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Integrity Management of Plastic Pipelines

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Abstract

The area of integrity management of pipelines is one of growing interest. In many pipeline applications, the aging infrastructure is posing a challenge for pipeline owners and operators. Particularly in applications involving potentially hazardous materials this is an issue that needs to be approached proactively. The Natural Gas Distribution industry is one falling into this category and new Pipeline Integrity Management Regulations are currently being considered by the federal Department of Transportation. Separate from the pending regulations, Gas Utilities are also proactively examining the integrity of plastic pipeline systems. This paper reviews the changing approach and pending legislation for managing the integrity of plastic distribution system materials. A general approach to examining the functional integrity of plastic piping systems is presented. A specific case study examining the integrity of an exhumed-from-service (natural gas distribution) plastic piping material is presented along with comparisons of projected pipeline functional integrity versus actual field service performance. It is concluded that, although the specific form of pending regulations for pipeline integrity management (PIM) is not known, some effective tools and techniques for assessing pipeline functional integrity, a subset of the overall PIM approach, are currently available.

Background

Pipeline Integrity Regulations

In the United States, there are approximately 300,000 miles of Transmission Pipelines and 1,900,000 miles of Distribution Pipelines in operation. These pipelines generally have an excellent record of performance and safety. There is a growing focus, however, on ensuring the consistent management of the integrity of Natural Gas Transmission and Distribution piping. Department of Transportation (DOT) Office of Pipeline Safety (OPS) regulations have been put in place for Transmission pipelines for Pipeline Integrity Management (PIM). New DOT OPS regulations are being considered for Distribution Pipelines. These Pipeline Integrity Management regulations will facilitate the continuation of the impressive performance record for these pipeline systems.

While Transmission pipelines are generally constructed from elastic materials such as steel, Distribution system pipelines tend to be constructed of visco-elastic materials such as Polyethylene. These two categories of materials, both with their strengths and weaknesses, behave quite differently in terms of material properties. The approach for PIM of each material category must, therefore, be tailored specific to the material type. The Pipeline Integrity Management regulations that are in existence today are specific to Transmission pipelines. While, due to the inherent differences in the materials, the details of these regulations will differ significantly from those that may be put in place for Distribution pipelines, the overall Objective is unlikely to change dramatically. The Objective of the current regulations is to:

Improve Pipeline Safety through:

- accelerating the integrity assessment of pipelines in High Consequence Areas;

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- improving integrity management systems within companies;
- improving the governments role in reviewing the adequacy of integrity programs and plans; and
- providing increased public assurance in pipeline safety.

As discussed, the nature of Transmission and Distribution piping materials are different. In addition, the physical demands on a Distribution pipeline are notably different that those on a Transmission pipeline. The response to these physical loads is also fundamentally different between elastic and visco-elastic materials. The Failure Modes and Effects of the two systems are not comparable. Therefore, service life estimation for new pipelines and residual life estimation for established pipelines are determined in different ways for the two types of materials. This activity is referred to as the Pipeline Functional Integrity assessment and represents a subset of the overall Pipeline Integrity Management activity.

Other differences of note between Transmission and Distribution pipelines that have been identified by the DOT OPSa are:

- Most pipe in Distribution pipeline systems is small diameter and operates at low pressure. Transmission pipelines are generally large diameter and high pressure.
- Distribution pipeline systems are a more complex network, with frequent branching and interconnections. Transmission pipelines generally run for many miles without such connections.
- Distribution pipeline systems include a range of materials, including a significant amount of polyethylene pipe. Transmission pipelines are generally constructed of steel.
- Distribution pipelines are usually difficult to take out of service for inspection without interrupting gas service to customers. Transmission pipelines often include loop lines and bypasses that allow individual sections of pipe to be removed from service temporarily.
- Distribution pipeline failures tend to occur as leaks. Gas can migrate underground, accumulating in areas remote from the leak so that fires and explosions occur away from the pipeline. Transmission pipelines, because of their high operating pressure, tend to fail by rupture and the consequences occur on the pipeline.
- State pipeline safety regulators regulate most Distribution pipeline systems.

The regulations being considered for Distribution pipelines will need to address these differences. Although the current form of the pending regulations is not known, Gas Utilities have been proactively examining the integrity of plastic pipeline systems through internal PIM programs and pending regulations will likely be comprised of the same general elements as the current ‘best practices’.

Pipeline Integrity Management (PIM)

Pipeline Integrity Management (PIM) of plastic Distribution piping systems, if properly conducted, promises to provide reduced pipeline operating costs through: 1. Improved Safety; 2. Improved Reliability; 3. Reduced Replacements; and 4. Reduced Leak Survey Requirements. There are two key areas for PIM of plastic distribution piping systems: 1. New and Future Pipeline Integrity Management; and 2. Current Pipeline Integrity Management.

Proactive methodologies can be applied to PIM for new/future pipelines. These proactive methodologies involve: 1. Material Performance Characterization; 2. ‘Perfect’ Key Data Collection

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(PKDC); 3. Auditing of Installation Quality; and 4. Pipeline Performance Tracking/Monitoring Systems. The issue with existing systems is that much of the data required for Pipeline Integrity assessment is not available. The question becomes one of how can one best assess the projected performance of an in-the-ground pipeline? Answering this question involves many components, including: 1. Dealing with a Lack of Performance Characterization Data; 2. Managing the Lack of Key Data; 3. Risk Assessment; and 4. Risk Management.

In this paper a methodology for examining the first of these, a lack of material performance characterization data, is examined. This is looking at the specific Functional Integrity of the pipeline from a pipe perspective. The integrity of an exhumed-from-the-ground polyethylene (PE) Gas Distribution pipeline is characterized. This pipeline material was exhumed from a Gas Utility experiencing Slow Crack Growth type failures due primarily to Rock Impingement (accelerated failure due to rocks impinging and deforming the pipe to create stress concentrations) and squeeze-off. The Rate Process Method (RPM) is used to project performance (lifetime) of the exhumed PE material at in-ground temperatures and pressures based on both internal pressure as the primary load and the secondary loads of rock impingement and squeeze-off. The data is compared to actual field performance data.

Experimental

Elevated temperature hydrostatic pressure testing was conducted in accordance with ASTM D1598b on a 5 cm (2") IPS PE piping material exhumed from the ground. The material was operating in a Natural Gas Distribution pipeline. Multiple specimens were tested at a number of temperature and stress conditions to generate Slow Crack Growth type failures. The detailed test conditions, including descriptions of the simulation of rock impingement and squeeze-off are presented in the Results section.

The data generated were fit to the Rate Process Method (RPM) extrapolation equation:

$$Log\ t = A + \frac{B}{T} + \frac{C\ Log\ S}{T}$$

Where:

t = slit mode failure time, hours
T = absolute temperature, °K
S = hoop stress, MPa (psi)

The resulting RPM equations were used to project average failure time at typical use temperature (average annual ground temperature) and use pressure conditions (Note: The developed RPM projections are not absolute and are subject to various experimental errors, unknown deviations and judgment factors. Calculations from the RPM equation should be used in conjunction with all other mechanical, performance and use factors in making judgments as to design, useful life or application suitability).

Results

Examination of Integrity of Exhumed Plastic Piping

A. Internal Pressure

Accelerated (elevated temperature) hydrostatic pressure testing with internal pressurization only (i.e. no other applied stress) was conducted at temperatures of 80°C (176°F) and 60°C (140°F) with the internal pressures selected to assure that the failure mode was that of the Slow Crack Growth variety (For RPM calculations it is imperative that all the data have the same failure mode). All the failures observed resulted from a crack that initiated at the inside surface and propagated through the wall until failure occurred (typical Slow Crack Growth type failure).

Based on underground thermocouple testing, the gas utility determined that the average annual service temperature was 21°C (70°F). The use pressure for the gas distribution system was 4 bar (60 psig). The RPM projected performance for the exhumed pipe material at the use conditions of 4 bar (60 psig) and 21°C (70°F) was an average failure time of about 150 years with a 5% lower confidence level (LCL) of 60 years. The data are presented graphically in Figure 1.

B. Rock Impingement

To simulate the rock impingement failures experienced by the gas utility, an indentation jig (Figure 2) was used in addition to internal pressurization to apply two stress influences unto the pipe. The indentation jig consisted of a collar with a bolted thread of 28 UNS pitch. Seven turns of the bolt after it is flush with the pipe introduced an indentation of 0.635 cm (¼"). The bolted collar remained on the pipe the entire time it was subjected to stress rupture testing to simulate the indentation from rock impingement in the field. Testing was again conducted at 80°C (176°F) and 60°C (140°F) with the internal pressure selected to assure a slow crack growth failure. All failures used in the RPM calculation were inside to outside cracks that initiated at the indentation. When the indentation jig was removed, there was residual indentation, which looked identical to the failure mode observed by the gas utility in the field failures. Another characteristic feature of an indentation failure is that they are off-axis by a few degrees (a failure due to just internal pressure is exactly in the axial direction). Rock indentation failures exhumed by the gas utility also had off-axis slit failures. At the gas utility use conditions of 21°C (70°F) and 4 bar (60 psig) the RPM projected performance for the indented exhumed-from-the-ground pipe material was an average failure time of 12 years with an LCL of 8 years. The data are presented graphically in Figure 1.

C. Squeeze-Off

To determine the RPM projected performance of squeezed pipe, a similar experiment was conducted. All pipe samples were squeezed-off using recommended procedures and a single bar squeeze tool. The bar was brought to the gap stop and left there for one hour. The tool was removed and all specimens subjected to stress rupture testing at 80°C (176°F) and 60°C (140°F). All failures used in the RPM calculations were inside to outside cracks that initiated at the squeeze-off location. At the gas utility use conditions of 21°C (70°F) and 4 bar (60 psig) the RPM projected performance for the squeezed exhumed pipe was an average failure time of 20 years with an LCL of 10 years. The data are presented graphically in Figure 1.

Comparison of Projected Pipeline Integrity with Observed Field Behavior

A. Internal Pressure

To the date in question, very few Slow Crack Growth type failures due to internal pressure only have been seen in service. This field experience is consistent with the RPM projections for internal pressure only (average failure time of 150 years with a 5% LCL of 60 years).

B. Rock Impingement

The gas utility first started to experience rock impingement failures after five years of in-ground service. The number of rock impingement failures increased every year and peaked after 12 years of installation. The number of failures then began to decrease every year. This field experience correlates well with the RPM projected performance of indented pipe at the end-use conditions (average failure time of 12 years with a 5% LCL of 8 years).

C. Squeeze-Off

The first failure in pipe experienced by the gas utility due to a squeeze-off was after 12 years of installation. The number of squeeze-off failures has increased slightly. This field experience is consistent with the RPM projections for squeeze-off failures at the use conditions calculated (average failure time of 20 years with a 5% LCL of 10 years).

Summary

The Rate Process Method is a very powerful tool that can be used to determine the projected life of old generation polyethylene pipe that is in service for natural gas distribution. RPM can project not only the life of control pipe based on internal pressure, but also the life of the pipe subjected to secondary loads such as rock impingement, squeeze-off, bending and deflectionc. The RPM can also be used to project the life of heat fusion fittings, such as butt fusion, socket fusion, saddle fusion and electrofusion. The RPM, therefore, represents one potential tool in an overall PIM program.

Conclusions

The area of Pipeline Integrity Management (PIM) for plastic Distribution systems is one of growing focus. Although the specific form of pending regulations is not known, one tool for assessing pipeline functional integrity is currently available. This technique, which provides a methodology for examining the integrity of current in-the-ground pipelines, is the use of the Rate Process Method. With suitable replication of end-use conditions, this methodology is seen to provide service projections based on accelerated laboratory testing that correlate very well with actual end-use piping system performance.

Footnotes

a. Federal Register/Vol. 69, No. 208/Thursday, October 28, 2004/Notices.
b. ASTM D1598, 'Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure'.
c. Palermo, E.F., "Correlating Aldyl "A" and Century PE Pipe Rate Process Method Projections with Actual Field Performance", Plastics Pipes XII Proceedings, Milan, Italy (2004).

Figure 1: Project Performance of an Exhumed-from-Service PE Piping Material

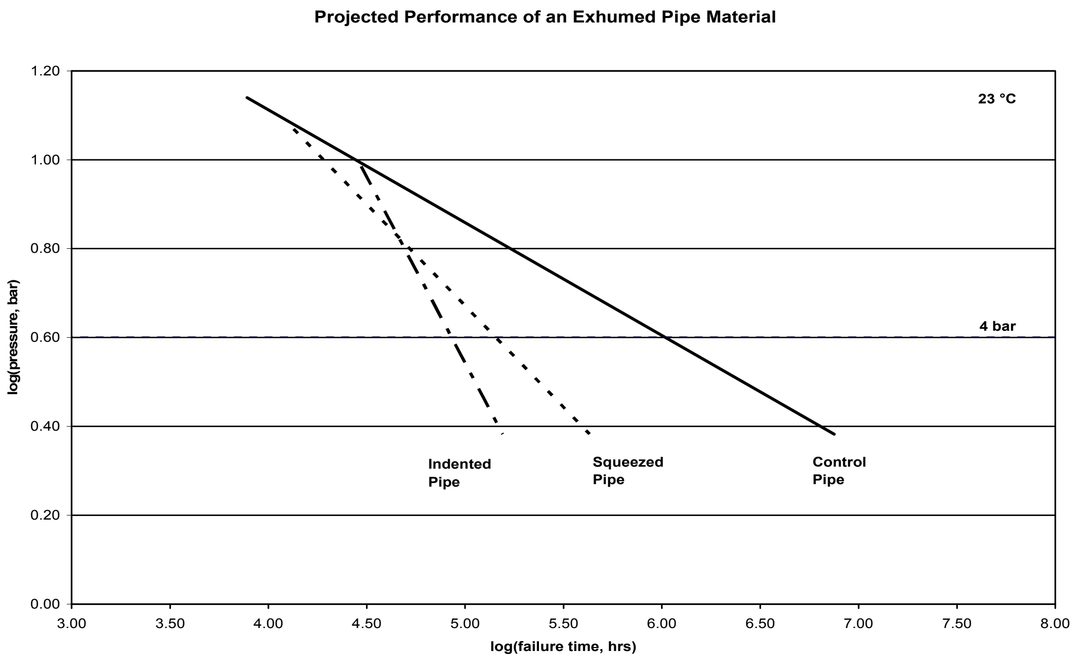

Figure 2: Indentation Jig for Simulation of Rock Impingement