

AC Corrosion of Cathodically Protected Pipelines – A Summary

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ABSTRACT

This paper presents a summary of the results obtained during 3 years of PhD studies on “AC Corrosion of Cathodically Protected Pipelines” at the Technical University of Denmark (DTU)¹, which was finalized in October 2018 and defended in January 2019.¹ Amongst the findings are: An improved understanding of AC corrosion as different corrosion phenomena under low and high levels of cathodic protection respectively. An enhanced understanding of the reactions in soil systems that lead to establishment of corrosive environments. Discovery of a close correlation between current density criteria and the Pourbaix diagram. An improved understanding of the influence of the CP level on the electrochemical double-layer characteristics. Presentation of a new model for AC corrosion that considers ionic dissolution and hydrogen evolution in the passive film destabilisation mechanism. The results are discussed in relation to literature and relevant cathodic protection and AC interference standards.

Key words: AC corrosion, AC interference, cathodic protection, corrosion rate

INTRODUCTION

AC corrosion is a topic that has gained a lot of attention in recent years, particularly in the pipeline industry. Characteristic for this form of corrosion, it has been found to be enhanced by traditional corrosion protection strategies such as cathodic protection and high impedance pipeline coatings, in the presence of an alternating voltage. The primary source of AC on buried pipelines is electromagnetic interference from high voltage transmission lines above ground, when the two are sharing the same right-of-way. The Danish company MetriCorr[†], has produced corrosion rate monitoring probes since 2002, specifically designed to investigate corrosion of cathodically protected structures under electrical interference conditions AC and/or DC. In 2014 an industrial PhD study was initialized in collaboration with DTU, financially supported by the Innovation Fund Denmark, to investigate the phenomenon in detail. This paper outlines the major findings of this study.¹

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[†] Tradename

AC alters DC polarisation characteristics and influences pH

It is well established that AC alters the DC polarisation behaviour of steel. In particular, the depolarisation of both anodic and cathodic reactions causes an increase of the cathodic current density, J_{DC} , under cathodic protection at the same polarised potential.²⁻⁸ This behaviour is also called *faradaic rectification* of the alternating current.⁹ On the other hand, the cathodic current also influences the AC current density, J_{AC} , at an induced AC voltage, U_{AC} , because of alkalisation of the local environment at the steel surface that alters the spread resistance, R_S , of a coating defect. R_S is a parameter that is inherently dependent on the soil resistivity, ρ_{soil} and the geometry of a coating defect. Depending on the soil system's response to alkalisation, R_S may do one of the following things:

- Increase - due to formation of calcareous deposits or drying of the soil
- Stay unchanged - e.g. due to the buffering capacity of some soils or flow of electrolyte that hinders pH elevation
- Decrease - due to increasing ionic conductivity of the local environment with increasing pH

The mutual influence of AC on DC and DC on AC is best illustrated by the “vicious circle” or “autocatalytic nature” of AC corrosion as shown in Figure 1. If the local environment is such that R_S decreases with alkalisation, then the circle becomes a self-perpetuating mechanism with increasing AC and DC current densities, which in turn may lead to high AC corrosion rates.

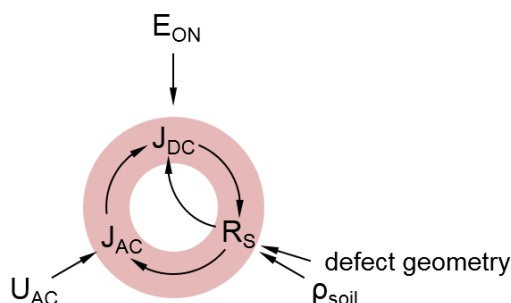


Figure 1: The vicious circle of AC corrosion.

A set of pre-requisites needs to be present for the vicious circle to run: A very negative protection potential, low soil resistivity, a small coating defect, and an AC interference voltage. These drive a self-perpetuating mechanism: The cathodic current influences soil chemistry and the spread resistance → spread resistance influences AC and DC current densities → AC current enhances the cathodic current via ‘faradaic rectification’ or ‘depolarisation’ → Corrosion occurs at high AC and DC current densities. The correlation between cathodic current density and pH is well known and well documented.^{10,11} However, one realisation from the present study is, that very high levels of AC has been found to lower the pH when the polarised potential is shifted positive of the hydrogen evolution potential – despite a cathodic current.¹² This effect is termed *AC induced de-alkalisation*, and at present the phenomenon still requires more investigation.

AC Corrosion is not an unambiguous corrosion phenomenon

AC corrosion is observed at both low and high levels of cathodic protection but does not occur for the same reasons at the two CP levels. Therefore, it must be treated differently in either case.

Low CP AC corrosion

AC corrosion at low levels of cathodic protection (or no CP) can be understood differently under potentiostatically applied CP or galvanostatically applied CP. In the case of potentiostatically applied CP,

the polarised potential may at all times satisfy the $-850 \text{ mV}_{\text{CSE}}$ CP criterion¹³, but the open circuit potential (OCP) of the steel is highly dependent on the AC interference level.^{2,4} Figure 2a shows a set of simplified generic polarisation curves at increasing levels of AC interference. They are based on numerous observations of shifting OCP and depolarisation of both the cathodic and anodic reactions in literature.^{3-8,14} In un-interfered conditions ($J_{\text{AC}} = 0 \text{ A/m}^2$, blue curve), a polarised potential of say $-0.9 \text{ V}_{\text{CSE}}$ sits comfortably on the cathode branch of the polarisation curve. But if the OCP shifts negatively of the polarised potential over an AC interference range as shown in Figure 2b, the direction of current will be inverted, and an anodic current will leave the pipe causing corrosion.

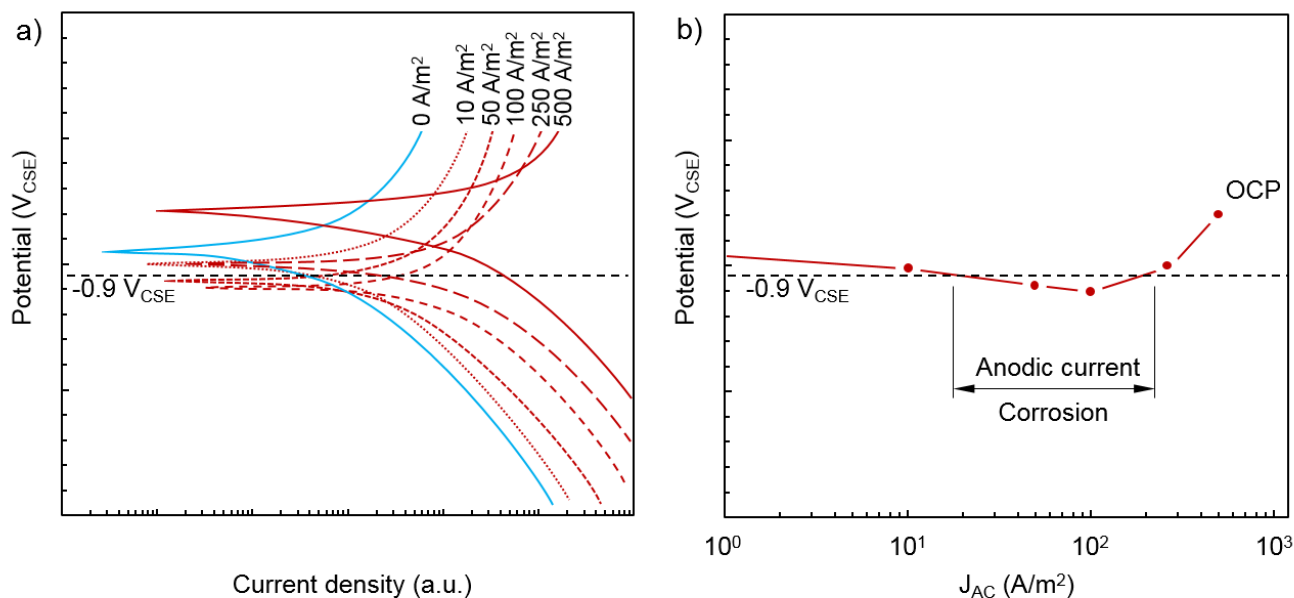


Figure 2: Explanation for low CP AC corrosion under potentiostatic control. Increasing level of AC causes a shift of the open circuit potential (OCP) in first the negative and later the positive direction. If the OCP is more negative than the rectifier potential, the rectifier system will deliver an anodic current of the pipe that causes corrosion.

Is low CP AC corrosion then avoided if a small galvanostatic CP current is applied under AC interference? – unfortunately, the answer is no. Figure 3a shows the same generic polarisation curves as in Figure 2a and vertical lines indicate two levels of galvanostatic CP current.

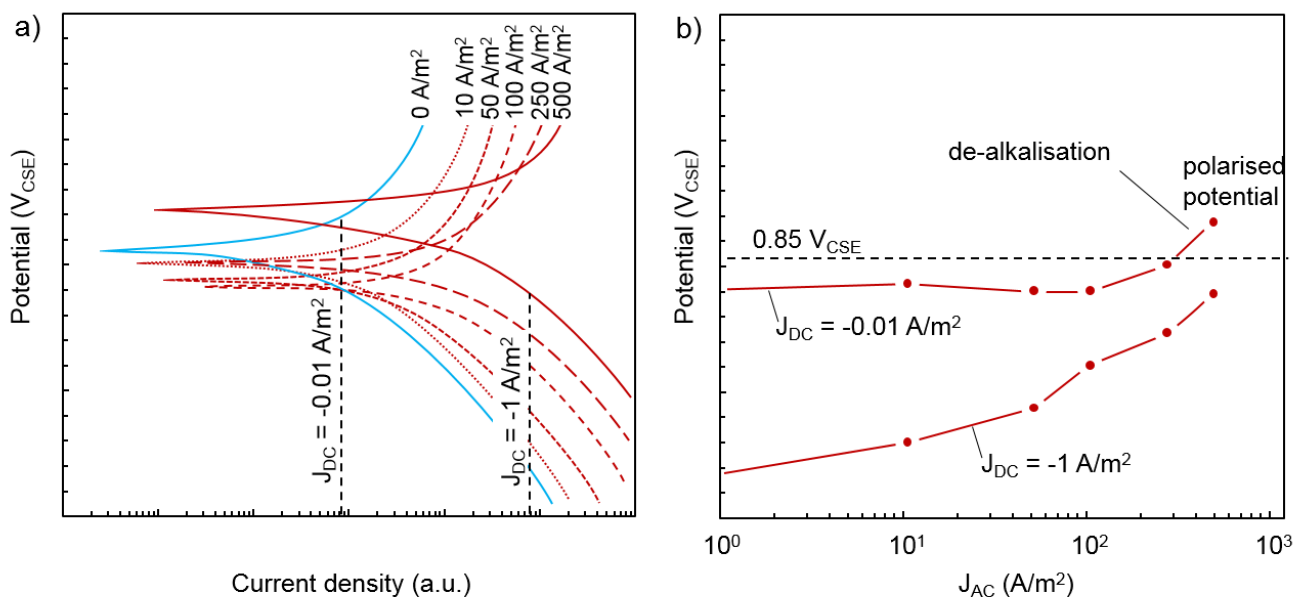


Figure 3: Explanation for low CP AC corrosion under galvanostatic control. The polarised potential corresponds to the intersection between the galvanostatically applied current and the cathode branch of the polarisation curve. Due to the effect of AC on DC polarisation behaviour, the polarised potential may end up positive of the $850 \text{ mV}_{\text{CSE}}$ CP criterion, which is associated with AC induced de-alkalisation.

The polarised potential is given by the intersection of these lines and the cathodic branch of the polarisation curve. It can be seen in Figure 3 that, at a certain AC interference level the polarised potential may end up shifting positively of the CP criterion, which is associated with AC induced de-alkalisation, loss of passivity and ultimately corrosion.

High CP AC corrosion

At high CP levels and AC interference, the pre-requisites for the vicious circle of AC corrosion in Figure 1 may be present. This will lead to strong alkalinisation of the environment around a small coating defect. Depending on the soil response to pH elevation (e.g. calcareous deposit formation or not) this may lead to higher AC and DC current densities. Formation of stone-hard-soil structures on top of coating defects is a well-known AC corrosion characteristic caused by the strong alkalinisation and the presence of earth alkaline metals (e.g. Ca and Mg). Figure 4 shows an example of such a structure.¹⁵