Knowledge gaps in the prediction of the lifespan and corrosion behaviour of decommissioned oil and gas 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

5 September 2022

Introduction

During the preparation of the final report on "Predicting the lifespan and corrosion behaviour of decommissioned oil and gas metallic infrastructure in the ocean" for NDRI it became clear that a number of topic areas would benefit from more detailed investigation. It was agreed with NDRI that these should be considered in a report separate from the report that deals with the recommended techniques [Melchers and Tan 2022] and also separate from the literature review [Melchers 2022] and the technical report [Tan et al. 2022] dealing with localized (i.e. crevice) corrosion. The present report summarizes the areas that could benefit from further investigation in the context of the prediction of the remaining life of decommissioned offshore oil and gas facilities. Herein, as before, the main emphasis is on steel pipelines located in deep ocean and continental shelf waters. Recommendations are made also for decommissioned structures that extend above the water surface. Where noted, the present report should be read in conjunction with the technical reports for further background and context.

Effect of degree of burial in soft sediments and sands

Pipelines for offshore O&G operations tend to be placed at considerable depths, directly on the ocean floor that usually consists of sediments and sands and sometimes rock outcrops. At depth the water currents tend to be relatively slow (< 0.1 m/s) [Melchers & Tan, 2022] but persistent and in time this may cause partial or complete burial in the sediments or sands. This could have an effect on the long-term corrosion behaviour and also potentially on loss of steel as a result of abrasion once protective coatings have lost their effectiveness or cathodic protection if present has been turned off. The information currently available for corrosion and abrasion is limited and largely qualitative. Similar comments apply to the effect of sediments and sands on protective coatings.

Where a pipeline comes onshore the environmental impacts tend to be more severe, caused by the addition of wave- and possibly wind-action and also by solar radiation. There are also additional challenges and issues related to shore-crossing pipelines constructed by horizontal direction drilling (HDD). A common condition for these pipelines is that they could suffer corrosion crossing multiple environmental zones; and corrosion mechanisms in each environmental zone can be different. Soil, marine and atmospheric corrosion could occur over different zones of the structures under the effects of various corrosion mechanisms such as differential aeration corrosion at the waterline areas and biological influenced corrosion in metabolically active locations. On the other hand, corrosion protection technologies applied on each zone can also differ and could interact with each other. For instance, an impressed cathodic protection (CP) system applied on a steel pipeline section buried in coastline soil could affect the sacrificial anode based CP system applied on pipeline section submerged in the seawater, creating a complex corrosion and protection situation. Corrosion monitoring using specially designed probes could be used to acquire data for understanding and predicting such complex forms of localized corrosion especially on interfaces between different environmental zones where the worst-case scenario corrosion often occurs. It is shown that corrosion data with good spatial resolutions across multiple environmental zones are required in order to ensure effective localized corrosion prediction, prevention and management.

Because corrosion and deterioration are slow processes in time, the above effects cannot reasonably be ascertained by conventional experimental testing programs. This can be seen in the changing nature of the corrosion process and the acute non-linearity of corrosion losses (and pit depths) as a function of exposure time for pipes (different steels, cast irons) buried for up to 12 years in soils, including sands [Melchers 2020]. Similar results but for much longer exposure periods, extending to some 100 years were obtained for corrosion behaviour of steels and cast irons buried in clays and sands soils using carefully controlled excavation of actual in-service water supply pipes [Melchers 2020]. The latter approach could be extended to the study of decommissioned offshore pipelines - namely, through recovering (parts of, or spools of) older pipelines that have been on the ocean floor, perhaps partially buried for many years, together with observations of the sediment (or sand) type and its properties, including compaction of the sediments. Where the pipeline is within scuba diving depths in-situ assessment might be contemplated as might the use of ROVs in deeper waters, noting that in-situ observations under the conditions and visibility at depth are unlikely to be as good as those that could be made on recovered spools or lengths of pipe. In all cases, it may be necessary to allow for the effective life of protective coatings, or the influence of (likely incapacitated) cathodic protection.

Effect of location on rock

The location of a pipeline on rock, particularly hard rock, presents an additional challenge if the pipeline is not suitably protected such as through the use of concrete sleeving. The critical issue is the expected life of the sleeving and this is difficult to determine by prediction owing to the uncertain nature of the response of the pipeline to local current conditions and the propensity for heavier pipelines to suffer greater contact forces. Again, in-situ (scuba, ROV) observations might assist in obtaining a portfolio of the range and severity of responses. From these it may be possible to synthesize a prediction model.

Life of protective coatings relevant to O&G pipelines

As noted in section 3.1 of Melchers and Tan (2022), little information is available about the effective life of external protective coatings of the type used for O&G pipelines but has been addressed in NDRI Project 2.2 Non-metal degradation. In common with other types of protective coatings, the only effective means for assessing their durability is from in-situ observations, despite the fact that this may involve may years of exposure. Unfortunately, accelerated testing is known not to be particularly accurate, although it is often the only possibility for obtaining some estimate of resistance to some aggressive environment.

The types of protective coatings overall have changed very little, but the precise formulations used are in continual evolution, with claims of superior performance for the newer formulations. The claims usually are based on accelerated testing and are comparative to other products and other formulations. There is very little 'absolute' information available, such as how many years before x% surface failure of the coating in a given exposure environment to assist assessments for field performance.

Again, field observations on recovered spools or shorter lengths of pipeline may assist in building predictive models with some degree of realism for the likely life of coatings. It is suggested that this work would be done in conjunction with the above-mentioned corrosion investigations. Accelerated testing and monitoring of coating degradation using techniques such as electrochemical impedance based corrosion probes would provide useful data for better prediction of coating degradation behaviour and life.

Effect of calcareous deposits from cathodic protection

Particularly for impressed current cathodic protection (ICCP) of steel pipelines calcareous deposits tend to settle out on the protected steel. These arise from the elevated pH set up on the surface of the steel by the IC system and the (super-)saturated nature of dissolved calcium carbonates (and magnesium carbonates) typical of seawaters. Sacrificial cathodic protection systems tend to show less calcareous deposition and are also generally considered less effective. However, the calcareous material provides excellent corrosion protection (Melchers and Tan 2022, Fig. 14). Some observations in coastal exposures have shown that the calcareous layers tend to break-up under wave action and thereby expose the steel underneath to the full effects of the environment. It is unclear whether this occurs also for decommissioned pipelines once the IC is turned off. The coastal observations suggest that delamination and loss of the calcareous material may depend on the water velocities at the depth of the pipeline and also on any protective or, contrary, any erosive effects of the sediments.

Since the processes involved in the deterioration of the calcareous layer(s) are mechanistic, it should be possible to set-up a laboratory based test program in which erosion by sand and also delamination and deterioration is simulated by a range of water flow conditions. The observations under coastal exposure conditions suggest the dynamics of the processes are such that an experimental project is feasible within 1-2 years experimentation. Field testing and monitoring of the efficiency of cathodic protection using corrosion probes would provide in-situ data for better understanding and prediction of corrosion under various levels of cathodic protection (e.g. the needs and effects of different CP current and potential requirements).

Effect of pipeline length

For the external corrosion of decommissioned pipelines length should have little effect on deterioration of coatings or the subsequent corrosion of the steel. Any differences in steel properties would be slight and galvanic action due to steel properties are very unlikely. Where the sediment environment changes it is potentially possible to have a degree of galvanic action along the pipe, but again this is almost certainly a second-order effect.

Of more interest is the effect of length on internal corrosion, noting that internal linings or protective coatings are not used. The question arises whether an uncorroded internal surface well inside a long pipeline can receive enough oxygen to begin to corrode and then enter into Mode 1 (Melchers and Tan 2022, Fig. 3) to then transition to Mode 2 for which there is no requirement for oxygen for continued corrosion. Irrespective of whether corrosion inside such pipelines needs to be developed or attempted to be prevented, an estimate is required of the length of pipeline, compared to diameter that will permit the very low concentration of oxygen required to allow Mode 1 to occur and for corrosion to then transition to Mode 2. It is proposed that this could be established by an experimental program on smaller diameter pipes and numerical simulation.

For pipelines that have already undergone internal corrosion the situation is completely different. In such cases the corrosion process can progress under Mode 2, using only water to supply the required electron acceptor. Inward diffusion or transport of oxygen (to supply an electron acceptor) is not required.

Longer term field testing and monitoring of corrosion by placing corrosion probes of various designs at selected location of a pipeline would provide in-situ data for better understanding and prediction of corrosion of pipeline length under various environmental and CP, coating effects.

Internal corrosion of capped pipelines

Some observations about the potential for internal corrosion of parked, end-capped pipelines have been made earlier [Melchers 2015] and argued that much depends on the type and quality of the water with which the pipes were filled prior to capping. That previous work, based on various practical observations, could do with reassessment, based on modern practice.

Effect of prior internal corrosion and pitting

The amount of corrosion that is likely to occur over a period of time is unlikely to be affected to any significant degree by prior corrosion, but the overall effect and the total loss of steel pipe-wall will be. It follows that allowance for prior corrosion should be included in any assessment or estimation of likely life of a decommissioned pipeline.

Release of constituents of steels into the environment after corrosion

The constituents of the steels commonly used for offshore O&G pipelines are well-known, their rates of release can be estimated from the rates of corrosion (loss) and the likely end-products predicted, but verification of the latter remains a matter for further investigation. This can be done with a modest relatively short-term research program since it is known that the corrosion products do not change with extended exposures and, in any, are known from various field studies (e.g. Refait et al. 2020). However, the precise form of the end products requires verification.

Release of constituents of protective coatings into the environment after degradation

Determining the constituents that might be released from a particular type of protective coating is more difficult (compared with that for corroding steels). This is because the rate of deterioration of protective coatings likely extends over many years. If it can be assumed that the deterioration of external layers of the protective coatings is indicative of subsequent deterioration then a relative short experimental program is likely to yield sufficient information for any particular type of protective coating. Unfortunately, accelerated testing regimes are likely to modify the end products.

Longer-term behaviour of crevice corrosion

Longer-term behaviour of crevice corrosion is still unknown. Extended testing is needed to acquire longer term corrosion data for corrosion trends diagrams. From the results available to-date it appears that crevice corrosion, like pitting corrosion, causes an increase in (localized) corrosion penetration in the early stages of exposure but then steadies to a rate similar to that for general corrosion (Melchers and Tan 2022; Fig. 9; Tan et al. 2022, Fig. 2). In terms of understanding the development of crevice corrosion it would be prudent to ascertain whether this is indeed the longer term trending effect. It is proposed that this can be ascertained by the continuation of the current testing programs at Queenscliff and at Taylors Beach for crevice corrosion.

References

Melchers RE (2005) Effect of immersion depth on marine corrosion of mild steel, Corrosion, 61(9) 895-906.

Melchers RE (2015) Internal corrosion of parked steel oil pipelines, Proc. Conf. Corrosion & Prevention, South Australia, Adelaide, 15–18 Nov., Aust. Corrn. Assn., Melbourne, paper 055.

Melchers RE (2020) Models for prediction of long-term corrosion of cast iron water mains, Corrosion, 76 (5): 441-450.

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

Refait, Ph., A.-M. Grolleau, M. Jeannin, C. Rémazeilles and R. Sabot (2020) Corrosion of Carbon Steel in Marine Environments: Role of the Corrosion Product Layer, *Corros. Mater. Degrad*. 1: 198–218.

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.