Effects of Disinfection on Newly Constructed Polyethylene Water Mains
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Foreword

This report was developed and published with the technical help and financial support of the members of Plastics Pipe Institute, PPI. The members have shown their interest in quality products by assisting independent standards-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

The intent of this technical report is to provide information on the effects of chlorine disinfection on the durability of PE piping for water systems. The testing reported herein was conducted on service pipe sizes and on resins in the form of plaques in accordance with the various test methods employed. At the time the testing was conducted, high performance PE materials such as PE4710 were not available. In 2006, PPI established a new program to provide test information on high performance PE materials, and will update this report when the information is available.

Tests on piping in this report were conducted on service sizes; however, larger PE pipes produced to AWWA C901 and AWWA C906 are subject to the identical water service design criteria and in-service operating stresses. Furthermore, chlorine resistance tests of other olefin materials such as PEX have demonstrated that tests of service sizes are representative of larger sizes. Therefore, the test results herein are expected to be representative of larger sizes.

PPI intends to revise this report from time to time, in response to comments and suggestions from users of the report. Please send suggestions of improvements to the address below. Information on other publications can be obtained by contacting PPI directly or visiting the web site.

The Plastics Pipe Institute

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Table of Contents

1. Introduction

Disinfecting of water mains has been a common industry practice for many years. The first AWWA standard covering this practice was approved in September 1947 (as 7D.2-1948). In 1986, the designation of the standard was changed to AWWAC651; the latest revision is ANSI/ AWWA-C651-92. The standard describes methods of disinfecting newly constructed potable water mains; mains that have been removed from service for planned repairs or for maintenance that exposes them to contamination; mains that have undergone emergency repairs due to physical failure; and mains that, under normal operation, continue to show the presence of coliform organisms.

Because the chlorine disinfection process puts pipe in contact with a strong oxidizer, a task group was formed in June 1993, within the PPI Technical Committee to investigate possible effects of disinfection on the durability of PE piping in potable water service. While C651 covers all piping materials used in potable water service, this investigation was confined to polyethylene systems. Chlorine was the only disinfecting agent investigated; chloramines were not evaluated. All tests conducted were short term, run at ambient temperature conditions on pipe samples made from particular polyethylene pipe compounds. The report is not to be construed as an indicator of the long-term performance of polyethylene pipe in general, or in the specific user's environment and operating conditions.

2. Scope

At the first task group meeting, the following scope was adopted: To investigate and quantify, if possible, any effects on the durability of PE piping caused by disinfection per AWWA C651. Exposure times and concentration levels were chosen to be consistent with the requirements of the standard. Note that the disinfection practices outside the constraints used in this study (i.e., exposure time, etc.) may yield different results - e.g., if a contractor leaves a pipe full of concentrated disinfectant for 6 months.

3. Methods of Chlorination

Three methods of chlorination are explained in AWWA-C651: tablet, continuous feed, and slug. The tablet method is intended to give an average chlorine dose of approximately 25 mg/L, and precautions shall be taken to ensure that air pockets are eliminated and the water shall remain in the pipe for at least 24 hours. If the water temperature is less than 41°F (5°C), the water shall remain in the pipe for at least 48 hours ; the continuous feed to give a 24 hour residual of not less than 10 mg/ L; and the slug method to give a 3 hour exposure of not less than 50 mg/L free chlorine. .. Residual free chlorine In the slug method, shall be measured as it moves through the main. If at any time it drops below 50 mg/ L, the flow shall be stopped, chlorination equipment shall be relocated at the head of the slug, and, as flow is resumed, chlorine shall be applied to restore the free chlorine in the slug to not less than 100 mg/ L.

4. <u>Industry Practice</u>

To compare actual industry practice with AWWA C651 recommendations, a task group member conducted an informal survey of numerous City Water Departments. The survey was geographically broad and included utilities in Seattle (WA), Fresno (CA), Chicago (IL), Minneapolis (MN), San Antonio (TX), Savannah (GA) and Augusta (ME). It was learned that chlorine was by far the disinfectant of choice. All three methods described in C651 (tablet, continuous feed, and slug) are used, with the tablet method being the most popular because it requires no additional equipment.

For the tablet method, AWWA C-651 recommends the use of an average chlorine content of 25 mg/L for at least 24 hours. The utilities surveyed stated that concentrations ranging from 25-150 mg/L were used for durations from 24 to 72 hours. Preferably, disinfection should be carried out overnight, however, not on a day before the weekend or holidays

In the continuous feed method, the chlorine may be added as dissolved calcium hypochlorite, sodium hypochlorite, liquid chlorine or dissolved chlorine gas. Several opinions were given that dissolved chlorine gas offered the “best” disinfection; however, environmental concerns and regulations have made this option less desirable. The water utilities that were interviewed use concentrations ranging from 25-60 mg/ L for durations of 24-72 hours.

The slug method is generally used in conjunction with the tablet method. After the tablet method is completed and flushed, a heavily concentrated slug of chlorine is added to the main and slowly forced through the system. The concentration of the slug is monitored and more chlorine is added if the free chlorine residual drops below 50 mg/ L. Several of the utilities use this method at concentrations of 300-500 mg/L. Disposal and treatment of the heavily chlorinated water can become a problem with this procedure.

5. <u>Test Results</u>

To evaluate the effects of chlorine exposure on PE water pipe during typical disinfection, physical properties of selected PE pipe samples were studied. Properties of pipe specimens exposed to chlorine were compared to properties of the same specimens that were not exposed. The test methods and the results of these tests are presented herein.

<u>5.1 Quick Burst</u>

Test Objective: To determine if the chlorine exposure had a detrimental effect on the burst strength of the pipe. Testing was conducted on pipe specimens filled with a 185-ppm chlorine water solution and conditioned for 72 hours at room temperature. Control specimens were also tested. The controls were not filled with tap water until tested.

Test Method: Quick burst testing was then conducted in accordance with ASTM D-1599, Standard Test Method for Short-Time Hydraulic Failure Pressure of Plastic Pipe, Tubing, and Fittings. Several specimens were prepared from each sample. The specimens were 18” in length and sealed at each end with Swagelok fittings. For each sample, half the specimens were filled with water containing chlorine at 185 ppm, the other half were not filled until testing. The specimens exposed to chlorine were then placed on a sealed manifold for 72 hours. The control specimens were conditioned in the same room as the chlorine specimens for the same time period.

Description of Test Samples:

- 1: ½” SIDR 11.5 PE2306, ASTM D2239
- 2: ½” SIDR 11.5 PE3408, AWWA C901
- 3: ¾” SDR 9 PE3406, ASTM D2737
- 4: ¾” SDR 9 PE3408, ASTM D2737
- 5: ¾: SDR 9 PE 3408, ASTM D2737

Test Results and Data:

Burst Pressures, psi		
Sample	Without Chlorine	With Chlorine
1	545	530
	510	530
2	610	600
	600	590
	620	610
3	800	960
	800	810
	810	830
4	1040	1030
	990	960
	960	990
5	850	830
	840	850

Failures for samples 2, 3, 4 and the chlorine specimens of sample 5 were in a ductile mode with ballooning prior to rupture. Failures for samples 1 and the non-chlorine specimens of sample 5 were in the slit mode.

Conclusion: The burst strength of Polyethylene (PE) pipe exposed to 185 mg/L chlorine for 72 h, showed no apparent difference from that filled with tap water.

5.2 Sustained Hydrostatic Burst

To further evaluate the possible effects of chlorine exposure on actual pipe samples, sustained pressure testing per ASTM-D1598, Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure, was conducted on samples of the PE3408 pipe. Testing was performed at 176°F to accelerate any adverse effects on performance. Two different conditioning times were used: 72 hours and 240 hours. Further details of the test and results are listed below.

Set 1

Conditioning: 72 hours

73+3°F

321 mg/ L free chlorine at start of conditioning

Control samples were not exposed to any chlorine during conditioning

Testing: 176+3°F

Specimen	Hoop Stress	Conditioning	Failure
1	600 psi	Chlorine	916 hr (no failure)
2	600 psi	Control	916 hr (no failure)
3	600 psi	Chlorine	916 hr (no failure)
4	600 psi	Control	916 hr (no failure)
5	600 psi	Chlorine	916 hr (no failure)
6	600 psi	Control	916 hr (no failure)
7	750 psi	Chlorine	953 hr (no failure)
8	750 psi	Control	953 hr (no failure)
9	750 psi	Chlorine	953 hr (no failure)
10	750 psi	Control	953 hr (no failure)
11	750 psi	Chlorine	953 hr (no failure)
12	750 psi	Control	953 hr (no failure)

Set 2

Conditioning: 240 hours

73+3°F

305 mg/ L free chlorine at start of conditioning:

210 mg/L at 120 hrs, refilled;

309 mg/ L at refilled (120 hrs);

217 mg/ L at 240 hrs

Control samples were not exposed to any chlorine during conditioning

Testing: 176+3°F

Specimen	Hoop Stress	Conditioning	Failure
1	600 psi	Chlorine	420 hr (no failure)
2	600 psi	Control	420 hr (no failure)
3	600 psi	Chlorine	420 hr (no failure)
4	600 psi	Control	420 hr (no failure)
5	600 psi	Chlorine	420 hr (no failure)
6	600 psi	Control	420 hr (no failure)
7	750 psi	Chlorine	446 hr (no failure)
8	750 psi	Control	446 hr (no failure)
9	750 psi	Chlorine	446 hr (no failure)
10	750 psi	Control	446 hr (no failure)
11	750 psi	Chlorine	446 hr (no failure)
12	750 psi	Control	446 hr (no failure)

Although somewhat limited, the results of sustained hydrostatic burst testing do not suggest any significant effect of chlorine exposure on long term performance. Unfortunately, testing could not be continued longer because of the need for the test stations being used. Ideally, data at sufficient pressures and times to permit calculation of Hydrostatic Design Basis would provide a better estimate of long term performance.

It should be noted that all of the specifications for polyethylene water pipe (ASTM D2239, D3035, D2447, etc.) contain a sustained pressure requirement. The high-density material used for this study would be required to pass a 176°F sustained pressure test of 60 hours (minimum) at 725 psi or 150 hours (minimum) at 580 psi. It can be seen that all of the samples used in this study easily met these requirements.

5.3 Tensile and Elongation

A standard PE 3408 resin was compression molded in accordance with Procedure C of ASTM Method D1928. The molded specimens were randomly divided into two groups. One group was placed in a glass vessel containing a 200-ppm chlorine water solution at room temperature. Measurements of free chlorine were made every other day and sodium chlorite solution added to maintain the 200-ppm target. The second group of specimens was exposed to “tap water” with a measured chlorine content of approximately 1 ppm. Samples were then removed periodically from the vessel and tested for tensile strength at yield and elongation at break in accordance with ASTM D638. A grip separation rate of 2-in/ minute was used. It should be noted that, because of the large number of samples required, only two specimens were tested at each of the time periods noted. This undoubtedly contributed to the scatter seen in the results. Based on the early test results, exposure times were extended well beyond the original intent in an attempt to detect any possible downward trend. Exposure testing was carried out to 1176 hours without any indications of adverse effects. Test results are summarized below:

Hours	Tensile Strength (Break)		(Elongation Break)	
	Chlorine	Water	Chlorine	Water
24	4210		805	
48	4141		796	
72	4180		748	
168	4285	4262	760	762
336	4249	4484	731	779
504	4314	4902	730	756
672		4753		805
840	4125	4329	793	752
972	4107		721	
1008	4272	3990	781	788
1176	4310		803	

5.4 Oxidative Induction Time

Because the chlorine disinfection process puts polyethylene pipe in contact with a strong oxidizer, it was decided to monitor the effect on chlorine exposure on thermal stability. Oxidative Induction Time as measured by a differential scanning colorimeter (DSC) was used as an indication of thermal stability. The same compression molded samples (PE3408) and chlorine solution (200 ppm) used for tensile strength and elongation measurements in Section 5.4 were used in this study. Again, exposure times were extended well beyond the original intent in an attempt to detect any possible downward trend. Exposure time and OIT results are summarized below:

Hours	OIT, minutes	
	Chlorine	Water
24	17.2	17.2
48	18.8	17.9
72	16.2	16.8
168	18.8	19.2
336	19.9	20.1
504	16.3	16.6
672	19.5	20.1
840	19.0	20.2
1008	17.8	16.9
1176	17.4	16.4
1512	17.9	17.5
1872	18.2	17.9
2400	18.4	17.6
2568	17.9	17.6

It is apparent that no downward trend is evident even after 2,500 hours of exposure. Although some variation in the individual measurements is visible, there does not appear to be a significant difference between the chlorine and water exposures.

5.5 High Speed Tensile Impact

A new high-speed tensile impact test (the McSnapper) has been gaining increased popularity in the industry to evaluate the integrity of heat fusion joints. It was believed that the test might be sensitive enough to detect any adverse effect of chlorine exposure on the fusion joint. Two samples of PE3408 pipe were prepared by heat fusing two segments each together. One sample was capped, filled with tap water and stored at room temperature (75°F) for 30 days. The other sample was capped, filled with 200-ppm chlorine water and stored for 72 hours. No internal pressure was applied to either sample at the end of the exposure periods; the samples were drained and flushed with distilled water.

Four sample coupons were cut from each sample. The results of measuring high speed tensile with impact device are summarized below.

Energy, in-lbf		
Sample Number	Water	Chlorine
1	240.6	247.6
2	256.8	273.8
3	300.3	211.3
4	260.0	305.5

It was concluded that there was no appreciable difference in tensile strength between the two samples.

5.6 PENT Testing

One of the major concerns for long term performance of polyethylene pipe (for both water and gas) continues to be its resistance to slow crack growth. Although the standard method for determining Hydrostatic Design Basis (ASTMD2837) has provided an excellent estimate of this parameter; it is admittedly a lengthy and labor intensive procedure. Over the years, a number of tests have been developed to provide an accelerated estimate of resistance to slow crack growth. These include Test Method for Environmental Stress-Cracking of Ethylene Plastics (D1693) and Test Method for Determination of Environmental Stress Crack Resistance (ESCR) of Polyethylene Pipe (F1248). However, as polyethylene materials have improved over the years, the time to failure using these ESCR tests has increased dramatically. In the continuing search for a quicker slow crack growth test, two more recent tests have emerged. One is the PENT Test that is officially designated as ASTM F1473 - Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins. The other is the British Gas Notch Test which has been adopted by ISO as FDIS 13479-Polyethylene Pipes for the Conveyance of Fluids-Determination of Resistance to Crack Propagation Test Method for Slow Crack Growth on Notched Pipes (notch test). It has also been added to ASTM as F1474. Both of these tests have demonstrated promise in predicting resistance to slow crack growth in a reasonable time frame.

It has become apparent that the European/ World community has selected the notched pipe test to measure resistance to slow crack growth while the U.S. pipe industry has selected the PENT Test. A number of Task Groups have been formed in both PPI and ASTM to refine the test method and to build a data base for establishing acceptance values for the various end use applications. For those reasons, a standard PE 3408 pipe material was compression molded and milled to size following the procedure outlined in ASTM F1474. A total of six specimens were prepared from the same resin sample. Two were notched and used as the control; two were exposed to 200-ppm chlorine water and then notched. The third set were notched and then exposed to 200-ppm chlorine water. Constant Tensile Load testing at 80° (PENT Test) was then performed.

Results are summarized below:

	PENT Values, hr	PENT Average, hr.
Control	68.36	69.40
	70.44	
72 hr Cl, then notched	65.44	68.03
	70.61	
Notched, then 72 hr Cl	68.82	67.72
	68.27	

All of the above values would be considered to be within the accuracy of the test method. Chlorine exposure did not appear to adversely affect test life of the PE resin.

6. Other Experience

Studsvik Material AB in Sweden has done a number of studies on the long-term behavior of polyolefin pipes used in hot water environments. One - "Long-Term Properties of Hot-Water Polyolefin Pipes - A Review " by U.W. Gedde, J. Viebke, H. Leijstrom and M. Ifwarson is of particular interest. A collective view of the changes in antioxidant concentration profiles and molecular/ physical structure accompanying hot-water exposure is presented. A presentation is also made of current lifetime extrapolation methods. Studsvik performs long-term hydrostatic burst testing using chlorine for clients on a proprietary basis.

The effect of chlorine on PE piping in water distribution service has been a concern in Japan for many years. However, the major part of their investigations has been with piping made from lower density PE materials and used in water distribution. A test method on blistering caused by chlorine contact has been written and acceptance levels for the degree of blistering have been established.

7. Chlorine Dissipation Rate

To estimate the dissipation rate of chlorine, without the addition of fresh chlorine, seven pipe samples were filled with water originally at 321-mg/ L free chlorine. The samples were then capped with mechanical steel fittings and sealed. At each of the times shown below, one sample was opened and the water immediately analyzed for free chlorine.

Start	321 mg/L
24 hours	271 mg/L
48 hours	227 mg/L
72 hours	216 mg/L
96 hours	168 mg/L
8 days	140 mg/L
14 days	58 mg/L

8. Conclusions/ Recommendations

The testing performed in this study indicates that chlorine disinfection, when conducted within the guidelines of AWWA-C651, does not have a significant adverse affect on the performance of PE pipe. No indications of any downward trends in the exposure tests were evident.

9. References

ASTM D-1599, Standard Test Method for Short-Time Failure Pressure of Plastic Pipe, Tubing and Fittings.

ASTM D-1598, Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure.

ASTM D-638, Test Method for Tensile Properties of Plastics

ASTM D-2837, Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials.

ASTM D-1693 Stress-Cracking of Ethylene Plastics

ASTM F-1248, Test Method for Determination of Environmental Stress Crack Resistance (ESCR) of Polyethylene Pipe.

ASTM F-1473, Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins.

AWWA C-651, Disinfecting Water Mains

AWWA C-901, Polyethylene (PE) Pressure Pipe and Tubing, ½ in Through 3 inch, for Water Service

AWWA C–906, Polyethylene (PE) Pressure Pipe and Fittings, 4 in. (100 mm) through 63 in. (1,575 mm), for Water Distribution and Transmission

ISO FDIS-13479, Polyethylene Pipes for the Conveyance of Fluids - Determination of Resistance to Crack Propagation Test Method for Slow Crack Growth on Notched Pipes

U.W. Gedde, J. Viebke, H. Leijstrom and M. Ifwarson, Polymer Engineering and Science, 34, 24 (1994).