

# Investigation of the effect of Water Quality, Lime and Calcite Dosing on Pipelines

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## Abstract

*Cement lining in mild steel cement-lined (MSCL) pipework will naturally degrade over time, but the rate of degradation and the factors controlling the process are not fully characterised. Improved understanding of the process will reduce the risk of failures, loss of water, damage to environment or property and disruption of service to customers, as well as enabling the Water Corporation to optimise their pipe asset management operations. Currently, lime and carbon dioxide are dosed at certain assets for cement lining protection and pH or alkalinity correction. However, the full extent of protection provided has not been fully understood or realized.*

*The two-year project includes a literature review of the effectiveness of various calcium carbonate saturation indexes as indicators of the impact of lime and calcite dosing on the condition of MSCL pipe. A sampling program and corrosion model is developed for systematic assessment of Western Australia water quality and pipe condition from this investigation.*

*It is expected that a corrosion model built upon experimental data will be completed in the second year of the two-phase project. The model will allow active prediction and assessment of the condition of MSCL pipeline assets. It will also inform future policy direction in regards to lime or calcite dosing for pipe protection.*

## 1. Introduction

The Water Corporation (WC) schedule of standard economic lives suggest a 80 to 110 year life for MSCL pipe. The MSCL piping is used across the WC water supply network, experiencing a wide variety of water qualities. The lack of understanding or prediction for pipeline deterioration due to water quality factors brings question to the suggested life expectancy of MSCL. Lime and alternative dosing is currently being used for pH and alkalinity adjustment to mitigate the degradation of cement lining. This is an expensive process, estimated to cost in excess of \$3 million/year.

The effectiveness of lime or alternative dosing is unclear, and the relationship between water quality and the rate of deterioration on MSCL pipeline assets is poorly characterised. It could be cost effective to renew the pipeline asset earlier rather than protective dosing. Further understanding of lime and calcite dosing effectiveness is required to provide a basis for assessing this argument.

It is possible that the life of MSCL is overestimated, which could result in unexpected pipe failures, service interruption to customers, loss of water and damage to environment or property. There may also be health, safety and customer complaint issues regarding compliance to drinking water guidelines due to changes in pH, metal ions, alkalinity and risk of scaling.

Water Corporation currently adopts the Langelier Saturation Index (LSI) to assess calcium carbonate ( $\text{CaCO}_3$ ), there is concern that this index may not be effective in characterising chemical equilibria and protection in water transmission lines. The Calcium Carbonate Precipitation Potential (CCPP) is a relatively new index and has shown a better direct relation to the reaction kinetics involved in  $\text{CaCO}_3$  crystal growth. When compared to LSI or other  $\text{CaCO}_3$  saturation indexes, it incorporates chemical equilibrium more accurately (Brodeur, 2006). The CCPP attempts to quantify the mass of calcium carbonate that will dissolve or precipitate. A study by Rossum & Merrill (1983) evaluated various saturation indexes and found limitations in different environments or pH ranges. However CCPP showed applicability across the whole pH range and was able to adapt to almost all circumstances.

## 2. Process

The first phase of the two year project follows 3 relevant stages: state of the art review, sampling plan and test method, cost analysis.

### 2.1 Calcium Carbonate and Cement-Lining Failure Mechanism

Lime leaching of calcium hydroxide is the cause of cement-lining deterioration. An effect of this was found by US case studies conducted by Miller (1965). which showed reduced cohesive strength after 30 years of service in some cement-lined cast iron piping.

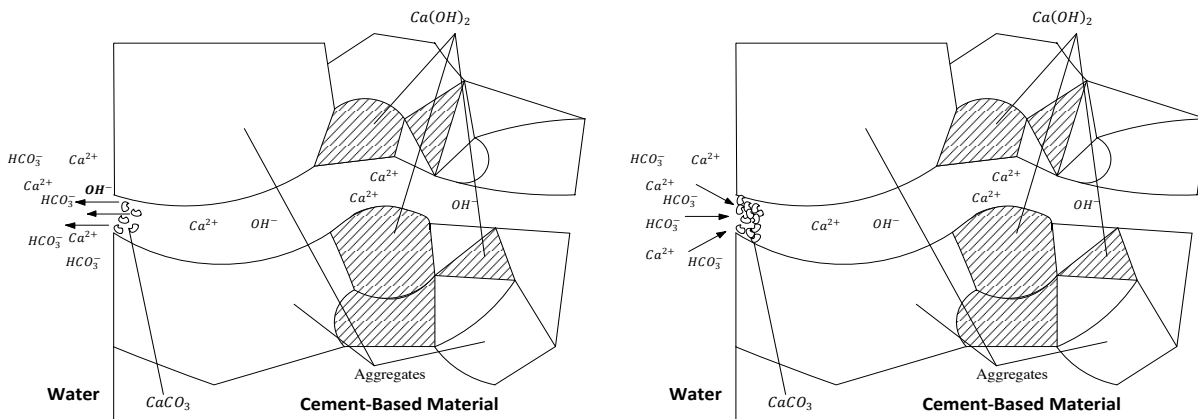
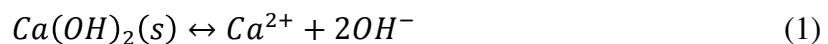


Figure 1 Lime leaching (left) and Stabilization (right) (AWWA, 1996)

It has been found that cement-lining corrosion of MSCL will increase the pH, calcium and alkalinity of the water (Douglas, Merrill, & Caitlin, 1996). This is caused by the dissolution of free lime in the cement lining by the following equation (1):



Calcium oxide acts as the binding agent, and is hydrated by water to form calcium hydroxide (2).



A study conducted by (Koska, 2003) showed that calcium carbonate when precipitated in new mains would block pores in the cement-lining to reduce the dissolution of free lime as shown in Figure 1. Therefore stabilization of the cement-lining can be assessed by the increase in pH, calcium and alkalinity (Douglas, Merrill, & Caitlin, 1996). The stability of the cement-lining in all ages and conditions must be addressed through methods of water quality analysis and pipe condition assessment. Calcium oxide can be used as an indicator of pipe condition and measured through X-ray Fluorescence. Low levels of calcium oxide would indicate corrosion and reduced cohesiveness.

## 2.2 Cement-Lining Deterioration Base Model

The following base model was developed; it takes into consideration the inner diameter of pipe, change in CCPP over length, calcium oxide content and the age of pipe. It includes considerations from a CSIRO (2011) study.

$$Corrosion \propto \frac{1}{T_o} * \frac{dCCPP}{dL} * t \quad (3)$$

Corrosion is directly proportional to the change in CCPP over the length of pipe. If there is dissolution (corrosion), then CCPP will increase to reach equilibrium over a length of pipe. If there is precipitation (scaling), then CCPP will decrease to reach equilibrium over a length of pipe. The age of the pipe is also directly proportional to corrosion due to mechanical wear and tear. The diameter of the pipe is inversely proportional to corrosion due to the larger surface area.

$$a' = f(T_o, t) = \frac{at}{T_o} \quad b' = f\left(\frac{dCCPP}{dL}\right) = b * \frac{dCCPP}{dL} \quad (4) \& (5)$$

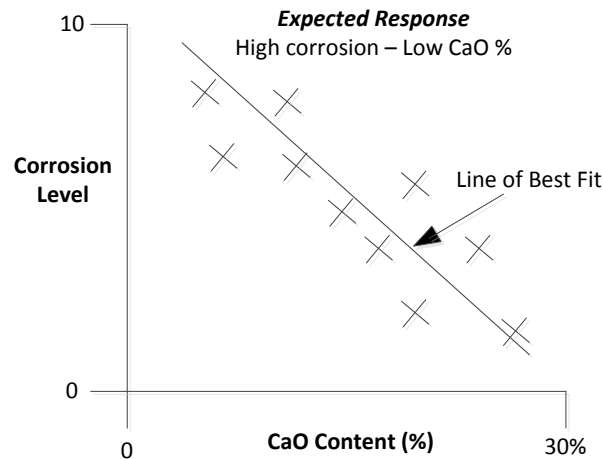
Where,

$$\begin{aligned} T_o &= \text{inner diameter of Pipe} \\ dCCPP &= \text{change in calcium carbonate precipitation potential} \\ dL &= \text{change in length of the pipe} \\ t &= \text{age of the pipe (years)} \end{aligned}$$

The overall corrosion level relationship (6):

$$Corrosion Level = 1 + \frac{at}{T_o} + b * \frac{dCCPP}{dL} \quad (6)$$

The variables a and b are calibration factors that are determined depending on the empirical data to fit. A graphical interpretation of the model can be created through utilizing different calcium oxide levels across piping to their associated “Corrosion Level”.



**Figure 2** Graphical example of cement-lining corrosion model

Figure 2 is an example of utilizing corrosion level and calcium oxide content to build a predictive indicator to the condition of the pipe. It is expected that an increase in corrosion would lead to a decrease in calcium oxide content.

### 2.3 Water and Pipe Sampling Plan

The locations for the water and pipe sampling plan are determined by the following criteria and critically analyzed for opportunistic or redundant testing.

- The pipeline type is limited to MSCL exclusively.
- The minimum length required is approximately 2km. The pipeline needs reasonable contact time with water to show meaningful effects.
- The water conveyed needs to be an original source or non-blended line to reduce risk of changing water quality.
- Priority would be given for sources with lime, calcite or pH correction dosing. To ensure the objectives of the project are met.

The following criteria will be used to prioritise sample locations and reduce redundant testing.

- A range of pipeline diameters should be analyzed to measure the effect of physical pipe size on corrosion.
- A range of CCPP values from scaling to highly corrosive should be analyzed to measure the effect of  $\text{CaCO}_3$  saturation in pipeline protection.
- A range of pipeline ages are assessed to ensure an understanding of cement-lining life expectancy.
- A pipeline with significant back-flow history will be analyzed to better relate source waters to blended waters.

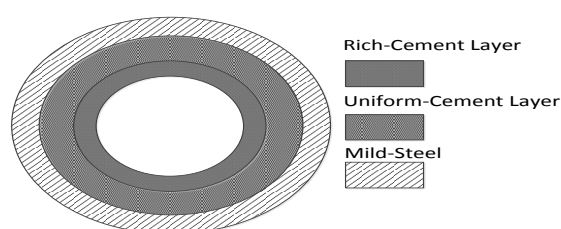
### 2.4 Cost Analysis

The cost analysis is currently in progress and will be determined through consultation with key personnel at Water Corporation, associated contractors and suppliers. Data on lime or calcite dosing operating and capital costs are compared to cement-line refurbishment or replacement. An overall sampling plan cost estimate is also conducted to ensure maximum research effectiveness for minimum cost.

### 3. Results and Discussion

#### 3.1 MSCL Structure Analysis and Model Correlation

In general, it has been assumed that most Water Corporation MSCL assets follow a rich-cement layer and uniform cement matrix as in Figure 3. Based on the Serpentine Main analysis the key mechanism for pipe deterioration is through a loss of adhesion (lime as a binding agent) between the interface of rich-cement layer and uniform cement layer. The rich-cement layer displaces from the uniform cement-lining upon full depletion of lime at the interface through lime leeching. This results in accelerated degradation through grinding of displaced cement-lining debris in the pipeline. In this case, the pipe is at an increased risk of failure due to displacement of cement-lining from the pipeline. Pipe failure is at the point at which the pipe leaks or bursts.



**Figure 3 Common MSCL Cement structure**

The corrosion model developed in section 2.2 will correlate the water quality, age and diameter against calcium oxide content (at the interface of rich-cement and uniform-cement). Using empirical data to validate this correlation will allow life expectancy prediction of the cement-lining. The remaining life or condition of the cement-lining can be predicted using the model through water quality, age and diameter parameters without the need for pipeline condition assessment as shown in Figure 2.

#### 3.2 Sampling Plan Determination

There are 26 sample points available across Western Australia that met the criteria in section 2.3.

|               |                  | Age                         |                    |                     |
|---------------|------------------|-----------------------------|--------------------|---------------------|
| Diameter (mm) | Water Quality    | 1 - 20 yr                   | 20 - 40 yr         | 40 - 60 yr          |
| 100 - 500     | Highly Corrosive |                             |                    |                     |
|               | Corrosive        |                             | Two Peoples Bay    | Arrowsmith (A)      |
|               | Mild             | Dunsborough                 | Ten Mile Brook     | Nannup              |
| 500 - 1000    | Highly Corrosive |                             |                    |                     |
|               | Corrosive        | Allanooka                   | Harris             | Allanooka (A)       |
|               | Mild             | Samson Brook (A) (D)        | De Grey            | Millstream (A)      |
| 1000 - 1400   | Highly Corrosive |                             |                    |                     |
|               | Corrosive        | Mirrabooka (D)              |                    | Serpentine (A) (PB) |
|               | Mild             | Stirling (A) (D), Lexia (D) | South Dandalup (B) | Mundaring (A)       |

\*Note: (A) is representative of available pipe data, (PB) is representative of a pump-back source (D) is representative of dosing

**Table 1 Overall sampling plan**

From Table 1, there are 16 recommended sampling sites from the following criteria.

- A maximum of 2 backflow sites are to be sampled, to evaluate the risk of significant changes in water quality and its effect on corrosion.
- If there is more than 1 available sample point for the same type of age, size and water quality, the longer pipeline will be sampled for a greater range of results.
- Preference will be given to pipelines that have historical maintenance data describing the condition of the cement-lining.
- A minimum of 3 dosing sites are to be sampled. The effectiveness of dosing lime or calcite must be determined.

The sampling plan will validate the model developed in section 2.2.

## 4. Conclusions and Future Work

It has been found that cement-lining has the ability to sustain service for a long life-span given optimal water quality conditions. In contrast, with corrosive water, degradation at an accelerated rate was found. It is expected that the full potential of the project will be realized during the second year of the two-phase project. With a validated model, Water Corporation will be able to effectively adopt sustainable policies with regards to cement-lining renewal or refurbishment in MSCL trunk mains, and/or chemical dosing.

## 5. Acknowledgements

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