

FEM Simulation Analysis of the Pipe-Casing Under Cathodic Protection

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ABSTRACT

In the present study, pipe-casing under cathodic protection is modeled by using FEM. The inner and outer surface of the casing and coating defects at the pipe surface is considered as corrosion and protection interface that follows non-linear polarization behavior. The coating of casing, electrolyte resistivity in pipe-casing space and electrical resistivity between pipe-casing are the main variables. FEM model is approved by tens centimeters of the pipe-casing section experimental setup. After proofing the FEM model, it is scaled up to study more realistic dimensions and broader variable ranges.

The FEM simulations show that when the casing is bare and electrically isolated from the pipe, coating defects of the pipe are easily protected in a wide range of solution resistivity in pipe-casing space. If pipe-casing resistance is reduced to lower than 10 ohms, the cathodic protection nullified, and corrosion could happen on the pipe coating defects. The presence of a coating on the inner surface of the casing will only lead to localization of the corrosion on its defects. Lower solution resistivity leads to an overall flattening of the potential distribution to an average value.

Keywords: FEM simulation; cathodic protection; pipe; casing; non-linear behavior

Introduction

A crossing between buried pipelines and transportation arteries such as railways and highways is a common reality. Nowadays it is ordinary practice, and standards are available for such practice¹, to protect such pipelines by encasing them in a wider pipe, named Casing. The goal is to protect the carrier pipe providing an outer shell capable of withstanding mechanical stresses and eventual corrosion, without leakage risk. In usual conditions this kind of safety measure should not be necessary, still due to the difficult maintenance and monitoring accessibility below railways and highways it becomes a dependable protection method and device.

Cathodic Protection is a further protection applied on this kind of buried structures, to slow down the corrosion process that could endanger the carrier pipe.

Casings should be watertight and electrically insulated from the carrier pipe (to avoid interference with CP), and this is achieved through some expedients such as end seals and insulating spacers¹. Due to failures, one of these two conditions may lack, and this study focuses on the possible outcomes, modeling them through FEM while varying some sensible parameters: resistivity of electrolyte inside the casing-pipe space, electrical insulation or connection between casing and carrier, presence of coating and defects.

All active surfaces are described through a non linear polarization behaviour, following Tafel's Law:

$$E(i) = E_{eq} + \beta \ln \frac{i}{i_0} \quad (1)$$

where $E(i)$ is the measured potential, E_{eq} the equilibrium potential of the reaction, β the Tafel slope and i_0 the exchange current.

More specifically in the FEM models three reactions are simultaneously taking place on the steel active surfaces: Oxygen Reduction Reaction (ORR) and Hydrogen Evolution Reaction (HER) as the main cathodic reactions, and Fe corrosion as anodic reaction. The data used in the simulations (Table 1 and Fig. 1) are obtained from literature and previous articles on CP topic²⁻⁵.

Table1: Tafel's Law parameters used in FEM models

Parameter	Value	Unit	Description
$i_{H_2}^0$	0.0002	A/m ²	HER exchange current
E_{HER}	-0.729	vs. CSE	Hydrogen Equilibrium potential (pH 7)
β_{H_2}	-0.12	V/decade	HER anodic Tafel's slope
$i_{O_2}^0$	0.001	A/m ²	ORR exchange current
E_{ORR}	0.6	vs. CSE	Oxygen Equilibrium potential
β_{O_2}	-0.06	V/decade	ORR anodic Tafel's slope
i_{lim}	0.01-1	A/m ²	Oxygen limiting current
i_{Fe}^0	0.02	A/m ²	Fe corrosion exchange current
E_{Fe}	-0.492	vs. CSE	Fe Equilibrium potential
β_{Fe}	0.06	V/decade	Fe cathodic Tafel's slope

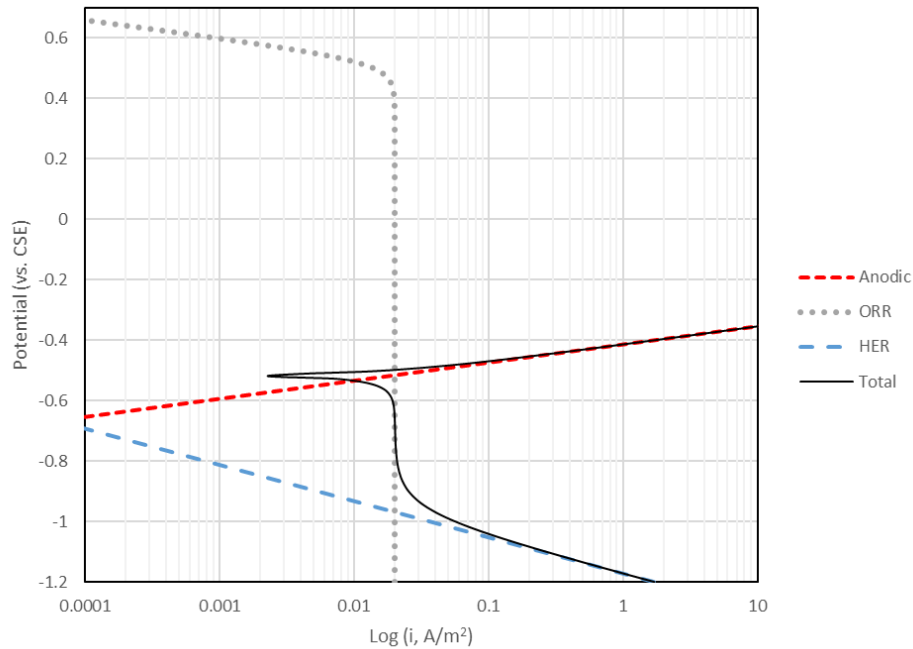


Figure 1: Graphical representation of anodic and cathodic characteristic curves, oxygen limiting current set at 20 mA/m²

The total polarization equation, summing up the three reactions would be:

$$i_{act} = i_{Fe}^0 e^{\left(2.3 \frac{E - E_{Fe}}{\beta_{Fe}}\right)} - i_{H_2}^0 e^{\left(-2.3 \frac{E - E_{HER}}{\beta_{H_2}}\right)} - i_{O_2}^0 e^{\left(-2.3 \frac{E - E_{ORR}}{\beta_{O_2}}\right)} \quad (2)$$

In the concentration polarization condition, the typical condition for structures buried in soil, the total current density, i , is calculated by:

$$i = \frac{i_{act.}}{1 + \left| \frac{i_{act.}}{i_{lim}} \right|} \quad (3)$$

where i_{lim} is the limiting current density and i_{act} is the extracted from equation (2). The graphical presentation of the Eq. 2 and Eq. 3 with the value in Table 1 is presented in Figure 1.

Experimental setups reproducing a slice of the whole length of the casing-carrier couple have been analyzed in different conditions², to provide reliable data to compare with the FEM models.

Once the FEM models replicating the experimental setups were proven to be reliable, a scaled up version of dimensions similar to real application pipelines has been developed and analyzed, varying the parameters described above with the intention to search for an acceptance range.

EXPERIMENTAL PROCEDURE

FEM models were developed matching the geometry and conditions of four different experimental setups ², consisting in a small section of 15 cm of the whole length of a pipe-casing structure.

In the experimental setup two concentric cylinders of steel (casing 25 cm diameter, carrier pipe 15 cm diameter) were settled inside a plastic tank of dimensions 70 x 30 x 40 cm, which was then filled with electrolyte solution up to 15 cm. The resistivity of the solution was set to 200 Ωm , both outside the casing and inside the annulus between casing and carrier.

Three Ag/AgCl/KCl_{sat} reference electrodes were placed like in Fig. 2, one on the outer surface of the casing, one on the inner surface and the last one on the surface of the carrier, to obtain potential data.

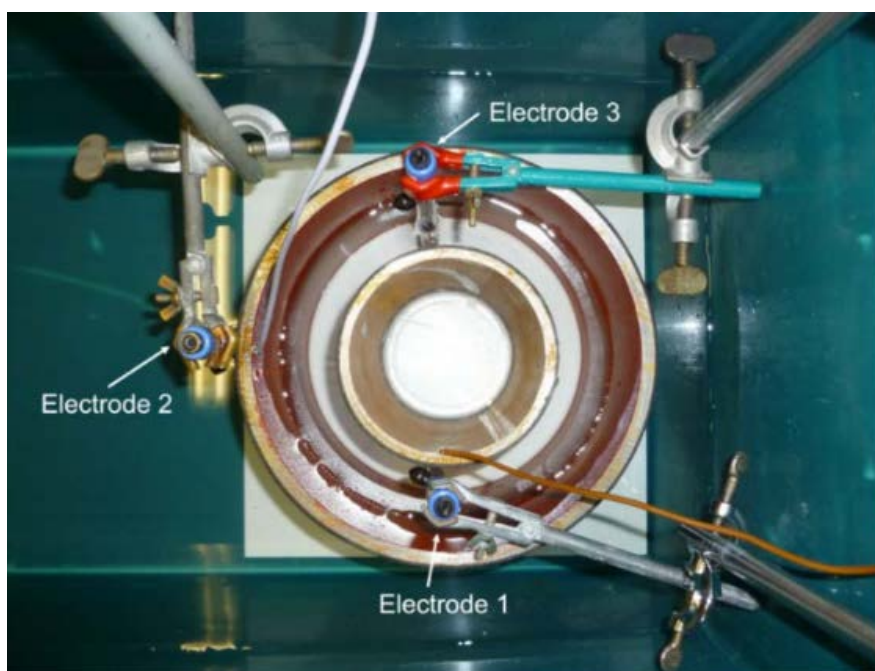


Figure 2: Reference electrodes positioning to monitor the experiment

The four different configurations tested were²:

- A. Uncoated casing pipe, both on internal and external surfaces
- B. Uncoated casing pipe (as case A), having a through hole (diameter 1 cm) facing the coating defect of the gas pipe