Investigation of Root Cause of Polyethylene Pipe Leaks & Bursts

Rui Xiang Wong

Dr Jeremy Leggoe
School of Mechanical and Chemical Engineering
The University of Western Australia

Dr Nazim Khan
School of Mathematics and Statistics
The University of Western Australia

Regina Wu
Water Corporation

Abstract

Polyethylene (PE) pipes have been reportedly failing through leaks and bursts at a higher rate in the North West Region (NWR) compared to other regions. These high failure rates mean frequent expeditions are required to fix the pipes, which raises issues in cost and resource allocation, as well as the safety of the personnel involved,. This issue is of increasing concern as the usage of PE pipes is increasing. Thia project is investigating the root cause of the higher rate of burst or leaks of polyethylene pipe in the NWR, to recommend solutions that will mitigate the high rate of failures of the pipes.

To achieve these objectives, we have undertaken a root cause analysis on the failure mechanisms found during literature review, desktop studies on historical data of PE pipe connection, laboratory tests on failed PE pipe samples from NWR, and a pilot test to analyse the progression in properties of the PE pipe during early life exposure to chlorinated water at set temperature. Through these studies, the mechanism in which the pipes are failing will be better understood and an effective mitigation strategy can be recommended.

1. Introduction

Polyethylene (PE) has recently become a major pipe material used for water distribution. For pipes installed from the 1800s to 2010s, PE pipes constitute around 7% of all pipes installed. Pipes installed in the 1960s to 1970s were only 0.16% PE, and in the next two decades (1980s to 1990s), the percentage of PE pipes installed grew to 9.3%. 28% of all pipes installed in the 2000s and 2010s were made of PE. The fraction of PE pipes in the NWR with nominal size of 63mm or less used in reticulation is approximately 63%.

Unfortunately, PE pipes that were designed to last 50 years have started to fail in 5 years. Higher than normal rates of bursts/ leaks of PE pipes were noticed specifically in the North West Region (NWR). This rate of failure exceeds the acceptable Key Performance Indicator (KPI) of 20 bursts/ leaks per 100km of pipe set by Water Corporation (WC). The preliminary study done to confirm these high rates reported that the rates can be as high as one leak being repaired a day. 2016 data reveals that the average cost per repair is around 2000 AUD. In the year 2016, the total cost for repairs of PE reticulation pipe's leaks/ bursts in the NWR was in excess of 460 000 AUD.

Due to the high rate of PE pipe repairs, a preliminary study for this project was conducted by Andre Azis into the higher rate of PE pipe failures in NWR (Azis, 2016). The report provided an overview of current practices, and recommended improvements that can be made based on these practices. Key recommendations from the report were:

- To improve the records of job orders to provide sufficient data for trend analysis
- To ensure WC's standards for proper backfill, bedding and installation methods are followed
- To avoid clamping PE pipes for isolation during repairs
- To store PE pipes appropriately to maintain the integrity of the pipes
- A future study on the sample pipes for any weakening due to the combined effects of temperature and pressure.

The root causes of these higher rates of leaks/ bursts of PE pipes are not well understood, and so a clear proactive solution cannot yet be implemented and evaluated. Currently, a more reactive approach is taken, where time and resources are spent in repairing the leaks/ bursts. Every time a leak/ burst is found, the Civil Team members have to excavate, locate the leak, isolate and restore the reticulation (Azis, 2016). This not only increase the issues with safety, cost and time spent to reinstate the pipe, but also increases the risk of incidents such as hitting underground services. There will also be interruption and loss to water supply, and if the rate of failures reaches extremities, the reputation of WC in the region may be affected.

This project will develop a better understanding on the root cause of these PE pipe failures through the applying a root cause analysis to the failure mechanisms found through literature review, desktop studies on historical data for PE pipe connection, laboratory tests on failed PE pipe samples from NWR, and a pilot test to analyse the progression in properties of the PE pipe during early life exposure to chlorinated water at set temperature. Through these steps, the failure mechanism for the pipes from NWR will be better understood, and recommendations can be provided to mitigate these high failure rates.

2. Process

2.1 Historical Data

Historical data related to the PE pipe is collected from databases used in the WC. These include PI, SAP, ODSS, and MyWorld. The data has been stored in excel as a CSV file, and statistical analysis is done using the free software, R.

Analysis completed includes relating the daily maximum and minimum ambient temperature retrieved from the Bureau of Meteorology in Karratha Aero and to the water temperature from sample points in Karratha's water reticulation system. This enable estimation of the temperature of the water during days where water temperatures were not sampled using ambient temperature from Karratha Aero.

Work orders were retrieved from SAP and filtered to contain work orders related to PE pipe repairs. Analysis of this data will reveal information on the relationship between the frequency of repairs and the daily temperature or the time at which repairs occur.

2.2 Case Study on PE pipes from NWR

Failed pipe samples received from the NWR are being studied to determine the properties that the pipe has in a post failure state. New (unused) pipes will also be studied to determine the initial properties of the pipe. Three tests will be considered: two tests concerning the chemical properties of the PE samples, and one test concerning the mechanical properties of the PE samples. The chemical tests to be conducted are Differential Scanning Calorimetry and Fourier Transform Infrared Spectroscopy, and the mechanical tests include the Vickers hardness test.

Differential scanning calorimetry will be used to determine the oxidation induction time of the failed pipe samples. Oxidation time is a measure of the material's resistance to oxidation decomposition, and hence progression in antioxidant consumption and PE degradation. This is achieved by taking the time interval to the onset of exothermic oxidation of a material at a specified temperature in an oxygen or air environment, under atmospheric pressure (International Organization for Standardization, 2013). The test will be conducted in accordance to the procedures set in ISO11357-6:2013 (International Organization for Standardization, 2013).

Fourier Transform Infrared Spectroscopy (FTIR) will reveal the chemical composition in the pipe sample. When the pipe has undergone degradation due to oxidation, it may form carbonyl or hydroxyl functional groups on the polymer chain. This test will show the infrared absorption spectra, in which the presence of carbonyl or hydroxyl absorption bands will indicate that the pipe has undergone oxidation, and the resulting products from the reaction will indicate the type of reaction that has occurred.

Vickers hardness testing will reveal the hardness and brittleness of the PE pipe. This will involve pressing an indenter into the material with a specified force, and then the surface of the material will be evaluated. Procedures will follow the standard ISO7619-1:2010 (International Organization for Standardization, 2010). The test will account for the PE reticulation pipes in the NWR being backfilled with abrasive backfill or native soil, and so may be subjected to stone impingement on the pipe; higher fracture toughness of PE pipe will enable higher resistance to stone impingement.

2.3 Pilot Test Experiment

An experimental test will be performed only on the PE100 HDPE pipes, as PE80 HDPE pipes have been phased out. The experimental test will involve exposing controlled conditions to new pipe samples for a period of 9 weeks, in order to determine the degradation of the pipe over time. A pilot test assembly will be used to achieve this and an isometric view of the design can be seen in figure 1 below.

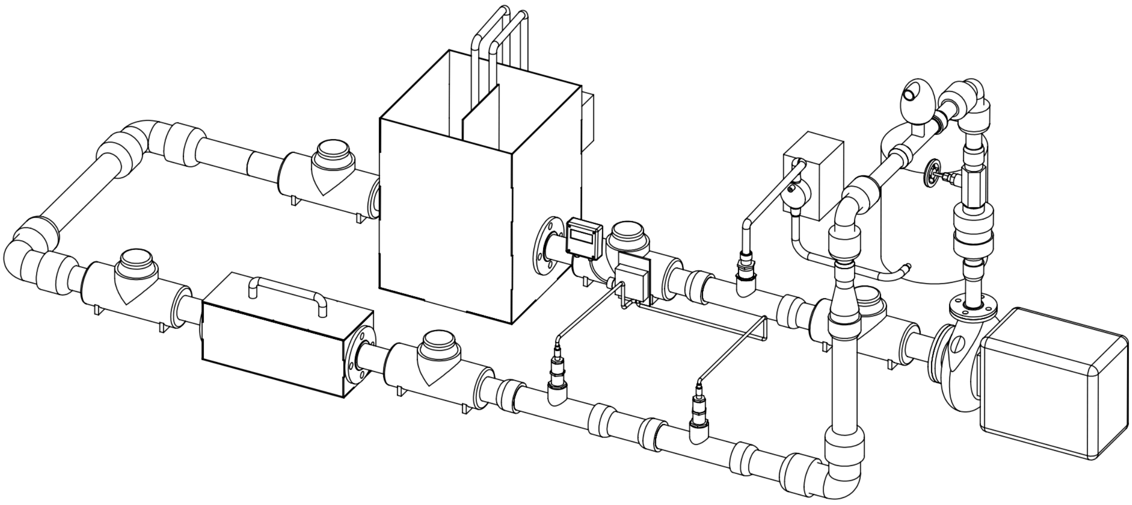

Figure 1 An isometric view of the pilot test assembly used in the experimental task

During the test period of 9 weeks, one of the eight pipe samples in the tank will be taken out and replaced with a new pipe sample after each of the first eight weeks. The pipes taken out will be tested using the same test methods as the PE pipe samples from NWR, while the replacement pipe sample will remain in the tank until the end of the final ninth week. After the end of the ninth week, there will be eight pipe samples (The replaced samples) available in the tank to be tested on, resulting in a total of 2 sets of 8 pipe samples that has an exposure period from 1 week up to 8 weeks. Given that the second set will be exposed to the water flow during the latter part of the testing period, a comparison between the first and second set may reveal information on whether the attacking species (free radicals) in the system is accumulating over time; an autocatalytic reaction where the attacking species is producing attacking species with the degradation of the pipe.

Results found from the tests will reveal the initial life of the PE pipe, and may reveal the onset and early progression of degradation of the pipe. The results may be extrapolated, if appropriate, to predict the conditions of the pipes extending past the duration of the test. The difference in properties between the pipe samples from the experiment and those from the case studies (failed pipe samples from site) can be compared to reveal potential information on the extent that degradation of PE will lead to failure.

3. Results and Discussion

Linear regression models were used to analyse the relation between the daily ambient temperatures (maximum and minimum) and the water temperature taken monthly at 8 sample points located within Karratha. P-values for all regression analysis are smaller than 2e-16, which means that the relation found between ambient maximum temperature and water temperature are statistically highly significant. It was found that the standard error for the models were reasonably low (highest standard error for one sample point being 5.078), and so for simplicity the daily ambient maximum temperature will be used as a reference for the water temperature at any days during analysis of historical data.

Work Orders for civil repairs in Karratha were retrieved from SAP, and filtered to to contain data related to PE pipe repairs. The ambient maximum and minimum temperature were then matched with the days of the repair work order, and plotted as histograms. These histograms are presented in figure 2 below, where the top three histograms (from left to right) corresponds to minimum, maximum and difference between the two ambient temperature from 2013 to 2017, and the bottom three histograms (from left to right) corresponds to minimum, maximum and difference between the two ambient temperature during the day at which the PE pipe repair work order has started from 2013 to 2017.

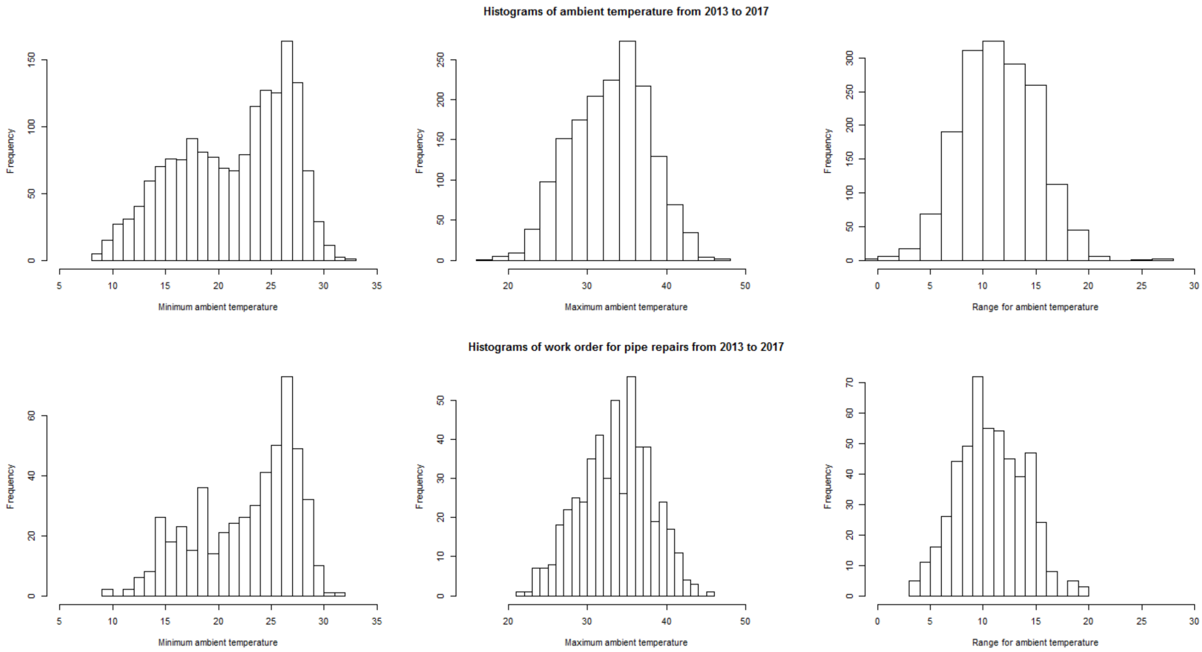

Figure 2 Histograms for frequency of temperature from 2013 to 2017 (top) and for the temperature for the day at which PE repair takes place from 2013 to 2017 (bottom).

These histograms show similarities in distribution between the top and the bottom three, implying that the daily temperature that the pipes are exposed to, are not an immediate cause of the failure.

The design of the pilot test was to enable exposure of PE pipe samples to controlled water conditions, while enabling water to flow through the system. The water flow was a desirable design requirement as mass transfer will affect the reaction that may occur; it is known from literature that PE pipes are subsceptible to oxidative attacks, and that the antioxidants present in PE may be consuming at a higher rate when exposed to conditions that differs from designed conditions.

The pilot test rig (shown in figure 1) will involve a coupon tank that holds eight PE pipe coupons, a PE pipe system that carries the water through the system, a water bath that controls and maintains a constant temperature in the system through a water tank which can be used to refill the water in the system, PVC tubes for the transportation of sodium hypochlorite and also to carry water through the chlorine analyser system, a chlorine analyser that measures the free chlorine level in the water flow and has an in built proportional, integral, derivative (PID) controller that sends signals to the chlorine dosing pump to control dosing rate in order to maintain a constant free chlorine concentration, a chlorine dosing pump that doses the water with sodium hypochlorite, ball valves to enable isolation of the tanks during retrieval of samples or the pump during maintainence, check valve to prevent water from flowing back to the pump during shut down, gate valve which controls the flow from the pump, air valve to release entrapped air from the highest point of the piping system, and a water pump that pumps and circulate the water through the system.

4. Conclusions and Future Work

It has been found so far that the daily temperature is not an immediate cause of the failure of the PE pipes. Data will still need to be analysed to confirm the distribution of failure times, which will confirm whether the failure mode of the PE pipe is indeed through long term degradation. As of this moment, the PE samples are being prepared for examination, and the pilot test rig is in its final stages of assembly. Through these steps, the project will be able to confirm if oxidative degradation of PE pipe is indeed the root cause of the failure of the pipes.

Future work following this project will include testing the rates of oxidative degradation with temperature, if oxidative attack is indeed occurring, and the mechanism at which the antioxidants are being consumed.

5. Acknowledgements

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6. References

Azis, A. (2016). *NWR PE Service Pipe Failures Investigation Report*. NWR Operations Support. Water Corporation.

International Organization for Standardization (2010) *Rubber, vulcanized or thermoplastic – Determination of indentation hardness - Part 1: Durometer method*, ISO 7619-1:2010.

International Organization for Standardization (2013) *Plastics-Differential scanning calorimetry (DSC) – Part 6: Determination of oxidation induction time (isothermal OIT) and oxidation induction temperature (dynamic OIT)*, ISO 11357-6:2013.