

Project on AC corrosion conducted at:
Department of Manufacturing Engineering, Materials Technology, Building 204,
The Technical University of Denmark, DK-2800 Lyngby, Denmark

Funded by:
DONG Natural Gas A/S. Agern Allé 24-26, DK-2970 Hørsholm, Denmark.

August 2000

AC Corrosion Rates of Steel Exposed in Non-Scaling Soil Solution – Correlation with DC Scans

Lars Vendelbo Nielsen
lvn@ipt.dtu.dk

Keywords:

Polarisation scans, IR-free peak potentials, AC current density, corrosion rate, ER-technique

Abstract

Slow (30 mV/hour) DC scans superimposed by fixed AC current have been performed on steel exposed in a non-scaling artificial soil solution. The resulting instant corrosion rate was measured real-time using the refined ER-technique. 4 scans were made in separate experiments – a pure DC scan from –1150 mV SCE to –550 mV SCE in the ON condition, as well as similar scans with 30, 100, and 300 A/m² superimposed AC current. The Ramlog Correal recorder was applied for establishment of IR-free (peak) potentials.

It was observed that the superimposed AC depolarised (activated) the DC behaviour, and the corrosion rate under influence of AC dramatically increased. In the cathodic region, the pure DC scans showed no corrosion below –850 mV SCE (IR-free), whereas the AC introduced corrosion even at maximum IR-free peak potentials of –950 mV SCE. At –950 mV, the highest AC current density (300 A/m²) provoked a corrosion rate of 0.1 mm/year.

The scan technique using ER-probes connected to an AC infected pipeline as corrosion rate sensors can be recommended for use in field for the establishment of critical IR-free peak potentials in-situ.

Introduction

This paper deals with the AC-corrosion rate of steel exposed in a non-scaling artificial soil solution. The corrosion rate was investigated during slow DC polarisation scans superimposed by AC of different levels.

The scale forming environment employed in the study reported in paper 6 of the present report¹ have been modified for the present study by a replacement of the earth alkaline cations (Mg^{2+} , Ca^{2+}) with the alkaline cation Na^+ . This eliminates the increase of spread resistance and offers the possibility of performing DC scans superimposed by AC current without the disturbing effects of the increasing spread resistance in the sense that a superimposed AC voltage now creates a constant AC current.

The experimental approach offered the possibility of comparing the AC corrosion rate with the DC polarisation behaviour of the steel. More precisely, the investigation concentrated on the effect of AC on the DC polarisation behaviour (an effect that has been reported in paper 5 of the present report²) and comparing this behaviour with the resulting corrosion rate as a function of the IR-free peak potential and DC current.

Experimental

The chemical composition of the solution employed in the studies is listed in table 1. The solution was purged with nitrogen throughout the experiments.

Component	Mg/L	Mol/L
Na_2SO_4	710	$5.0 \cdot 10^{-3}$
$NaHCO_3$	210	$2.5 \cdot 10^{-3}$
$NaCl$	585	$1.0 \cdot 10^{-2}$

Table 1. Chemical composition of the solution (pH 8.20, conductivity 2530 $\mu S/cm$).

The experimental set-up used in the investigations is illustrated in figure 1.

Electrochemical three-electrode arrangements were established in 2-liter glass vessels each equipped with a 2-cm² ER-probe as working electrode, a large (500 cm²) titanium-mesh as counter electrode, and a saturated calomel electrode (SCE, +0.242 V vs. SHE) as reference electrode.

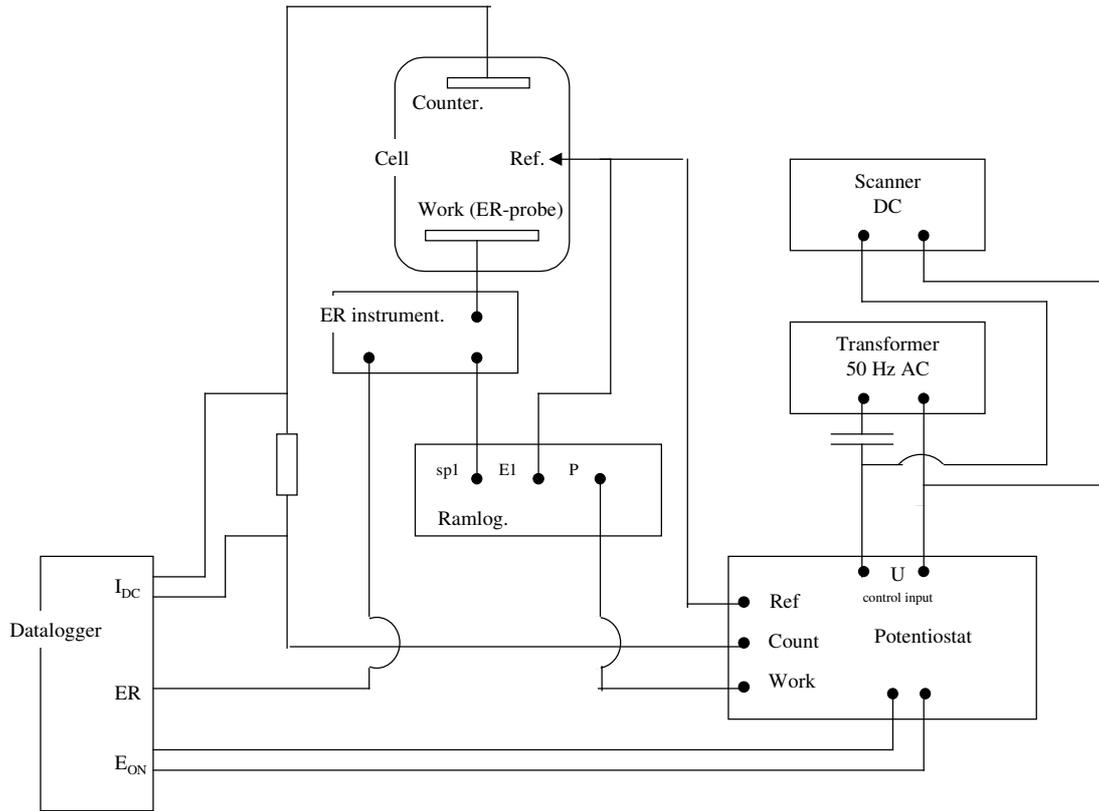


Figure 1. Electric diagram used for the potentiostatic AC- and DC-charging of the ER-probe.

The ER-probes were prepared from 25 μm thick steel foils. As described elsewhere^{3,4} the sensitivity of the ER-instrument is below 0.1 $\mu\Omega$ allowing for real time logging of the corrosion rate of the probe according to the algorithm:

$$V_{\text{corr}} = \frac{dR}{dt} \cdot \frac{\rho}{R^2} \cdot \frac{L}{W} \quad (1)$$

in which R is probe resistance, ρ is specific material resistivity, L is probe length and W is probe width.

A Wenking type potentiostat was fed with AC from a transformer and a DC scanner was coupled to control the DC potential. Scans were made from a DC (ON) potential of -1150 mV SCE and in the anodic direction using a scan rate 30 mV/hour. Typically, the scans were completed after approximately 20 hours at -550 mV SCE. Ramlog Correal recorders picked up the average ON-potentials, the instant IR-free OFF potentials and the instant current. A datalogger picked up the signals from the ER-instrument as well as the slowly changing ON potential controlled by the potentiostat and the DC scanner. In addition, the DC current flowing to the cell was recorded by the datalogger as the voltage across a 1 or 10 Ω resistor inserted in the counter electrode circuit.

Four scans were made. The first was performed as a pure DC scan, whereas 30, 100, and 300 A/m² AC current was superimposed in the other three scans. Since the spread resistance of the electrode was constant throughout the test period, the AC voltage from the transformer was simply adjusted to give the desired current, and no adjustments throughout time were necessary.

Results and discussion

The spread resistance was calculated from the data (in the DC scans as the difference between ON- and OFF potential divided by the current density, and in the AC infected scans as described in paper 4 of the present report⁵) in any case showing a constant value of 0.018 Ω.m².

Figure 2 shows the results from the DC scan .

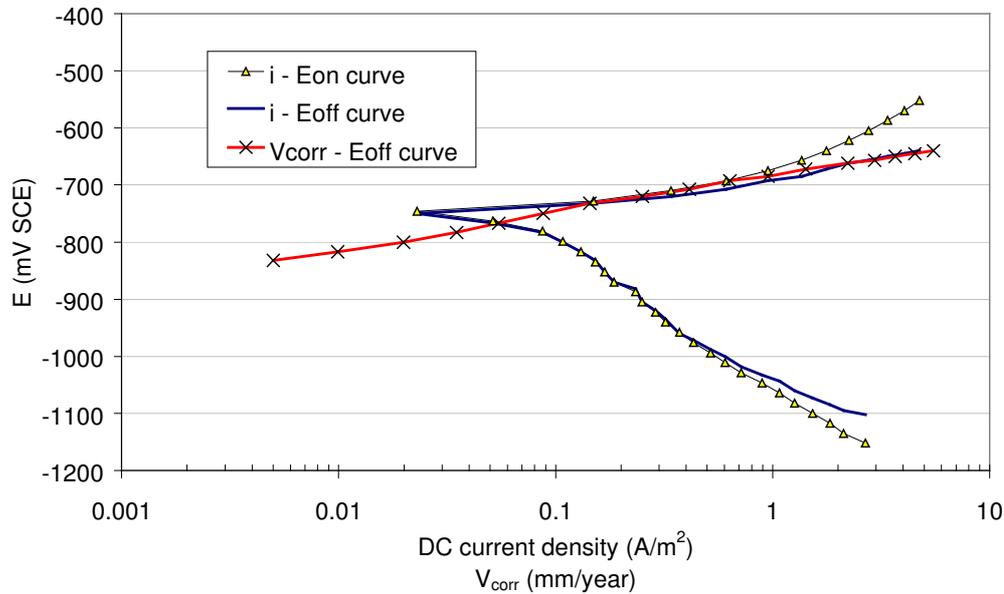


Figure 2. DC scan and measured corrosion rate.

When cleansed from IR-drops, the polarisation curve exhibits quite nice activation controlled behaviour, particularly in the anodic region. It is important to notice that the corrosion rate measured by the ER-technique yields an excellent correlation between current and corrosion rate in the anodic region (1 A/m² corresponds to approximately 1 mm/year corrosion rate). If the corrosion rate at the OCP were to be assessed from the E-log(i) curve by extrapolation, the extrapolated value is an exact match of the value measured by the ER-technique. Further, ER-measured corrosion rate exhibits linear E-log(V_{corr}) behaviour in the entire region from –850 mV to –650 mV, thus justifying the accuracy of the corrosion rate measured in the cathodic region as well.

When superimposing AC, the well-defined E-log(i) curve no longer exists, since the potential oscillates between a maximum peak potential, and a minimum peak

potential. The curves are now to be represented as shown in figure 3 (for the 30 A/m² AC case).

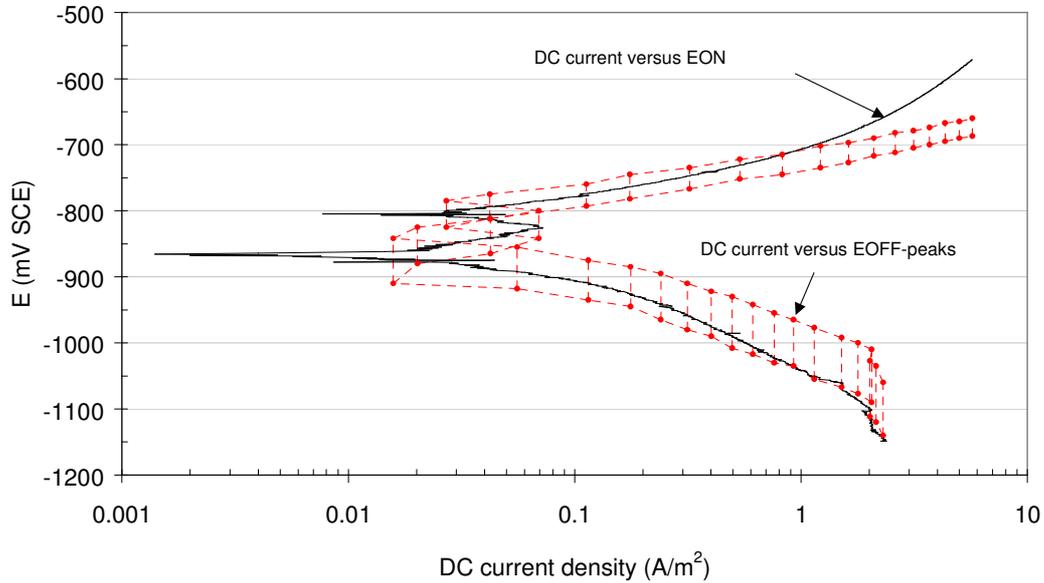


Figure 3. Resulting scan with 30 A/m² superimposed AC current density.

Obviously, the corrosion rate has to be presented as a function of the peak potentials as well. The corrosion rates measured during the scan presented in the scan in figure 3 is included in figure 4.

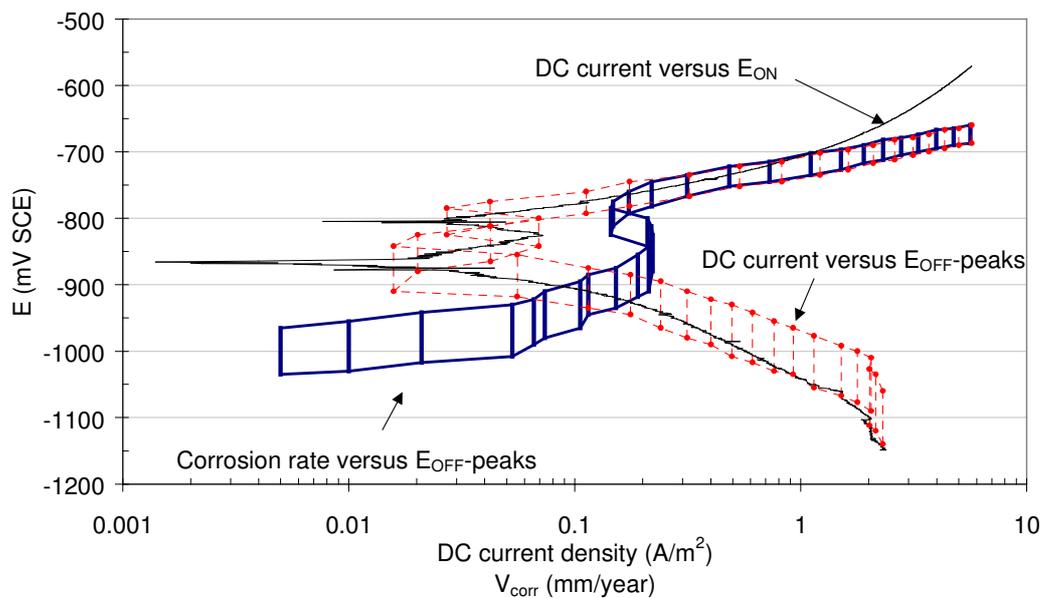


Figure 4. Resulting scan with 30 A/m² superimposed AC current density – corrosion rate included.

Also under these conditions, the corrosion rate correlates nicely with anodic DC current density in the anodic region of the curve, thus justifying the integrity of corrosion rates measured under cathodic polarisation. Figures 5 and 6 show the scans performed under 100 A/m^2 and 300 A/m^2 AC load.

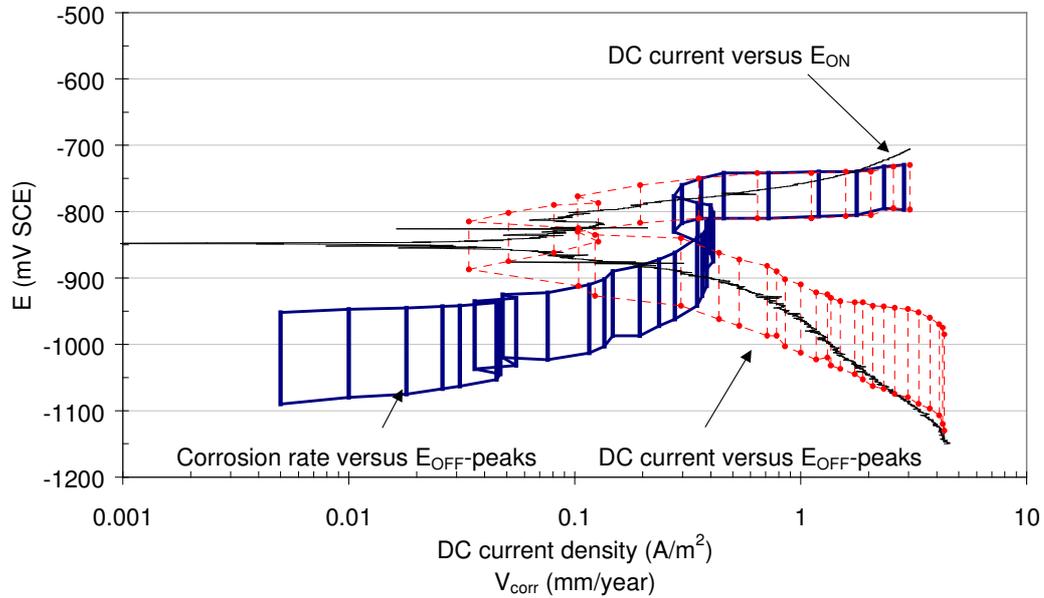


Figure 5. Resulting scan with 100 A/m^2 superimposed AC current density.

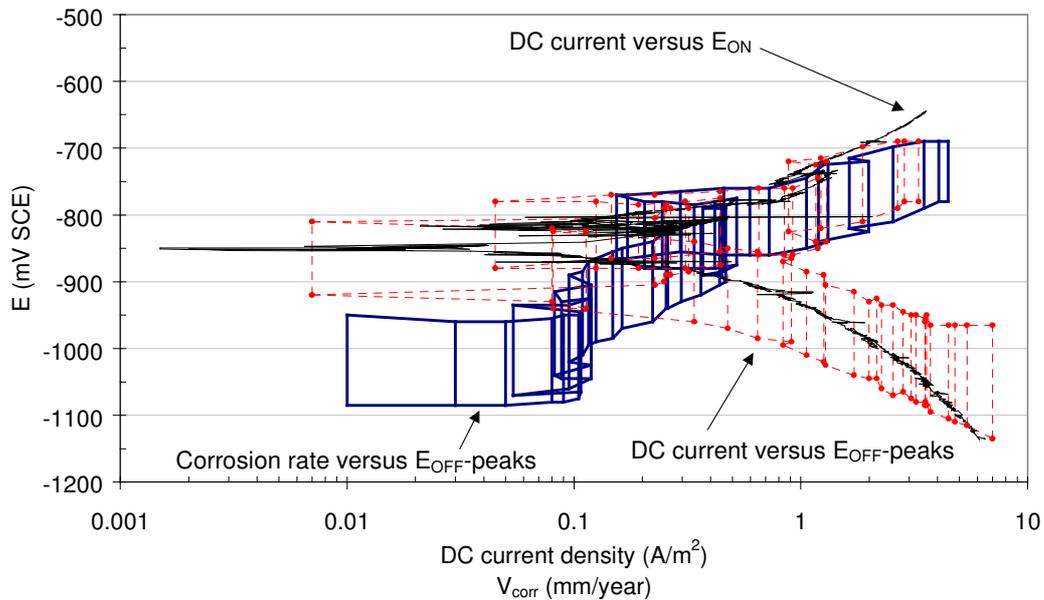


Figure 6. Resulting scan with 300 A/m^2 superimposed AC current density

Comparing the resulting DC current density versus ON-potential of the scans gives the picture in figure 7.

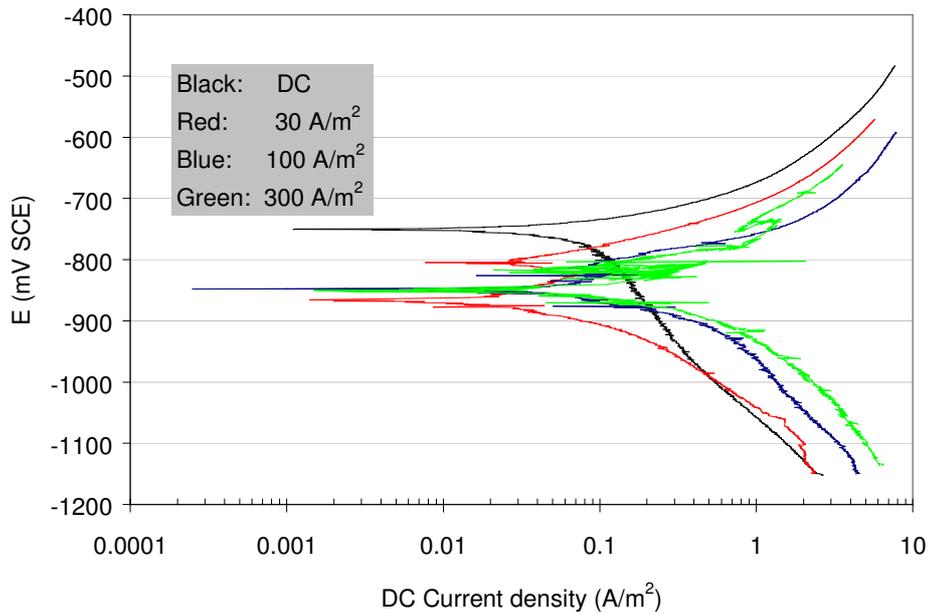


Figure 7. Comparison of the DC current versus ON-potential obtained by the scans.

As observed from this figure, the electrode behaviour becomes depolarised by the AC as also observed and described in paper 5 of the present report.² The DC curve (anodic branch in particular) becomes rather scattered for the highest AC, and the scan seems to be less controllable.

It further appears that the AC introduces a second potential of zero current, but careful studies of the more anodic of these zero current potentials reveal that the current is anodic all the way through, i.e. a local minimum in the anodic branch is created. Current changes from cathodic to anodic only when passing the more cathodic of the zero current potentials. This is forwarded as an observation only, and establishment of the reason behind this requires further analysis. However, it has to be related to the iron dissolution behaviour, since (as observed from figures 4, 5, and 6), the corrosion rate decreases as well when the E_{OFF} variation passes through this region.

Figure 8 shows the corrosion rates obtained in all scans plotted against the OFF-potential. Although it becomes somewhat difficult to distinguish the curves, it is obvious that the effect of AC on the corrosion rate is quite dramatic, and the steel corrodes even at potentials within the region normally considered safe as a CP criterion. The curves are simplified a bit in figure 9, showing the corrosion rate plotted against the anodic OFF peak potential.

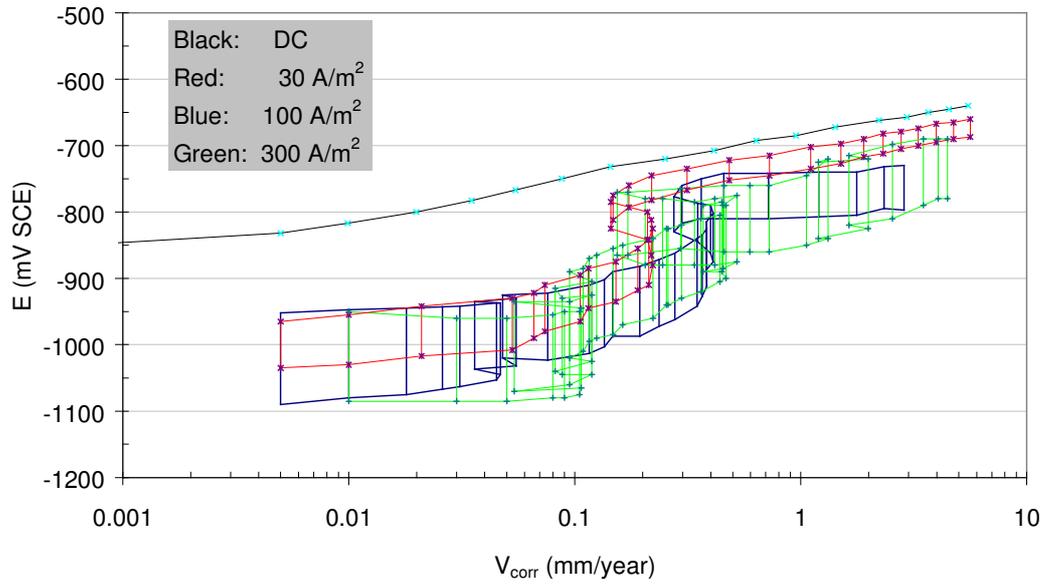


Figure 8. Corrosion rates against OFF-potential for all scans.

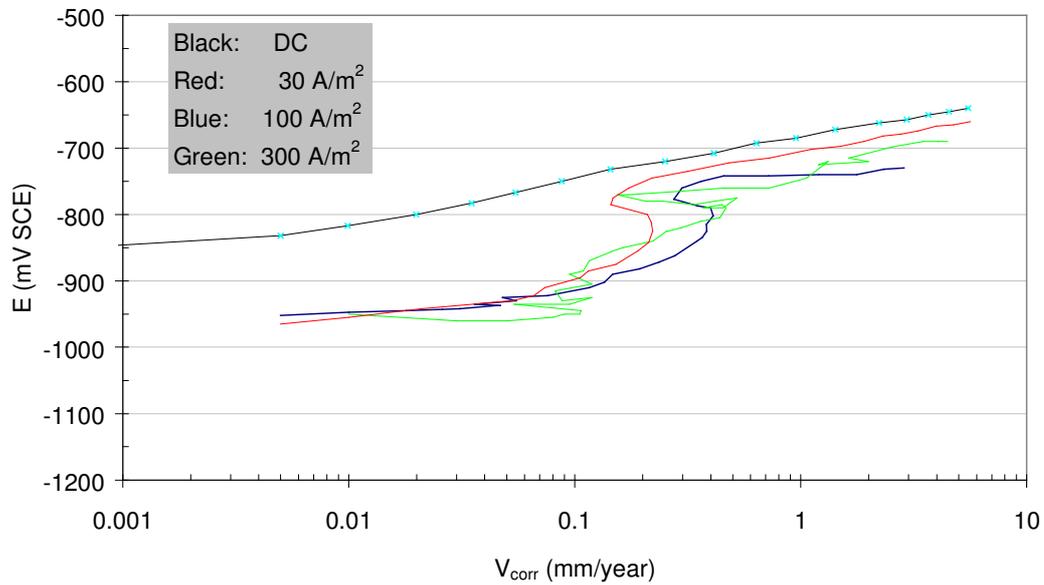


Figure 9. Corrosion rates plotted against the maximum OFF peak potential.

As a whole, the scans show that the AC influences the DC behaviour of the steel, and that the corrosion rate may be related to depolarisation in DC behaviour. In this environment it seems that the more anodic the OFF potentials become, the faster the steel corrodes, but with the exception that when the local minimum in anodic DC current appears, the corrosion rate accordingly decreases as well.

The scans presented here may be regarded solely as representing the condition existing at the time at which the scans were run. Like in a pure DC-case, at long term exposure, the polarisation behaviour eventually may change. It is quite usual, that when exposed throughout an extended amount of time, the steel polarises and becomes less active. This may be expected in case of the AC corrosion behaviour as well, and should be investigated by establishing fixed AC/DC conditions for extended period of time. This is dealt with in paper 8 of the present report.⁶

Conclusions

- Slow (30 mV/hour) DC scans superimposed by fixed AC have been performed on steel exposed in a non-scaling artificial soil solution. The resulting instant corrosion rate was measured real-time using the refined ER-technique. 4 scans were made in separate experiments – a pure DC scan from –1150 mV SCE to –550 mV SCE in the ON condition, as well as similar scans with 30, 100, and 300 A/m² superimposed AC current.
- It was observed that the superimposed AC depolarised (activated) the DC behaviour, and the corrosion rate under influence of AC dramatically increased.
- In the anodic region of the polarisation curve, the AC introduced local minimum in the anodic DC current, and the corrosion rate under influence of AC decreased accordingly (however, still higher than for pure DC).
- In the cathodic region, the pure DC scans showed no corrosion below –850 mV SCE (IR-free), whereas the AC introduced corrosion even at maximum IR-free peak potentials of –950 mV SCE. At –950 mV, the highest AC current density (300 A/m²) provoked a corrosion rate of 0.1 mm/year.
- Like traditional DC scans, the AC influenced scans should be regarded solely as an instantaneous behaviour, and quite commonly, the polarisation behaviour eventually changes. Hence, the stability throughout time – specifically in the cathodic region, should be investigated.
- The scan technique using ER-probes connected to an AC infected pipeline as corrosion rate sensors can be recommended for use in field. In particular, the probes should be connected to the pipeline for extended period of time before the scans are performed, hereby allowing for the establishment of critical IR-free peak potentials in-situ.

References

1. L.V. Nielsen, AC Corrosion Rates of Cathodically Polarised Steel Exposed in a Scaling, Neutral pH Soil Solution, Paper 6, this report.

2. L.V. Nielsen, Effects of 50 Hz AC on the DC Polarisation Behaviour of Steel Exposed in Artificial Soil Solutions, Paper 5, this report.
3. L.V. Nielsen, K.V. Nielsen, Measurement of Accumulated Corrosion and Instant Corrosion Rate using a Refined Electrical Resistance Technique. VN-Instrument, Internal Report.
4. Method and Apparatus for Measuring Accumulated and Instant Rate of Material Loss or Material Gain, VN-Instrument, Danish Patent Application PA 1999 01772.
5. L.V. Nielsen, Comparison of EIS and Ramlog Measurements of Spread Resistance and Polarisation Impedance for Steel Exposed in Artificial Soil Solutions with and without Scaling Capacity at 50 Hz AC, Paper 4, this report.
6. L.V. Nielsen, Stability of the Polarisation Behaviour and Corrosion Rate of Steel at Fixed AC/DC Conditions in Non-Scaling Soil Solution, Paper 8, this report.