Effects of Disinfection of

Newly Constructed Polyethylene Water Mains

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The intent of this technical report is to provide information on the effect of chlorine disinfection on the durability of PE piping for water systems. The testing reported herein was conducted on several pipe sizes and on resins in the form of plaques in accordance with the various test methods employed. The investigations were done in two separate studies. The first study focused on PE2306, PE3406, and PE3408 compounds and the second study was conducted with a PE4710 compound.

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1. Introduction

Disinfecting 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 AWWA C651; the revision used in Study 2 is ANSI/AWWA C651-23 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 for Study 1 of this report, within the PPI Technical Committee to investigate possible effects of disinfection on the durability of PE piping in potable water service. Study 2 was started by a PPI task group convened in 2023 to update TR-34 with test information on the current generation PE4710 materials. While C651 covers all piping materials used in potable water service, this investigation was confined to polyethylene systems following ANSI/AWWA C901 and ANSI/AWWA C906. Chlorine was the only disinfection agent investigated. This 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

This report aims to investigate and quantify the effects on the durability of PE piping caused by disinfection per ANSI/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). For continuous chlorine exposure of potable water applications, PPI TN-43 should be referred to.

3. Methods of Chlorination

At the time of Study 1, three methods of chlorination were explained in ANSI/AWWA C651: tablet, continuous feed, and slug. A brief description of the methods is provided; for more details, see ANSI/AWWA C651.

- 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 method is intended to give a 24 hour residual of not less than 10 mg/L;
- The slug method is intended 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.

It should be noted that the tablet method is not recommended for HDPE pipe in ANSI/AWWA C651-23 but the continuous feed and slug methods are recommended.

4. Industry Practice

Prior to conducting Study 1, 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 1997 version of C651 (tablet, continuous feed, and slug) were used with the tablet method being the most popular because it required no additional equipment.
For the tablet method, AWWA C651-97 recommends the use of an average chlorine content of 25 mg/L for at least 24 hours. The utilities surveyed stated concentrations ranging from 25-150 mg/L 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.

In the slug method, 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. Test Results

To evaluate the effects of chlorine exposure on PE water pipe during typical disinfection, physical properties of selected PE pipe samples were studied in two separate studies. Study 1 included PE2306, PE3406, and PE3408 materials.

Study 2 focused on PE4710 material and was conducted by TRI Environmental. Since the studies were conducted in different time frames the test conditions differ. However, in both studies, properties of pipe specimens exposed to chlorine were compared to properties of the same specimens that were not exposed to chlorine. Details of test methods and the results of these tests are presented herein.

5.1 Quick Burst

Test Objective*: Quick burst test was only conducted in Study 1 to determine if the chlorine exposure had a detrimental effect on the burst strength of the pipe. Based on the results of Study 1, the task group members for Study 2 decided that the high temperature, sustained pressure test (see Sec. 5.2) was a more appropriate test.*

Testing in Study 1 was conducted on pipe specimens filled with a 185 mg/L 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 D1599, "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 mg/L, and 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. The *Test Samples are described below*:

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

Table 1: *Quick Burst Test Results and Data for Study 1*

Burst Pressures, psi		
Sample	**Control**	**Chlorine Exposed**
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 of control pipes 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.

Study 1: The testing was conducted on samples of the PE3408 pipe. After chlorine exposure, testing was performed at 176°F to accelerate any adverse effects on performance. Two different chlorine exposure times were used: 72 hours (Set 1) and 240 hours (Set 2). Further details of the test and results are listed below.

Set 1

- Conditioning (chlorine exposure): 72 hours, 73 ± 3°F
- 321 mg/L free chlorine at the start of conditioning
- Control samples were not exposed to any chlorine during conditioning.
- *Testing:* 176 ± 3°F

Table 2: *Sustained Hydrostatic Burst Test Results and Data for Study 1, Set 1*

Conditioning	Hoop Stress, psi	Failure Time, hrs.
Chlorine	600	> 916 (no failure) > 916 (no failure) > 916 (no failure)
	750	> 953 (no failure) > 953 (no failure) > 953 (no failure)
Control	600	> 916 (no failure) > 916 (no failure) > 916 (no failure)
	750	> 953 (no failure) > 953 (no failure) > 953 (no failure)

Set 2

- Conditioning (chlorine exposure): 240 hours, 73 ± 3°F
- At the start of conditioning, 305 mg/L free chlorine was measured:
- At 120 hrs. 210 mg/L free chlorine was measured; the solution was replaced with a concentration of 309 mg/L free chlorine;
- At 240 hrs. 217 mg/L of free chlorine was measured.
- Control samples were not exposed to any chlorine during conditioning
- *Testing*: 176 ± 3°F

Table 3: *Sustained Hydrostatic Burst Test Results and Data for Study 1, Set 2*

Conditioning	Hoop Stress, psi	Failure Time, hrs.
Chlorine	600	> 420 (no failure) > 420 (no failure) > 420 (no failure)
	750	> 446 (no failure) > 446 (no failure) > 446 (no failure)
Control	600	> 420 (no failure) > 420 (no failure) > 420 (no failure)
	750	> 446 (no failure) > 446 (no failure) > 446 (no failure)

Study 2: The testing was performed on 12 pieces of 1” diameter, IPS, SDR 11, HDPE PE4710 CC3 pipe which were manufactured by a PPI TR-4 dependent listing holder (Infra Pipe Solutions). The first set of 6 pipes were filled with 300 mg/L solution of chlorine (chlorine source: 15% by weight reagent grade Sodium hypochlorite, Thermo Scientific). The chlorine solution was removed after 36 hours and pipes were rinsed with clean water. The other set of 6 pipes were used as controls. All of the pipe specimens were tested per ASTM D1598.

- Control pipes were maintained in the same laboratory environment but were not exposed to chlorine or water prior to testing.
- Conditioning (chlorine exposure): 36 hours, 73 ± 3°F, 300 mg/L free chlorine
- *Testing*: 176 ± 3°F

Table 4: *Sustained Hydrostatic Burst Test Results and Data for Study 2*

Conditioning	Failure Time at 750 psi Hoop Stress, hrs.
Chlorine exposed	> 1010 (no failure)
	> 1010 (no failure)
	> 1010 (no failure)
	> 1010 (no failure)
	> 1010 (no failure)
	> 1010 (no failure)
Control	> 1010 (no failure)
	> 1010 (no failure)
	> 1010 (no failure)
	> 1010 (no failure)
	> 1010 (no failure)
	> 1010 (no failure)

The results of sustained hydrostatic testing for Study 1 and Study 2 do not suggest any significant effect of chlorine exposure on 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. At the time of Study 1 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. For Study 2 the water pipe standards required to pass a 176°F sustained pressure test at any of the 6 conditions; the quickest test duration is 200 hours (min) at 750 psi; the longest test duration is 1,200 hours (min) at 640 psi. It can be seen that all of the samples used in these studies far exceeded these requirements.

5.3 Tensile and Elongation

Study 1: A standard PE3408 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 200mg/L chlorine water solution at room temperature. Measurements of free chlorine were made every other day and sodium chlorite solution added to maintain the 200mg/L target. The second group of specimens were exposed to "tap water" with a measured chlorine content of approximately 1 mg/L. 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/min. 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. 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:

Table 5: *Tensile and Elongation Test Results and Data for Study 1*

	Tensile Strength at Break (psi)		Tensile Elongation at Break (%)	
Exposure Time, hrs.	**Chlorine Exposed**	**Control**	**Chlorine Exposed**	**Control**
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	

Study 2: Type IV tensile bars (ASTM D638) were prepared at the accredited laboratory of a PPI TR-4 independent listing holder (LyondellBasell) by cutting up 1" SDR 11 pipe, producing a crepe using a two roll mill and then compression molding the crepe per ASTM D4703. This preparation method added two additional heat histories compared to the pipe material. Chlorine exposure was done in a 6-liter jar containing 200 mg/L chlorine solution (chlorine source: 15% by weight reagent grade sodium hypochlorite, Thermo Scientific). The chlorine solution and deionized water were made fresh every day using the exact same

proportions. Seven test specimens were removed from the jar, at each exposure time of 24, 48, 72, 168, 336, and 504 hours. Five of the specimens were tested for tensile properties and the results were averaged. One specimen was used in the OIT test and the last one was kept as spare. The tensile and elongation testing was conducted at 73 ± 3°F. It should be noted that Study 1 included a control specimen exposed to tap water at each exposure time. Based on the findings from Study 1 only one control sample was used in Study 2 for tensile and oxidative induction time testing to minimize the number of samples and testing time. Additionally, in Study 2, the control specimen was not exposed to chlorine or water.

Table 6: *Tensile and Elongation Test Results and Data for Study 2*

Chlorine Exposure Time, hrs.	Tensile strength at yield, psi	Elongation at Break, %
Control (0)	3446	619
24	3457	662
48	3481	659
72	3459	681
168	3402	713
336	3395	707
504	3422	685

These results confirm that the exposure to 200 mg/L of free chlorine at 73°F for 504 hours had no statistically significant effect on tensile and elongation properties for the PE4710 tested in Study 2.

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 of chlorine exposure on thermal stability. Oxidative Induction Time as measured by a differential scanning colorimeter (DSC) was used as an indication of thermal stability.

Study 1: The same compression molded samples (PE3408) and chlorine solution (200 mg/L) 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.

Table 7: *Oxidative Induction Time Test Results and Data for Study 1*

Exposure Time*, hrs.	OIT, minutes	
	Chlorine Exposed	Control
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

*Note – Test temperature is not known

Although individual measurements vary over time, there appears to be no significant difference between chlorine exposure and the control.

Study 2: The test specimens for the OIT test were taken from the reduced area section of tensile specimens and two specimens were tested at each chlorine exposure time. First, a full cross-section of the tensile specimen was obtained, then the exposed surfaces were removed with a razor blade. The remaining core was used for OIT measurement at 200 °C. The control sample was not exposed to chlorine.

Table 8: *Oxidative Induction Time Test Results and Data for Study 2*

Chlorine Exposure Time, hrs.	OIT at 200°C, minutes
Control	149
24	151
48	157
72	153
168	154
336	154
504	155

The results from Study 1 and Study 2 don't show any significant difference between the OIT of the control and the chlorine exposed samples.

5.5 High Speed Tensile Impact

A high-speed tensile impact test (ASTM F2634) is used in 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. In Study 1, two samples of PE3408 pipe were prepared by heat fusing two pipe segments 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 during 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 impact are summarized below.

Table 9: *High Speed Tensile Impact Test Results and Data for Study 1*

Energy, in-lbf		
Sample Number	**Control**	**Chlorine Exposed**
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 performance between the control and the chlorine exposed samples. As this test was not able to detect a difference in performance with chlorine exposure, it was not repeated in Study 2.

5.6 PENT Testing

A concern for long term performance of polyethylene pipe is the resistance to slow crack growth. Although the standard method for determining Hydrostatic Design Basis (ASTM D2837) has provided an excellent estimate of this parameter; it is admittedly a lengthy procedure. Over the years, a number of tests have been developed to provide an accelerated estimate of resistance to slow crack growth. 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."

In Study 1, a standard PE3408 pipe material was compression molded and milled to size following the procedure outlined in ASTM F1473. A total of six specimens were prepared from the same resin sample. Two were notched and used as control; two were exposed to 200 mg/L chlorine water and then notched. The third set were notched and then exposed to 200 mg/L chlorine water. The PENT test was then performed in air at 80°C.

Results are summarized in Table 10:

Table 10: *PENT Test Results and Data for Study 1*

Sample	Individual PENT Values, hr.	PENT Average, hr.
Control	68.4	69.4
	70.4	
72 hr chlorine exposure, then notched	65.4	68.0
	70.6	
Notched, then 72 hr chlorine exposure	68.8	67.7
	68.3	

The variability observed in the above values would be considered to be within the accuracy of the test method. The PENT results indicate that chlorine exposure did not appear to adversely affect failure times of the PE resin. Since this test did not reveal any measurable performance differences with chlorine exposure and the PENT performance of PE4710 compounds are much higher, it was not repeated in Study 2.

6. Chlorine Dissipation Rate

During Study 1, 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.

Table 11: *Chlorine Dissipation Rate Test Results and Data for Study 1*

Exposure Time, hrs.	Chlorine Concentration, mg/L
0	321
24	271
48	227
72	216
96	168
192 (8 days)	140
336 (14 days)	58

7. 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 effect on the newly constructed PE pipe.
For long-term performance of HDPE in chlorinated potable water applications, refer to PPI TN-44 and PPI TN-49.

8. References

ASTM D1599, Standard Test Method for Short-Time Failure Pressure of Plastic Pipe, Tubing and Fittings

ASTM D1598, Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure

ASTM D638, Test Method for Tensile Properties of Plastics

ASTM D2837, Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials

ASTM D1693 Stress-Cracking of Ethylene Plastics

ASTM F1248, Test Method for Determination of Environmental Stress Crack Resistance (ESCR) of Polyethylene Pipe

ASTM F1473, Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins.

ANSI/AWWA C651, Disinfecting Water Mains

ANSI/AWWA C901, Polyethylene (PE) Pressure Pipe, Tubing, and Fittings 3/4 In. (19 mm) Through 3 In. (76 mm) for Water Service

ANSI/AWWA C906, Polyethylene (PE) Pressure Pipe and Fittings, 4 In. Through 65 In. (100 mm Through 1,650 mm), for Waterworks

PPI TN-43, PE Compound Categorization for Potable Water Applications

PPI TN-44, Long-Term Resistance of AWWA C906 Polyethylene (HDPE) Pipe to Potable Water Disinfectants

PPI TN-49, Recommendations for AWWA C901 Service Tubes in Potable Water Applications