

Modelling pipeline stray current corrosion

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DC stray current interference is a stochastic process that is determined by the passage of DC traction systems crossing buried pipelines. The signals are not constant, neither in amplitude, neither in duration as it is in AC interference. Understanding the corrosion mechanisms behind stray current corrosion is therefore very complex.

It is the aim of this article to investigate via modelling the corrosion behaviour of steel under various DC interference signals. Through computational modelling the mechanisms occurring on the steel surface of a pipeline coating defect or coupon are simulated over time for various interference conditions and CP levels. As a first stage pulsed signals were applied. Based on the simulation results a better understanding of the conditions under which DC interference is a risk are highlighted such that uncertainties are reduced, and Fitness for Service is improved.

Introduction

DC stray current interference is a severe corrosion threat on pipelines caused by third party DC traction (dynamic) systems or by neighbouring pipelines CP (static) systems. Mitigation measures against DC stray current requires additional investment as a surplus of the conventional cathodic protection and coating systems.

Typical mitigation measures consist of forced drainage systems with a rectifier, unidirectional drainage with diodes or direct drainage through a resistor. These systems are operating for a relatively small pipeline section of a few hundred feet closest to the source of interference and are therefore relatively expensive compared to the normal CP system that is effective for several tenth of miles.

Besides investment in equipment the survey cost is higher. In the presence of DC stray current the frequency of the functional checks that need to be performed on pipeline systems is reduced to 1/3 in comparison with the surveys required on normal CP installations (acc. EN 12954). As a result, survey costs are higher than for conventional CP system.

Although the cost and corrosion risk in presence of DC interference is high, there is still a requirement for developing a proper procedure for adequate assessment. There is a different in approach between the US and Europe. According to the NACE SP 0169:2013, which is currently under review, the assessment method is based on potential and soil gradient measurements ('beta curve') which does not provide information on corrosion rates. According to the European standard EN 50162, the DC interference criteria refer to maintaining the IR-free and current density measured on a probe or coupon within the cathodic protection criteria, or at least not exceeding a percentage of the CP current for a given time. This is very ambitious for dynamic DC interference effects. Moreover, recent experiments [1,2] have demonstrated that the corrosion risk ranking does not always comply with the EN 12954 criteria. In many cases the standard is too conservative resulting in large investments in counter measures on the pipelines which could not be justified.

Corrosion mechanism

Pipeline steel will corrode at unacceptable rate ($> 10 \mu\text{m}/\text{year}$) when is not cathodically polarized into the immunity region or the passivity layer (Fe_3O_4) is not sufficiently protective. Under DC stray current the pipe-to-soil potentials tend to be pushed towards more electro-positive potentials because of the change in adjacent soil potentials due to perturbations caused by DC traction systems when the rail potential goes more electronegative than the pipe protection potential.

The corrosion kinetic in soil environment is different than in beaker solutions under laboratory conditions. The soil is a complex environment that consists of a solid matrix (soil particles) and an electrolyte (soil moisture) that may completely fill the pores under saturated conditions, or that may form a film around the particles allowing more air/oxygen entering the soil. Especially the lower mobility of (electro)chemical species makes soils a different environment than aqueous solutions. More details have been described in [3,4]. The corrosion mechanisms in a soil environment under various conditions (soil type, moisture content, CP level, AC interference level, etc) are implemented in an advanced software tool which allows to investigate the influencing parameters on the corrosion rate on pipeline coating defect of a given size. In this article the software will be used to study the effect of DC stray current in a simplified form.

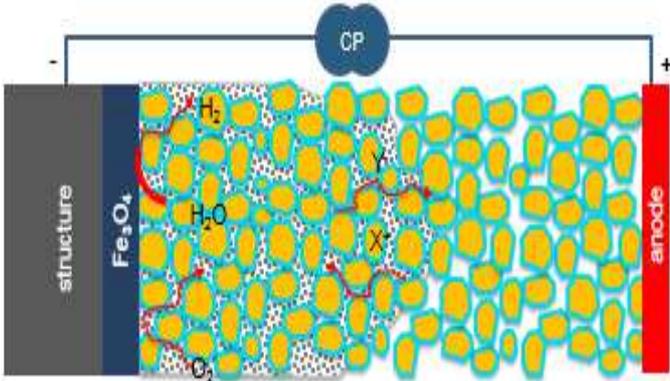


Figure 1 – schematic of cathodic protection in soil environment

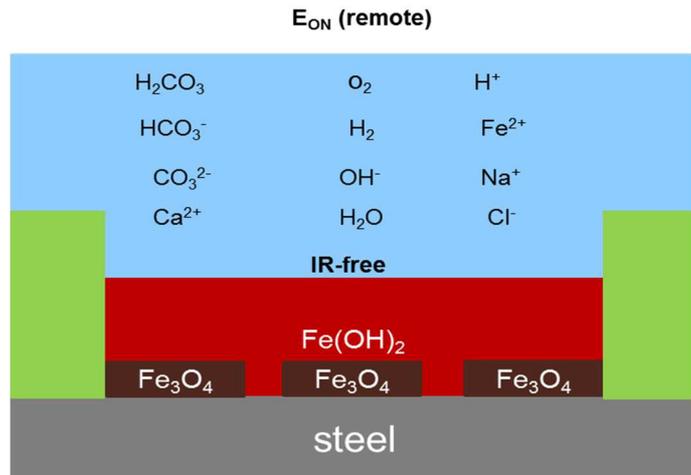


Figure 2 – schematic of Elsyca CorSolver computational model

Example

The experimental set-up of 1 cm² carbon steel in sand with simulated soil solution (700 mg/l SO_4^{2-} and 100 mg Cl^- with $\rho = 15\Omega m$) from [1] was considered. The researchers used a pulsed signal with various pulse widths to represent the DC stray current.

The cathodic polarization potential was targeted at respectively -0.85 or -1.10V_{cse} IR-free potential. The current density excursion during the anodic pulse was aimed to be 1 or 10A/m². The anodic peak duration was 1, 2, 5 or 60 minutes and the cathodic duration was 23, 46, 115 and 1380 minutes resulting in 60, 30, 12 and 1 peaks per day respectively. The results are shown in Figure 3.

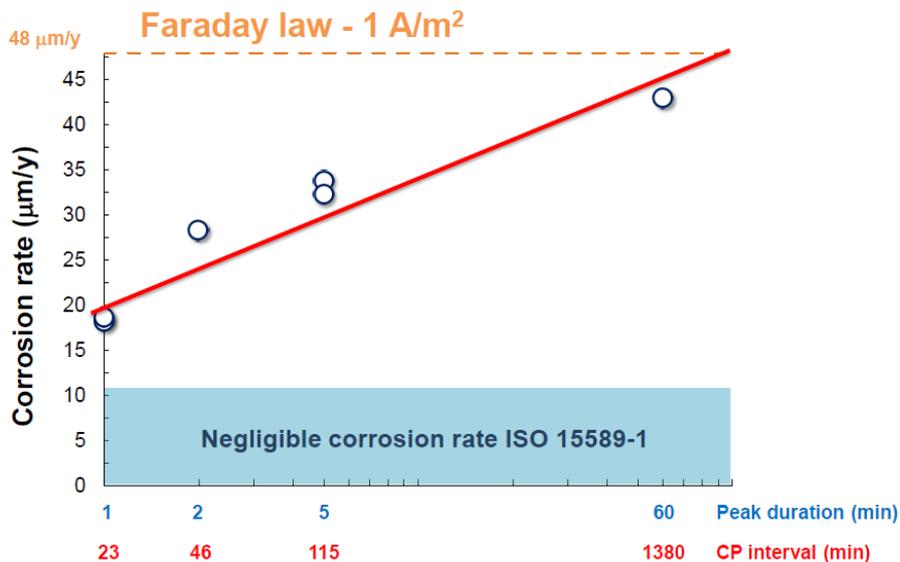


Figure 3 – results of corrosion rates under (pulsed) DC stray current corrosion from [1] in simulated soil solution in sand

Similar conditions were applied in the computational model with the only difference that the model is potential controlled from remote earth. Grain size of 0.5 mm was considered with 100% saturation. The oxygen concentration was assumed to be 5.6 ppm.

Only the first pulsed signals (1 and 2 min anodic peak duration) were applied. Results of the simulations are shown in Table 1. The IR-free potential under cathodic protection regime was well within the target polarization level. The anodic potential however was less electropositive than expected since the maximum current density ranged between 0.192 tot 0.292 A/m²

which is approximately 5 times lower than in the experiments. In the case of a target IR-free protection potential of $-0.850V_{CSE}$ the average corrosion rate is 17 and 15 $\mu\text{m}/\text{yr}$ for a 1 and 2 minute anodic pulse respectively which is in good agreement with the corrosion rate determined by weight loss of the experimental coupon. If the cathodic protection level is increased from -0.85 to $-1.10V_{CSE}$ the corrosion rate is further decreased to an acceptable value below $10\mu\text{m}/\text{yr}$. Interesting to note is the model simulates other interesting results which allows a better understanding what is happening on the metal surface. For example, the maximum instantaneous corrosion rate during the anodic pulse is simulated for the different cases, as well as the evolution of the pH at the metal surface. Figure 4 shows an example. The corrosion rate peaks proportional with the anodic current density. The pH decreases slightly but remains at high values. This indicates that no oxygen is formed during the anodic pulse with generation of protons and that the hydroxyls formed during the cathodic cycle diffuse only very slowly through the soil away from the metal surface. Another interesting observation is the formation of the passive layer (Fe_3O_4). A full coverage of the metal surface of a monolayer of magnetite is represented by the parameter theta equal 1. As can be seen from Table 1 theta has values below 1 with a maximum of 0.682. This means that a full coverage or full passivation does not occur. However, the model reveals that the anodic peak is first mainly attributed to the partly formation of magnetite ($\text{Fe} \rightarrow \text{Fe}_3\text{O}_4$) because of the high pH. As the pH decreases over time the oxidation of steel to ferric ion ($\text{Fe} \rightarrow \text{Fe}^{2+}$) comes into competition as shown in Figure 5. Both current densities decrease as pH decreases.

Table 1 – simulation results

anodic	duration [min]	1	2	1
	IR-free [Vcse]	-0.629	-0.638	-0.630
cathodic	duration [min]	23	46	23
	IR-free [Vcse]	-0.868	-0.864	-1.100
J [A/m ²]	min	-0.417	-0.417	-0.957
	av	-0.020	-0.021	-0.064
	max	0.192	0.207	0.292
CR [mm/y]	min	0	0	0
	av	0.017	0.015	0.005
	max	0.171	0.189	0.258
Teta	min	0	0	0
	av	0.454	0.444	0.066
	max	0.644	0.543	0.682
pH	min	10.6	10.7	11.0
	av	10.89	10.91	11.22
	max	10.93	10.93	11.35

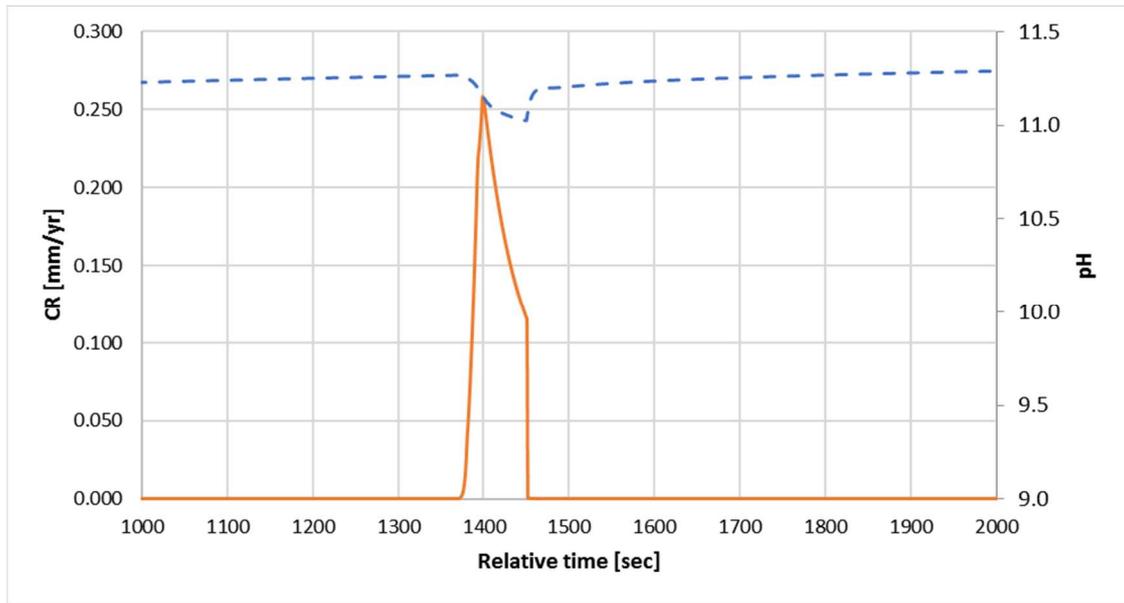


Figure 4 – corrosion rate (full line) and pH (dashed line) evolution for the anodic pulse (-0.630V) and cathodic protection level (-1.10V)

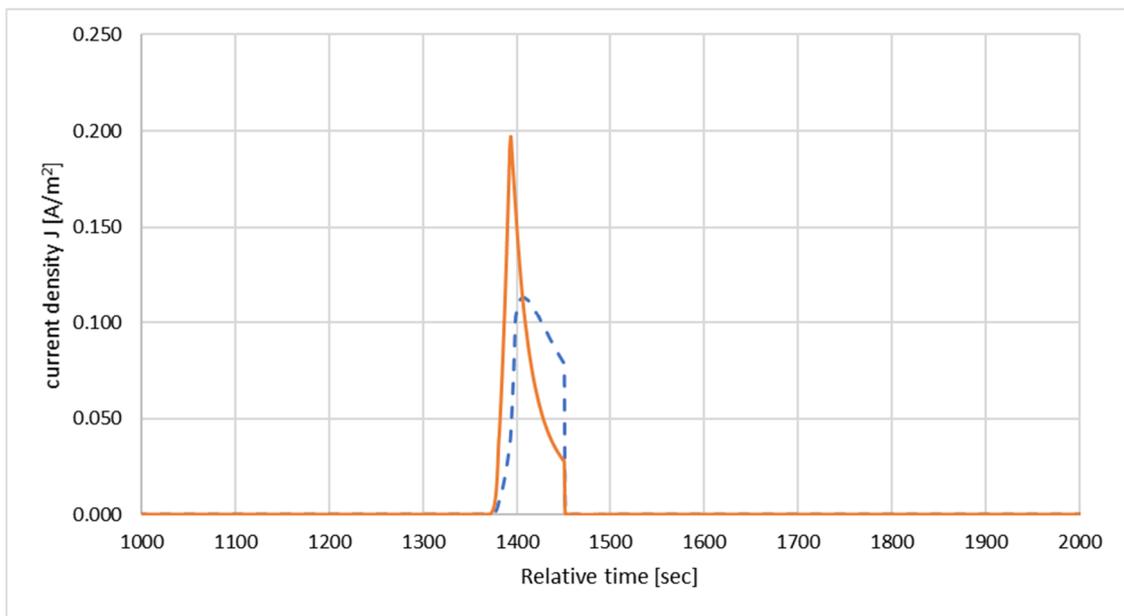


Figure 5 – current density distribution of Fe -> Fe₃O₄ (full line) and Fe -> Fe²⁺ (dashed line) to the total corrosion current

Conclusions

First attempts have been made to simulated DC stray current corrosion on pipeline coating defects in soils. The obtained corrosion rates were in good agreement with experimental observations from literature. The advantage of the computational model is to go deeper into the corrosion mechanisms occurring on the steel surface such that influencing factors such as the pH and the formation of a passivating magnetite film. Under the given circumstances corrosion occur during anodic peak and the instantaneous corrosion rates (and thus current density) decreased with the pH at the metal surface. Future work need to be done to simulate corrosion

rates under various conditions of soil (moisture content and texture), anodic/cathodic cycles or even real-world pipeline data.

References

- [1] A. Brenna, M. Ormellese, L. Lazzari, "Effects of intermittent DC stray current on carbon steel under cathodic protection", NACE paper n° 5721, Corrosion 2015.
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- [3] Ch. Baete, "Corrosion kinetics behind pipeline IR-free potentials" Ceocor 2017
- [4] Ch. Baete, "Modeling pipeline steel passivation", Ceocor 2018