Residual lifetime assessment of PE pipelines

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How can a polyethylene (PE) pipeline owner determine the remaining life of a pipe that has been in service for many years?

Pipe material

Advancements in the molecular design of PE materials have improved the durability and slow crack growth resistance of PE pipelines. The incorporation of antioxidants into the pipe material protects PE pipe from oxidative degradation.

A study conducted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the American Water Works Association noted that the average failure rate of PE pipes at 3.16 per 100 km was lower than the many other pipe materials.

The life expectancy of a PE pipeline system is highly dependent on the prevailing service conditions such as temperature, pressure and exposure to chemical agents. Pipelines may be exposed to conditions beyond the design parameters and this can lead to a variation in the expected lifetime of the pipes.

An assessment of the condition and the residual lifetime of a PE pipeline can provide the asset owner with valuable information, potentially preventing costly and unnecessary maintenance or alerting of the risk of a potential failure.

Failure modes of PE pipes

Ductile

A PE pipe that is operated beyond its pressure rating may experience ductile failure. PE pipes are assigned a pressure rating classification that is associated with the material from which the pipe is made.

The PE100 classification specifies a Minimum Required Strength (MRS) of 10 MPa at 20 degrees Celsius after 50 years. This is the maximum stress at which the pipe can operate without risk of ductile failure. The Hydrostatic Design Stress (HDS) is the stress at which the pipe has been designed to operate.

The HDS will be lower than the MRS as a down-rating occurs to reflect the use of safety factors that account for variations that may be present in design parameters specific to the relevant installation and concerns such as the consequences of the pipe failure and risk of interference with the pipe by the third party. The HDS is incorporated into the calculations which determine the pipe wall thickness.

A pipe that is in good condition and operating within conditions that are consistent with its service design will not experience a ductile failure.

Brittle

Environmental factors such as excessive heat, pressure and chemical agents in the medium being conveyed can lead to degradation in the strength of PE pipes. Processes which lead to the oxidation of the PE, can negatively impact the polymer's structural integrity. This type of degradation is known as brittle failure.

Pipe resin manufacturers actively work to counter this form of failure by incorporating antioxidants into the material. The amount of antioxidant contained within the pipe resin is finite and will eventually be consumed in the presence of oxidising factors.

Once the antioxidant has been consumed the polyethylene in the pipeline can start to oxidise leading to a decrease in the overall crack resistance of the pipe. This will eventually lead to the initiation and propagation of cracks within the pipeline.

Pipes made from older generations of PE resin are more likely to undergo brittle failure, as the latest generations have significantly improved slow crack growth resistance properties.

The framework of a residual lifetime assessment

There is no set amount of time which a PE pipe should last. Engineers design pipe networks to last 50 years or longer and even after 50 years of service, the product may still perform at the level it did at the beginning of its lifetime.

A PE pipe's expected residual lifetime is heavily dependent on the service conditions. Brittle and ductile failure modes are associated with the pressure, temperature, UV exposure and the presence of oxidative agents.

The residual lifetime assessment requires analysis of the current condition of the pipe material as well as the operating history of the pipe.

Conducting the residual lifetime assessment

Pipe material

The likelihood of brittle failure is the important consideration in the residual lifetime assessment of an existing pipeline.

The first step in the residual lifetime assessment is to verify that the pipe resin was manufactured in compliance with AS/NZS 4131. This standard specifies the physical properties that the PE resin must achieve in order to be suitable for pressure pipe applications.

While AS/NZS 4131 applies to the polyethylene resin performance, AS/NZS 4130 dictates requirements for the pipe's dimensions and physical characteristics.

This standard ensures that a particular pipe is designed to be capable of withstanding pressures inherent in the service conditions. A certified PE testing laboratory such as the Qenos Technical Centre will carry out several tests to enable it to estimate the residual service life expectancy of an installed PE pipe:

- Oxidative induction time (OIT) is a measure of a compound's thermal stability, and indicates the level of antioxidant remaining in the pipe. The remaining antioxidant is able to protect the pipe resin from oxidative degradation.
- Fourier Transform Infrared Spectroscopy (FTIR) is an analytic technique used to quantify the amount of oxidative degradation that has already occurred in the pipe.
- Melt flow rate (MFR) is a technique that links the viscosity of melted polymers to their physical size. This measure informs the laboratory on the toughness of the material.

Operating history

If a pipeline has been operated at varying service conditions such as different pressures and time details are known, Miner's rule could be applied to assess cumulative damage for failures caused by fatigue. It states that if there are k different stress levels and the average number of cycles to failure at the i^{th} stress, Si, is Ni, then the damage fraction, C, is:

$$\sum_{i=1}^{k} \frac{n_i}{N_i} = C$$

where:

ni is the number of cycles accumulated at stress Si.

C is the fraction of life consumed by exposure to the cycles at the different stress levels.

In general failure occurs when the damage fraction reaches 1. The above equation can be thought of as assessing the proportion of life consumed at each stress level and then adding the proportions for all the levels together. ISO 13760:1998 describes the method using Miner's rule for the calculation of cumulative damage for plastic pipes used for the conveyance of fluids under pressure.

This approach is used by the material testing laboratory to calculate a PE pipe's expected residual lifetime. In assessing the residual lifetime the laboratory will need access to the reports describing the original service conditions of the pipe.

Miner's rule can then be applied to account for the cumulative impact of changes in parameters such as operational temperature, pressure and disparate environmental factors and to calculate the impact that these parameters will have on the residual lifetime.

Summary

PE pipes are tough, durable and have a design life of up to 100 years. An assessment of the current state of a pipe combined with a view on the ongoing service conditions provides the information that enables the residual lifetime to be estimated.

Accessing the right information and having the assessment completed by capable service providers is critical to the condition assessment.

This type of assessment allows the owners of pipeline assets to optimally plan pipeline maintenance and replacement and avoid unexpected failures. **P**