The lifecycle of current HDPE pipes in potable water applications

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AWWA Hawaii Section 36th Annual Conference
Honolulu, HI, May 18-21, 2010
Outline

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- Introduction
- Features and Benefits of PE
  - Trenchless construction
  - Resistance to earthquakes/Hurricanes/Tsunamis
  - Corrosion cost; Water loss; Life cycle cost
  - Fatigue Life
  - Permeation
  - PE 4710
- Current R & D (Jana Lab/PPI):
  - Service life evaluations
  - Case studies
  - The PE life cycle (Suez Env.)
  - Lifetime prediction of a Blue PE 100 .. (Bodycote PDL/EXOVA)
  - Chlorine Dioxide
  - Other work: Engineering Services (UGSI)
- Summary
PPI

Divisions: Municipal and Industrial; Plumbing; Corrugated; Gas; Conduit

- contributing to the development of standards
- educating designers, installers, users and government officials
- publishing up-to-date technical and general reports
- collecting and publishing industry statistics
- establishing forums for problem solving and new idea generation
- maintaining liaisons with industry, educational and government groups
- providing a technical focus for the plastics piping industry
- supplying associated web sites with up-to-date information

Hydrostatic Stress Board (HSB)

Since 1958, the HSB has worked as a volunteer group under PPI's auspices to define appropriate test procedures and issue recommendations for long-term strength. The HSB's recommendations are often referenced by North American plastics piping standards for the qualifying of thermoplastic piping materials for pressure piping service, and for the establishment of pipe pressure ratings.
# PPI- Municipal & Industrial Members (55)

- **HDPE Pipe Manufacturers (14)**
  - A-D Technologies
  - ADS (Advanced Drainage System, Inc.)
  - Boreflex/Lamson Pipe
  - Charter Plastics, Inc.
  - Endot Industries Inc.
  - Flying W Plastics
  - Global Poly Systems
  - Independent Pipe Products Inc.
  - J-M Manufacturing Company
  - KWH Pipe Ltd.
  - National Pipe & Plastics, Inc.
  - Performance Pipe, a Division of Chevron Phillips
  - PolyPipe, Inc.
  - WL Plastics

- **HDPE Valves, Coupling & Fitting Manufacturers**
  - High Country Fusion Company Inc.
  - Improved Piping Products, Inc.
  - Industrial Pipe Fittings, LLC
  - Nupi Americas
  - Poly-Cam, Inc.

- **HDPE Distribution Members**
  - A.H. McElroy Sales and Service (Canada)
  - Ferguson Industrial Plastics
  - Forrer Supply Company
  - HD Supply
  - ISCO Industries
  - Sandale Utility Products, Inc.

- **HDPE Equipment Manufacturers**
  - American Maplan Corp.
  - Fast Fusion
  - Georg Fischer Central Plastics, LLC
  - IPEX/FRIATEC Incorporated
  - Milacron, Inc.
  - McElroy Mfg., Inc.
  - Ritmo America

- **HDPE Resin, Resin Concentrate, Catalyst & Additive Manufacturer**
  - Chevron Phillips
  - CIBA
  - Dow Chemical
  - Formosa Plastics Corp., USA
  - Ingenia Polymers Group
  - Ineos
  - LyondellBasell Industries
  - NOVA Chemicals
  - PolyOne Corp
  - Spartech Color & Specialty Compounds
  - TOTAL Petrochemicals, Inc.

- **Professional Members**
  - Alliance for PE Pipe
  - Gas Technology Institute
  - Hauser Laboratories
  - Jana Laboratories
  - NSF International
  - W R Grace
  - TRI Environmental

- **Individual Members**
  - Frank Volgstadt
  - Palermo Plastics Pipe Consulting

- **Foreign Affiliate**
  - Amiantit Oman; Dadex Eternit Ltd; Polyplastic Group
Introduction

- PE pipes have provided decades of exceptional performance in N. America and Europe in potable water and other applications.
- In the past 10 years alone, the PE industry (in US + Canada) has installed an estimated 3 billion feet of potable water service tubes, distribution and transmission pipes.
- With aggressive operating conditions (aggressive water quality, high stress, high temperature) the performance of all pipes need to be examined more closely.
- PE industry continues to improve materials, clarify operational parameters to help engineers and utilities design and operate better systems based on specific operating conditions.
- To enable this research, we have partnered with multiple cities in the US and invite you to assist in identifying the local operating conditions and to provide us with pipe samples (potable water) for analysis to understand your conditions.
Introduction

- Every pipe can fail if designed/installed improperly or operated in aggressive conditions.

- For example, the Unibell Handbook refers to a study by NRC of Canada that documented the average “Water Main Break Data…”
  - PVC: 0.7 breaks/100 KM/year
  - DI: 9.5 “ “

- For the 300 million ft. of PVC: results in 661 breaks / year
- For every 1 million ft. of DI: 29 “ “

- In the last 10 years alone, ~3 billion feet (estimated) of PE potable water pipe and tubing were installed in the US and Canada with an excellent performance record and with minimal breakage. Every break is important and need your help to identify it.
Features & Benefits  Trenchless Construction

PE is the material of choice for trenchless construction.

**ASTM F585:** *(sliplining)* Standard Practice for Insertion of Flexible Polyethylene Pipe Into Existing Sewer. Also, refer to PPI H/bk, chp 11

**ASTM F1962:** *(HDD)* Use of Maxi-Horizontal Directional Drilling (HDD) for Placement of Polyethylene Pipe or Conduit Under Obstacles, including River Crossings. Also, refer to ASCE MOP 108; PPI H/bk, Chp 12 and PPI TR 46 for Mini-HDD applications

**Pipe Bursting**
- ASCE MOP 112 and PPI PE H/bk, Chp. 16
- 9,000 miles of PE pipe installed by pipe bursting world wide, British Gas
- PE used to rehab water mains, gravity and force main sewers, and gas lines. **Upsize:** Common (0-25%), Challenging (25-50%), Experimental (50-125%)
Trenchless Construction- HDD

Underground Construction,
June 2007, 9th Annual Survey
HDD Case Studies

Calgary Water (PE 4710/PE100) Project: Spruce Trees Untouched as Water Rehab Project Goes On
City of Palo Alto, CA- Using HDPE 4710 for Water Main Replacement Projects
New HDPE (PE 100) Demonstrates Benefits with Michigan Project
Floating Pipes Pulled Underground
Frontier Pipeline Completes Record Setting Rock Drills
Pipeline staging area includes land and water
HDD Project Solves Water Supply Problem for Canadian Yacht Club
Wisconsin Contractor Successfully Completes Challenging HDD Bores for Sewer Project
Colorado Springs - HDPE Pipe Directionally Drilled to Protect Environmentally Sensitive Colorado Springs Landmark
Kansas' oldest city getting new water mains
Utilities Kingston, Great Cataraqui River Utilities Crossing Project, Kingston, Ontario
Gannett Fleming, Elizabeth River Crossing, Norfolk, Virginia
EBI Drilling projects in Wisconsin
TT Technology, Sauk River, St Cloud, Minnesota
Rosebud Sioux Rural Water System, South Dakota
Water World, Emergency HDPE Pipeline Helps Save City from Drought, Corsicana, Texas
EBI Drilling projects in Michigan
Water Online, DFW Insures Environmental Protection with HDPE
Environmental Crossings, St Joseph River Crossing in Indiana, and Crossing of the Shipping Channel at Port Canaveral, Florida
HDPE pipe crosses the Chesapeake & Delaware Canal
St. Petersburg initiates an 18-year $100 million water main replacement program
MEARS Chincoteague Channel/Black Narrows Crossing, Chincoteague, VA
MEARS JEA Beaver Street Wetland Crossing, Jacksonville, FL
MEARS JEA Riverside Avenue Crossing Jacksonville, FL
Indian Rocks Beach Crossing Florida
Chesapeake Beach, Maryland
ARB Port of Los Angeles
Pipe Bursting Case Studies

Oregon - HDPE Pipe Improves Water Supply and Lives Of Student Trainees in Government Pilot Project
How to be Environmentally Progressive, save Infrastructure in Tough Economic Times
HDPE Pipe Brings Life Back to Miami-Date Water System
Lansing, MI: Trenchless Water Main Replacement – A First In The Capital Of Michigan
HDPE replaces AC and PVC: CDM, Everglades Pipe-Bursting Approach to Replacing Water Lines
HDPE used to increase pipe size from 6" to 8": RJN, Pipe Bursting Water Lines in Limited Access Locations
HDPE used to replace CI and VCP: TT Technology, 3 Lateral Pipe Bursting in California
HDPE used to replace CI and DI: TT Technology, NIBCO Solutions take on Ductile Iron Bursting in Illinois
HDPE used to replace CI: TT Technology, Trenchless pipe bursting having a big impact on the utility construction industry
HDPE used to replace CI: TT Technology, Louisville Water Company: targeting trenchless water main replacement
HDPE used to replace concrete: TT Technology, Total Rehab- entire town gets new sewer
HDPE used to replace, CI, DI and steel: TT Technology, Winning the water war: Pipe bursting at the LA department of water and power
Pipe eludes corrosion issues
# Trenchless Construction - Resources

All PPI resources are available online for free download [www.plasticpipe.org](http://www.plasticpipe.org)

- **AWWA C901-08** for ½” - 3” water service
- **AWWA C906-07** for 4” – 63” water distribution and transmission
- **AWWA M55-06** for design and installation

## Resources

<table>
<thead>
<tr>
<th>Engineering Properties</th>
<th>Slip lining</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H. Directional Drilling</strong></td>
<td>Marine Applications</td>
</tr>
<tr>
<td>Pipe &amp; Fittings Manufacturing</td>
<td>Inspections, Tests and Safety</td>
</tr>
<tr>
<td>Joining Procedures</td>
<td>Above Ground Applications</td>
</tr>
<tr>
<td>Underground Installations</td>
<td>Specs and Test Methods</td>
</tr>
<tr>
<td>Design</td>
<td>Pipe Bursting</td>
</tr>
</tbody>
</table>
# Earthquake Vulnerability of Buried Pipelines

(ASCE, Seismic Screening Checklists For Water and Wastewater Facilities, 2003, p 44)

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Low Vulnerability</th>
<th>Low to Moderate</th>
<th>Moderate</th>
<th>Moderate to High</th>
<th>High</th>
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<tbody>
<tr>
<td>PE</td>
<td>AWWA C906</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ductile</td>
<td>C1xx</td>
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<td></td>
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<tr>
<td>Steel</td>
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<td>Concrete</td>
<td>C300, C303</td>
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<tr>
<td>PVC</td>
<td>C900, C905</td>
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<tr>
<td>Cast Iron</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>V. Clay</td>
<td></td>
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<tr>
<td>Asbestos C.</td>
<td></td>
<td></td>
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<td></td>
<td>c4xx</td>
</tr>
</tbody>
</table>
Features & Benefits …

Largest Recorded Earthquakes in each US State

- Hawaii (and CA) have experienced the 4th largest magnitude earthquake in US history
- Only MO, AR, AK (9.2) experienced higher magnitude earthquakes
Tsunami Resistance

Curtis Edwards, P.E., Vice President, Pountney Psomas – Thailand Team Leader, ASCE sent three teams to the tsunami disaster zone to conduct damage assessments. http://www.asce.org/page/?id=160

February 3, 2005 “One of the surprising findings of this investigation is the prevalent use of high-density polyethylene piping for potable water. Much of this piping was exposed due to erosion and subjected to harsh conditions from debris and waves. The piping performed very well, with few failures. The material is flexible, allowing it to conform to new contours after the erosion. It is also very light, making repairs very easy…”
Hurricane Resistance


‘The PE (gas) pipe maintained its integrity. The sewer pipe, the water pipe, the house, and the land didn’t’.

***************

The Honolulu Advertiser, May 20, 2010

Gov. Linda “Lingle urges residents to prepare for possibility of severe hit during season”

“Fewer hurricanes forecast for central pacific this year”
Features & Benefits … Corrosion Cost

Annual U.S. cost of corrosion for water and sewer systems (FHWA, 2002)

Drinking water ($20bn) + Sewer ($13bn) + un-accounted for water ($3bn) = $36 bn

$36 Billion $0
Features & Benefits Allowable Leakage of Precious Water

- HDPE (AWWA M55, 1st ed., p. 130) ZERO

For other materials, refer to the relevant AWWA manuals

1996 AWWA Water Stats Survey found losses ranging from 1% to 99%
“The lower cost for the polyethylene network is due to two main reasons. Firstly, because its failure rate is low, the cost per mile for repair/replacement is also low…” The second major benefit of PE networks is fusion-welded joints which ensure very low leakage rates and thus low water loss costs.”
# Features & Benefits ... Fatigue Life

## Design Fatigue Life (Years) at Velocity of 4 fps at 1 cycle every 15 minutes

<table>
<thead>
<tr>
<th>Pumping Pressure (psi)</th>
<th>DR14 PC305</th>
<th>DR18 PC235</th>
<th>DR21 PC200</th>
<th>DR25 PC165</th>
<th>DR9 PC200</th>
<th>DR11 PC160</th>
<th>DR13.5 PC128</th>
<th>DR17 PC100</th>
<th>DR21 PC80</th>
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<tbody>
<tr>
<td>25</td>
<td>&gt;100</td>
<td>71</td>
<td>64</td>
<td>36</td>
<td>&gt;100</td>
<td>&gt;100</td>
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<tr>
<td>50</td>
<td>86</td>
<td>43</td>
<td>26</td>
<td>17</td>
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<td>75</td>
<td>59</td>
<td>31</td>
<td>21</td>
<td>14</td>
<td>&gt;100</td>
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<td>100</td>
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<td>125</td>
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<td>150</td>
<td>50</td>
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<tr>
<td>175</td>
<td>46</td>
<td></td>
<td></td>
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<td>&gt;100</td>
<td>&gt;100</td>
<td>&gt;100</td>
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<td>200</td>
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<td></td>
<td></td>
<td>&gt;100</td>
<td>&gt;100</td>
<td>&gt;100</td>
<td>&gt;100</td>
<td>&gt;100</td>
</tr>
</tbody>
</table>

- **Pumping Pressure exceeds Working Pressure Rating, not suited for use.**
- **Design Fatigue Life less than 50 years.**

All AWWA pipe standards contain similar permeation statement for PE, PEX, PVC, Steel, DI, …

“Reports of permeation incidents involving potable water distribution are rare, with reports of 1 incident per 14,000 miles of mains and 0.9 incidents per million service connections in this survey.” AWWA-RF p. XXII

“… any PVC pipe that does become permeated without bursting should be replaced because remediation is not feasible.” AWWA-RF p. 175

“… 43% of reported permeation incidents involved PB pipe, 39% involved PE pipe, and 15% involved PVC” AWWA-RF p. 2

“BTEX and chlorinated solvents also soften PVC pipe, … causing it to be susceptible to permeation in a manner similar to PB and PE.” AWWA-RF p. 3
Features & Benefits- PE 4710

- The PPI Hydrostatic Stress Board set additional performance criteria for high performance materials.

- These materials could be operated at a higher design stress (1000 psi for PE 4710, instead of 800 psi for PE3608) without sacrificing service life or safety because the material does not get “weaker” over time and because short-term burst strength is about 3.5 x HDS
  - PE material continues to operate in the ductile state
  - Ensures higher statistical reliability in strength forecast.
  - ASTM F 1473 slow crack growth resistance indication (PE 4710 PENT = 500 hrs; in contrast, the first PE gas pipe had a PENT value of ~1.5 hrs). Essential immunity to effects of localized stress intensifications.

- Implemented in most ASTM Standards and in AWWA C901-08.
Older PE materials had stress regression curves showing transition to “brittle” type failures.

Higher performance PE materials (~ PE 4710)
Oxidation Induction Time (OIT)
- Indirect measure of level of stabilization
- Measures time to oxidize in oxygen environment at 200 °C

Simple use of OIT or Carbonyl Ratio (or both together) as a direct indication of remaining service life is not possible and can be misleading.

Carbonyl Ratio
- Measured through FTIR (Fourier Transform Infra-red)
- Measure of relative level of oxidation

Therefore, forecasting of residual pipe lifetime can be achieved by exhuming in service piping, testing to ASTM F2263 and considering the utility’s specific operating conditions.
“Significance and Use
The OIT is a qualitative assessment of the level (or degree) of stabilization of the material tested. This test can be used as a quality control measure to monitor the stabilization level in formulated resin as received from a supplier, prior to extrusion.

Note 2—The OIT measurement is an accelerated thermal-aging test and as such can be misleading. Caution should be exercised in data interpretation since oxidation reaction kinetics are a function of temperature and the inherent properties of the additives contained in the sample. For example, OIT results are often used to select optimum resin formulations. Volatile antioxidants may generate poor OIT results even though they may perform adequately at the intended use temperature of the finished product.

Note 3—There is no accepted sampling procedure, nor have any definitive relationships been established for comparing OIT values on field samples to those on unused products, hence the use of such values for determining life expectancy is uncertain and subjective.”
The PE industry has been working proactively to develop long-term validation methodologies for the Stage III brittle-oxidative regime.

**General Approach:**

- Data for current generation PE materials
- Testing in progress per ASTM F2263 and for actual utility end-use conditions used in model
- The methodology developed in this study provides a significant advancement over other approaches (OIT, …) and provides a means for forecasting specific pipe performance as a function of operating conditions
- To simplify analysis:
  - Standardized on DR11
  - Did not scale for pipe size (conservative approach)
  - Conservative approach to chloramines – set ORP to 650 mV
**Current R&D … Case Studies**

- “Case studies for four utilities and a modeled average utility show that greater than 100 years performance is projected for higher performance PE 3408 and PE 4710” in potable water applications.
- At aggressive conditions (aggressive water quality, high stress, high temperature) performance of potable water pipes needs to be examined more closely

<table>
<thead>
<tr>
<th></th>
<th>Indiana</th>
<th>Florida</th>
<th>North Carolina</th>
<th>Palo Alto CA</th>
<th>Avg. US Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. disinfectant residual, ppm</td>
<td>1.6</td>
<td>1.4</td>
<td>0.9</td>
<td>1.9</td>
<td>-</td>
</tr>
<tr>
<td>Avg. pH</td>
<td>7.7</td>
<td>9.3</td>
<td>8.6</td>
<td>9.0</td>
<td>-</td>
</tr>
<tr>
<td>Estimated ORP, mV</td>
<td>650</td>
<td>650</td>
<td>680</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>Avg. water temperature (Avg. range)</td>
<td>57°F (34-84) °F</td>
<td>79°F (55-82) °F</td>
<td>68°F (55-82) °F</td>
<td>61°F</td>
<td>57°F (37-84) °F</td>
</tr>
<tr>
<td>Avg. operating pressure, psi</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>65</td>
<td>70</td>
</tr>
<tr>
<td>Projected performance in the brittle oxidative regime</td>
<td>&gt; 100 Years</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Same general approach as the Jana Lab model

“... polyethylene is a reliable and cost effective material that is easy to install and that can be used in most cases ...”

Shows that high temperature, disinfectant type/concentration and high pressure impacts the service life of PE

“the pipe thickness is an important factor..., additional thickness will increase longevity... small diameter connections will be more affected as the pipe thickness decreases.”

“there are solutions: ...a new generation of products that are chlorinated disinfectant resistant is possible. The performance of PEX or cross linked polyethylene used in domestic hot water systems is also good.”
Current R&D … Lifetime Prediction of a Blue PE 100 Water Pipe (Bodycote PDL/EXOVA 2008)

- Research funded by the UK Water Companies: Veolia Water, Thames Water, United Utilities, …

- “Lifetime prediction over the range of 10-25°C proved to exceed 50-year lifetime requirements.”

- “… the use of stabilizers such as HALS has the ability to prolong the service lifetime of PE pipes.”
Jana Lab is in process of developing a white paper to estimate the usage of CLO2

Chlorine dioxide is more aggressive than chlorine

Preliminary results:
- Paper estimates less than 200 systems (out of 51,972) of US water utilities use Chlorine Dioxide as secondary disinfectant
- Performance criteria based on ASTM F2263 testing needs to be developed
- PEX F2023 CL testing requirements are adequate for CLO2 exposure.
Other Report: Engineering Systems, Inc (UGSI, 2009)

- Report presented what looks like a lot of data and looks very thorough and includes a lot of pictures and was probably very expensive, but the contents that should have been included are the established test protocols that actually assess the lifetime of PE pipes.

- For example, the report used OIT or Carbonyl Ratio: the use of these methods (or both together) as a direct indication of remaining service life is not possible and can be misleading.

- The report should have forecasted residual pipe lifetime by exhuming in service piping, testing to ASTM F2263 and considering the utility’s specific operating conditions.

- The clearly identified failures (with the exception of the 6” sample) are for small diameter service tubes and the PE industry will evaluate and need your help. AWWA 263 Cmt asked the researcher for more information.
The PE industry now knows of some isolated places in the desert and unique applications (like CLO2) where pipes did not reach their full design life.

Report highlights concerns in these extreme applications and attempts to apply conclusions to the entire use of PE in disinfected water applications.

The PE industry is working to address these issues through proper research and through AWWA and would appreciate your support and collaboration to exhume pipe and identify local operating conditions.
Other Work:

It is not clear which of the samples are failures, and of the failures presented, many have external factors as listed below:

- “While the failures of these pipes can be attributed in many cases to excessive in-service stress, …”
- “Most of the pipe failures that have been investigated have been from warmer climates, some where the ground temperature may have been as high as 100 degrees F at times.”
- “Several of these samples appeared to have failed due to rock impingement …”
- “The service times for these samples ranged from a little over one year to over 30 years.” with limited information on the operating conditions and type of materials associated with these samples.
Summary

- PE pipes have provided decades of exceptional performance in the US, Canada and Europe in potable and other applications due to its durability and resistance to earthquakes, tsunami, hurricane, corrosion, fatigue, zero leakage and lowest life cycle cost.

- In the past 10 years alone, the PE industry (in US + Canada) has installed an estimated 3 billion feet of water service tubes, distribution and transmission pipes.

- PE is the material of choice for trenchless methods that provide the most cost effective solutions (depending on local soil conditions).

- Every pipe can fail if designed/installed improperly or operated in extreme conditions.
Summary

- The PE industry has been working proactively to develop long-term validation methodologies for the Stage III brittle-oxidative regime. PE industry is researching the end-use conditions to refine and expand the design envelope for potable water applications.

- Simple use of OIT or Carbonyl Ratio (or both together) as a direct indication of remaining service life is not possible and can be misleading.

- Forecasting of residual pipe lifetime can be achieved by exhuming in-service piping, testing to ASTM F2263 and considering the utility’s specific operating conditions.

- For CLO2: Performance criteria based on F2263 testing needs to be developed (PEX F2023 CL testing requirements are adequate for CLO2 exposure).
Summary

Case studies for four utilities and a modeled average utility show that greater than 100 years performance is projected for higher performance PE 3408 and PE 4710 in specific potable water applications.

Jana’s Lab model is similar to what is being developed now in Europe.

With aggressive conditions performance of all type of pipes needs to be examined more closely.

PE industry will continue to improve materials, clarify operational parameters to help engineers and utilities design better systems.

PE industry has partnered with multiple cities in the US and invite you to assist in identifying the local operating conditions and to provide us with pipe samples (potable water) for analysis to understand your conditions.
Mahalo for your time and for your invitation to your 36th annual meeting.
Also, thank you to the conference chair, Mike Street and section chair Daryl Hiromoto.
I look forward to working with you in the near future.

Credit:
Pictures compliments of Miller Pipelines Co and City of Palo Alto, CA.