Final Report

Predicting the lifespan and corrosion behaviour of decommissioned oil and gas metallic infrastructure in the ocean

Robert E. Melchers
Centre for Infrastructure Performance and Reliability
University of Newcastle
rob.melchers@newcstle.edu.au

Mike Y. Tan
School of Engineering
Deakin University
mike.tan@deakin.edu.au

A report prepared for

National Decommissioning Research Initiative

15 September 2022

Summary

This report has been prepared at the request of NDRI to provide practical tools for predicting the corrosion behaviour and remaining life of decommissioned oil and gas metallic infrastructure in ocean conditions. Following discussions with operators, the project's main focus is on the corrosion of steel infrastructure in the marine environment with particular focus on submerged steel pipelines in Australian waters. Long-term corrosion information is required to assist decisions about the feasibility of in-situ decommissioning and to understand the timeframes and processes by which residual contaminants in pipelines may be released. Shorter term information about localised corrosion such as at joints and welds and general corrosion is also acquired for assessing the feasibility of recovery before extensive long-term corrosion has taken place.

The first part of this report presents corrosion prediction information based on an extensive survey of relevant literature for corrosion of steels in seawater, both theory and practice, and discussions with operators. There are also some observations about the effect of cathodic protection and the longer-term durability of protective coatings and how these relate to steel degradation timeframes. The second part of the report deals with results obtained in specific field testing for localised corrosion as might occur at pipeline welds and joints, and the conclusions that are relevant for condition prediction. Reference is made to three reports that provide more detailed information about long-term corrosion, the results from field corrosion testing and 'knowledge gaps' that have been identified during the project.

Predicting the lifespan and corrosion behaviour of decommissioned oil and gas metallic infrastructure in the ocean

Introduction

This project follows a request from NERA-NDRI to provide 'tools' for predicting the lifespan and corrosion behaviour of decommissioned offshore oil and gas infrastructure. It focusses on the corrosion of steel infrastructure, at the end of field life in preparation for decommissioning, with intended use for facilities located off the North-West Shelf off Western Australia and in Bass Strait, Victoria. Such tools are relevant for assessing the likely fate of steel infrastructure if left in place at these locations and the influence of corrosion on recovery of infrastructure if removed. This report only considers the likely corrosion losses over extended durations. It does not consider the structural engineering implications of such corrosion. This report is confined to high-strength low alloy (HSLA) and mild steels as these are the predominant alloys in use in the O&G industry sector.

The following section provides some background information essential to interpreting the subsequent sections that provide the 'tools' for prediction.

Background - steel corrosion in seawaters

Many factors conventionally are thought to affect the corrosion of steels in seawater. These include steel properties including steel composition, surface roughness, water dissolved oxygen, water pH, water temperature, water wave and velocity aspects, and water pollution. There are also the possible influences of cathodic protection (if still active) and protective coatings.

For exposures in seawater beyond about one year in waters around 20˚C (average) [1], the corrosion process is no longer governed by the availability of oxygen rather it can continue without a supply of oxygen after an early period of oxidation when the steel is first exposed. The change-over period becomes a little longer in colder waters. Any consideration of the availability of oxygen, such as dissolved oxygen in seawater can be considered as irrelevant for predicting long-term corrosion.

It is also the case that almost all factors usually of concern for short-term exposures (i.e., months or even a few years) are largely irrelevant for long-term corrosion. By far the most important factor is average water temperature. Higher temperatures cause faster corrosion (but it is not a linear function). The other potential factor is pollution of the seawater by nutrients such as nitrate, nitrite, ammonia and phosphorous. These nutrients can cause microbiologically influenced corrosion (MIC) of steels. As illustrated by oil and gas facilities in some parts of the world, such corrosion can be severe, in all cases exacerbated from environmental pollution or from discharges into the ocean local to the facilities. However, for abandoned oil and gas pipelines on the ocean floor, MIC is also unlikely to be a critical factor. The effect of MIC is discussed in detail in reference [**Error! Bookmark not defined.**].

It is well-known in the corrosion literature that the precise composition of steels has little effect on their long-term corrosion behaviour. This also applies to so-called corrosion resistant or stainless steels. These all rely on their corrosion resistance from fast oxidation of an alloy such as chromium to block corrosion of the iron in the steel. Such fast oxidation is much retarded in seawater and for this reason attempts to use stainless and similar steels largely have failed and, because of their relatively high cost, are seldom used offshore.

In line with the brief provided for this project and after discussions with operators, the only assets of interest are steels that are fully submerged. Information about corrosion of steels in tidal, splash zone or atmospheric zone conditions is available in reference [1]. Also available is specific information about the effect on internal corrosion of end-capped abandoned pipelines [**Error! Bookmark not defined.**].

Long-term corrosion loss trends in seawater

The corrosion of interest for consideration in abandonment is what is known as 'general' or 'uniform' corrosion, that is corrosion over larger areas of steel, even though it is in fact not particularly uniform. But it is known to occur at roughly the same extent over large areas under similar conditions, hence the terminology. The following deals with this type of corrosion.

For 'uniform' corrosion it is helpful to deal with average corrosion loss over the surface of a piece of steel. From this the conventional notion of a 'corrosion rate' can be derived, but as will be seen in Fig. 1, corrosion loss is not a linear function of exposure period. Hence a 'rate' tends to be misleading.

Figure 1 shows trend lines for the prediction of corrosion losses as a function of exposure period for steel and cast-iron objects in seawater, with the early part of the trend obtained from testing programs and the later part from detailed investigations for shipwrecks, anchors, cannon balls, etc. [1].

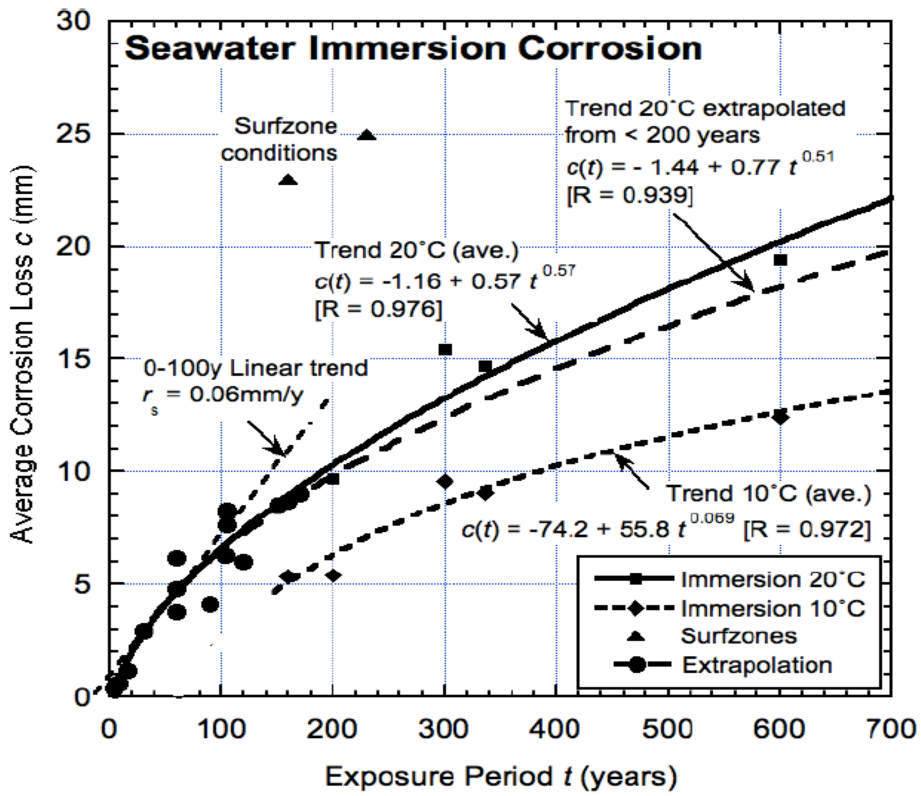

Figure 1. Trends for long-term marine immersion corrosion in nominally unpolluted seawater at 20˚C and 10˚C average seawater temperatures [**Error! Bookmark not defined.**].

Two trends are shown in Fig. 1. One trend is for seawater at 20˚C on average and the other for 10˚C on average. Interpolation between these two trends is sufficient for temperatures in the range 10-20˚C and a limited amount of extrapolation for seawater temperatures outside the trends shown.

Occasionally underwater observations show that the rusts that form on the steel objects contain or are covered with whitish-coloured calcareous material (essentially calcium carbonate). This is known to reduce the amount of corrosion that occurs for a given temperature and at a given exposure period. Details are given in reference [**Error! Bookmark not defined.**] but for practical purposes it is sufficient to reduce the corrosion loss to about 30% of that shown in Fig. 1.

Example 1

For Western Australian offshore locations, the average water temperature at the depth of many of the abandoned pipelines is around 12˚C. For 100 years exposure Fig. 1 shows a steel corrosion loss of approximately 6-7mm. This could be interpreted as a corrosion rate of 0.06-0.07 mm/y but as seen in Fig. 1, after 100 years the rate declines. In conditions for which calcareous deposition within and on the rusts is possible, the losses are much less, i.e., 2-2.3 mm in 100 years. Coatings obviously will affect these results, as discussed next.

Effect of coatings and remnant cathodic protection

Protective coatings tend to delay the development of steel corrosion. In most cases loss of coating tends to occur over significant areas of the steel. Localised lack or depleted coating (sometimes known as 'holidays') are likely to give quite localised corrosion that does not reflect the overall state of the asset.

There is very little quantitative information about the longer-term deterioration of coatings, particularly for coatings exposed in deeper water immersion conditions [2]. Reference [**Error! Bookmark not defined.**] provides some broad guidelines for older type coatings not intended specifically for pipeline use. For these, about 50% of the coating is likely to have disappeared after 50-80 years. Modern coatings such as those based on vinyl esters are likely to last considerably longer under immersion conditions. No quantitative information for these appears to be available. However, they can be expected to last many more years than the older-type coatings but as shown in the literature survey report [see reference 3, Fig. 13] and are subject to quite localised lack of cover and hence lack of corrosion protection.

Impressed current cathodic protection (ICCP) where use on pipelines at depth in seawater tends to build-up, over time, a layer of carbonate (calcium, magnesium) that forms under elevated pH conditions, drawn from the seawater carbonates. Limited information is available, but it suggests that the layer is relatively weak and physically easily dislodged and broken away, such as through abrasion, erosion and water currents. One set of observations in coastal conditions suggests the carbonate layer starts to deteriorate within 6 months of the impressed current being turned off while a piece of ICCP protected pipe recovered off WA coast suggests a period of several years being required.

Example 2

Using the above information and observations, it is possible to estimate the remaining life of, say, a trunkline pipe consisting of welded spools of wall thickness of 24 mm, exposed on both the inside and the outside to seawater with, on the outside, a vinyl ester coating and remnant calcareous deposits from impressed current CP.

The calcareous deposits will provide only a few months of protection and their remnant protective effect can be ignored. The vinyl ester coating, if applied with the same quality control as evident in the Fig 13 of reference [3] will provide essentially no protection where there are holidays in the coating. The loss of steel due to corrosion from both sides would then be expected to be about 12 mm per side and this, according to Fig. 1 would, for waters at 10˚C require some 500 years at these locations. The pipe would then be expected to be perforated but still retain largely in its original shape.

Where the vinyl ester coating is intact it is likely to remain protective much longer. The main influence of corrosion would then be from one side (the unprotected side) and to achieve a corrosion loss of 24 mm can be expected to take much longer. Extrapolating from Fig. 1 at 10˚C suggests 1000 years or so. At this point the steel in the pipe would have corroded away.

As described in the report on crevice corrosion in reference [4], it is now evident that such corrosion has a relatively short, transient effect. It is not expected to have a substantial influence on the corrosion losses for welded joints.

Potential toxicity of corrosion products

The rust products in marine corrosion are, in the main, oxides and hydroxides of iron, with the corrosion process returning the metal to its original mineral state. Most steels include small amounts of alloying elements, including C, Mn, Mo, P, S, and possibly Ni and Cr and V and these all oxidize (slowly) in seawater. Any potential toxicity of these small amounts dissolved in the locally large volumes of seawaters over the very long time periods involved in their dissolution (see Example 2 above) can be considered to render any potential effect essentially negligible. The loss of any calcareous deposits from the exterior of pipelines is not hazardous as the calcium carbonates and magnesium carbonates are plentiful in seawaters.

Trends for localised (crevice) corrosion

As noted, for the recovery of pipelines their structural strength is potentially important. In part this is governed by the amount of corrosion loss over the surface of individual or groups of pipeline spools. It also may be affected by the integrity, and thus the structural capacity, of joints between spools, including welds and flanges. Such capacity is influenced by localised forms of corrosion.

Common localised forms of corrosion on marine structures include pitting and crevice corrosion. These tend to be governed by mechanisms that differ from those of general corrosion, although there clearly are interactions. Much is known about the early stages of pitting and of crevice corrosion, mainly for stainless steels and aluminium but less for steels and for longer term exposures. This is more so for crevice corrosion. This was identified as a knowledge gap at the commencement of the project, specifically for (i) pitting corrosion at welds along spools, and between spools, (ii) crevice corrosion at bolts (heads, buts, washers) on flanges between spools, (iii) crevice corrosion between flanges bolted together, and at end plates on parked pipelines. All these three forms of corrosion could lead to pipe breakup, problems on the seafloor and problems in the case recovery is contemplated. To obtain some understanding of the potential for and severity of crevice corrosion for joints between spools soon after ICCP has been removed and where there was no protective coating in the joint region, two special field corrosion simulation and monitoring experiments were carried out, as described in a separate report [4], as a part of this project.

In brief, the results from these field experiments, although for only up to about 12 months exposure, show that the penetration of corrosion is greater at crevices than it is for general corrosion (Fig. 2). They also show that the main effect of the crevices is to increase the early stages of corrosion (corrosion penetration) and that after about one year the longer-term trend is similar to that for general corrosion. This is similar in effect to that of pitting corrosion [See Fig.9 in Reference 1], with the localised corrosion effect raising the corrosion trend curve by a small amount. The first estimates of this increase are +0.4mm for waters averaging 12.5˚C and +0.85 mm for waters averaging 20˚C. mm. This means that the trends in Fig. 1 may be used for long-term effects of crevice corrosion with an increase depending on average water temperature. These tests did not consider variations in the size or width of opening of the crevices. However, those used are considered reasonable representations of likely crevices in actual oil and gas field joints. There are on-going studies on crevice corrosion of steel in seawater [4, 5].

Example

For example, for an offshore location with mean water temperature of 12.5˚C, Fig. 2 shows that the metal loss due to crevice corrosion of 0.45mm can be expected to occur over the first year such as at bolts (heads, buts, washers) on flanges between spools, and between flanges bolted together and at end plates on parked pipelines. Over the same period only about 0.10 mm metal loss would be expected to occur over the general pipe surface. The effect over longer periods of exposure would be as in Fig. 1, with the trend for corrosion at 12.5˚C added and then raised by (0.45 - 0.10 =) 0.35 mm.

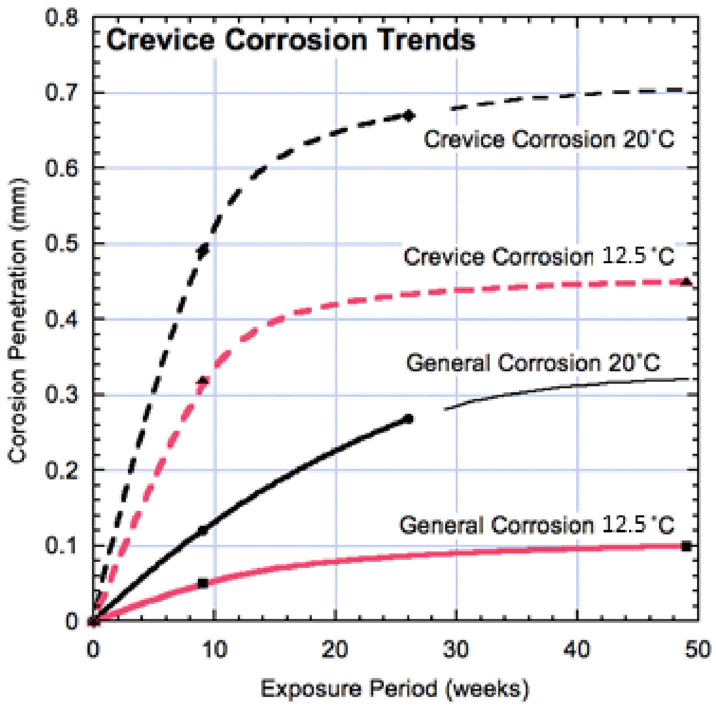

Figure 2. Trends for crevice corrosion and early general corrosion from field experiments at 20 and 12.5˚C (mean) showing effect that crevice corrosion increases corrosion penetration in the early stages and that this carries through to longer exposures.

Remaining Knowledge Gaps

The present project has shown that a number of knowledge gaps remain in the accuracy with which the lifespan and corrosion of decommissioned offshore oil and gas infrastructure can be predicted. A number of these have been noted in this report, as follows:

- Effect of degree of burial in soft sediments and sands
- Effect of location on rock
- Life of protective coatings relevant to O&G pipelines
- Effect of calcareous deposits from cathodic protection
- Effect of pipeline length
- Internal corrosion of capped pipelines
- Effect of prior internal corrosion and pitting
- Release of constituents of steels into the environment after corrosion
- Release of constituents of protective coatings into the environment after degradation
- Longer-term behaviour of crevice corrosion

A more extensive discussion of these knowledge gaps is given in a separate report [6].

References

1 Melchers RE (2022) Corrosion of steels and irons immersed in natural seawater for up to 600 Y, Corrosion, 78(1) 1-9.

2 Oluwoye I (2022) An investigation into the degradation of non-metallic components of oil and gas infrastructure in the ocean, Technical Reports 1 and 2, Curtin University of Technology, Report for NERA-NDRI May 2022.

3 Melchers RE and Tan, M (2022) Literature review on prediction of lifespan and corrosion behaviour in the ocean, Report for NERA-NDRI June 2022.

4 Tan, Mike; Majid Laleh; Ying Huo and Melchers RE (2022) Monitoring localised corrosion behaviour of decommissioned O & G metallic infrastructure in the ocean, Report for NERA-NDRI July 2022.

5 ARC Discovery Project DP200200747.

6 Melchers RE & Tan, M. (2022) Knowledge gaps in the prediction of the lifespan and corrosion behaviour of decommissioned oil and gas infrastructure in the ocean, Report for NERA-NDRI July 2022.