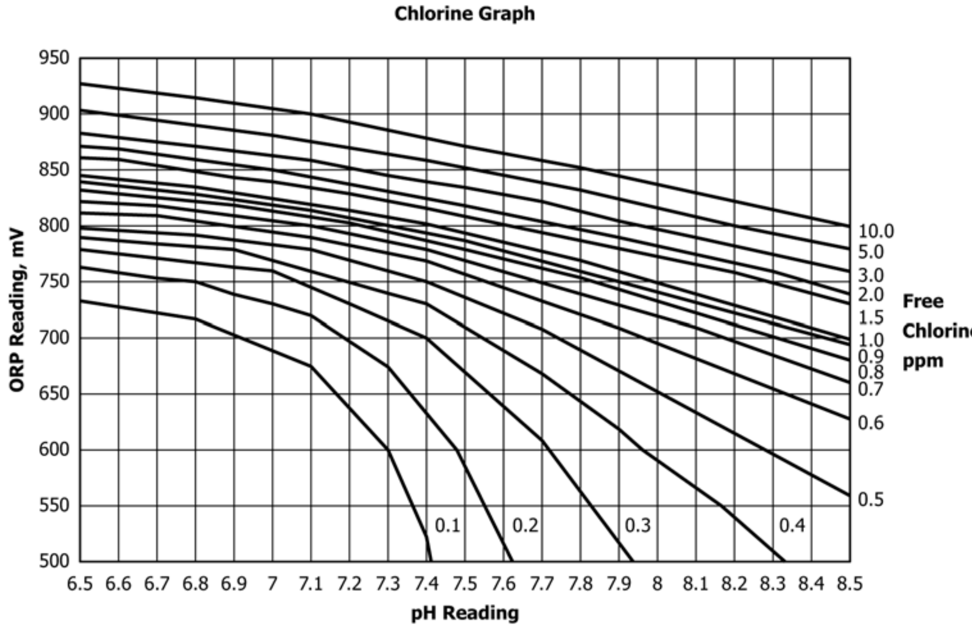

FIG. X2.1 Relationship of pH/Free-Chlorine to ORP in Deionized Water

SUMMARY OF CHANGES

Committee F17 has identified the location of selected changes to this standard since the last issue (F2023-13) that may impact the use of this standard.

(1) Added "Pipe" to the title.
(2) Revised Section 1, Scope, to include PEX pipe.
(3) Changed "tubing" to "pipe or tubing".