Effect of protective casing on the cathodic protection condition of a buried pipeline at rail crossing

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Abstract

The Italian Ministerial Decree (D.M. 4 April 2014) foresees that at rail crossing and parallelism, buried pipes for liquid and gas transportation shall be encased in a coated steel pipe called casing pipe. According to the decree, the ends of the casing pipe should ensure the perfect watertight seal of the annulus while spacers of insulating material should avoid electrical contact between the two pipes. Nevertheless, on-field experience proved that in most of the cases water from soil is present into the annulus in between pipe and casing, causing possible corrosion. Based on that evidence, laboratory tests have been performed to investigate the protection level on the gas transport pipe and the interference condition of the casing pipe. Different configurations were considered for the casing: bare pipe with a passing hole; coated pipe with a coating defect on the internal and external surface; bare casing electrically connected to the internal pipe with a shunt. Results showed that in the presence of a perfect watertight seal, no interference takes place on the casing pipe, as expected. If an electrolyte in present into the annulus, the external surface of the casing and the internal surface of the pipe are cathodically polarized, while internal surface of the casing is anodically interfered. Increasing the cell voltage, overprotection conditions on the internal pipe are reached in all tested configuration, with the exception of tests performed on the pipes electrically connected.

Keywords anodic interference; cathodic protection; crossing; overprotection

Introduction

Stray currents originating from direct current systems may cause severe material damage by corrosion on buried or immersed metal structures1. To prevent the effects of stray current corrosion caused by direct current, different methods can be used, such as cathodic protection (CP), forced drainage bond or insulating joints [1, 2].

The Italian Ministerial Decree dated 4th April 2014 [3] demands that ducts buried in correspondence of rail crossings or parallelisms shall be encased in a coated steel pipe, called casing pipe. To ensure the protection of the inner tubing (carrier pipe), the ends of the casing pipe must guarantee the perfect watertight seal of the annulus while spacers of insulating material keep the two tubes electrically separated (Figure 1). In practice, it is almost impossible to achieve a perfect watertight seal. To avoid corrosion of the carrier pipe, a first possibility is the injection of a suitable filler material into the annular space. The filler material should either inhibit corrosion (e.g. visco-elastic compounds, inhibited wax) or be designed to allow CP current to reach the carrier pipe [4]. For casings that pass CP current (i.e. bare or poorly coated steel pipes or uncoated concrete pipes), the external cathodic protection of the carrier pipe can be effective in protecting the carrier pipe provided there is no contact between the carrier pipe and the casing, and that there is enough electrolyte in the annular space. Without any electrolyte in the annular space, atmospheric corrosion can occur at coating defects. Moreover, if CP of the casing is required, the casing should be resistively bonded to the carrier pipeline.

The aim of this work is to investigate the behavior of the pipes in cases when the insulation of the carrier tube is not granted: this can occur if an electrolyte is present between the two tubes because of a leakage in the watertight system or in the casing. Laboratory tests have been carried out to investigate the protection (and over-protection) of the carrier pipe (from here on called “gas pipe”) and the interference condition of the casing pipe, in case of water in the annulus. Different conditions were taken into consideration in order to verify the effects of coatings on the casing pipe and eventually the effect of an electrical connection between the two tubes, which aims at avoiding anodic interference of the internal surface of the casing tube. In all conditions, CP was applied to the gas pipe and both tubes were submerged in a conductive solution. This way it was possible to analyze the level of protection (or overprotection) on the gas pipe and the conditions of anodic/cathodic interference on the casing pipe.

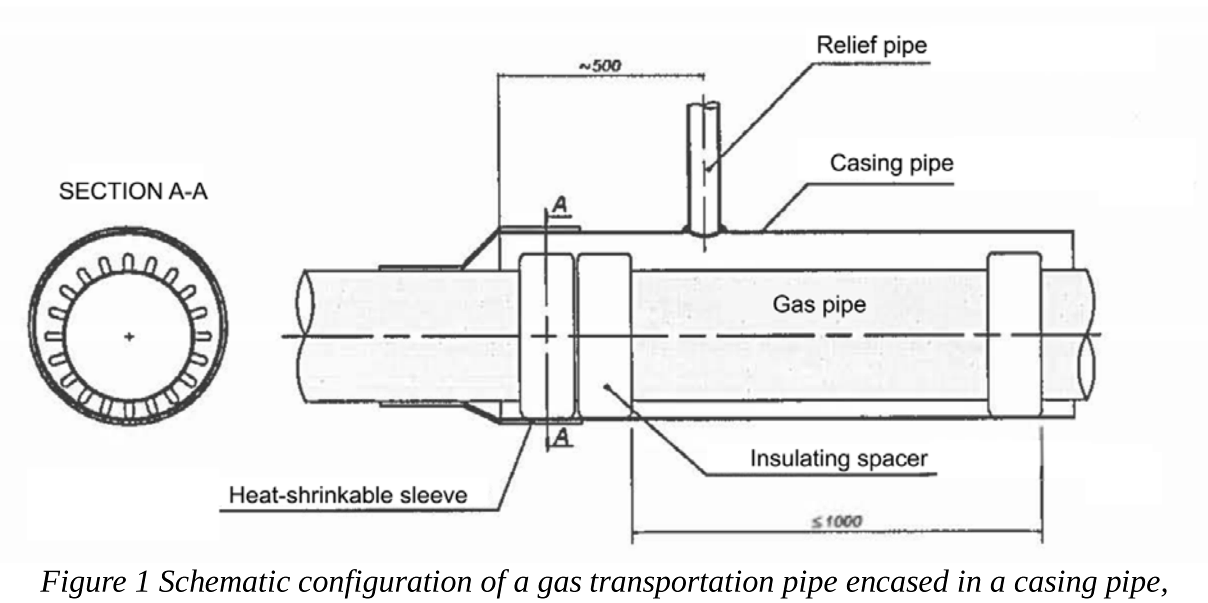

Figure 1 Schematic configuration of a gas transportation pipe encased in a casing pipe, separated by insulating spacers

Materials and Methods

Samples

Laboratory tests were carried out on carbon steel tube type L360 (according to EN 10208 [5]), chemically equivalent to type API 5L X52 steel pipes, according to API 5L [6]:

- gas pipe 25 cm in diameter, thickness 7 mm, coated on the external surface in polyethylene except for a 3 cm^2 artificial defect
- casing pipe 20 cm in diameter, thickness 7.5 mm, either coated (on both internal and external surface) or uncoated

Both pipes were fixed on a PVC plate by silicon. The gas pipe maintains the same characteristics throughout all the tests, while the casing pipe changes configuration according to the analysed cases.

Cell configuration

The cylinders were immersed in a 70 x 30 x 40 cm box in a conductive solution, such as to fill the gap between gas and casing pipe up to a 15 cm height. The external surface of the casing pipe was dipped by 15 cm as well. Two electrolytes were taken into consideration, both consisting in a solution of NaCl in distilled water, having resistivity 50 Ω m and one 200 Ω m, respectively. Three Ag/AgCl/$KCl_{sat.}$ reference electrodes (+0.2 V SHE) were accurately positioned to measure the IR-free potential of the gas tube and of both the internal and the external side of the casing pipe (Figure 2). As shown in Figure 2, Reference Electrode 1 was placed close to the defect of the gas pipe, Reference Electrode 2 was placed close to the external side of the casing pipe (close to the defect, if present) and Reference Electrode 3 was positioned close to the internal side of the same (close to the defect, if present).

The free corrosion potential was measured 15 minutes after immersion. Then, the gas pipe was connected to an impressed current cathodic protection system by a DC power supply, using an activated titanium (Ti-MMo) mesh as an anode.

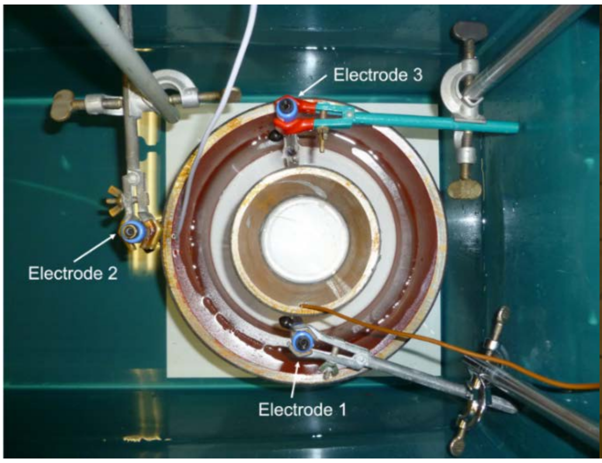

Figure 2: IR-free potential monitoring system

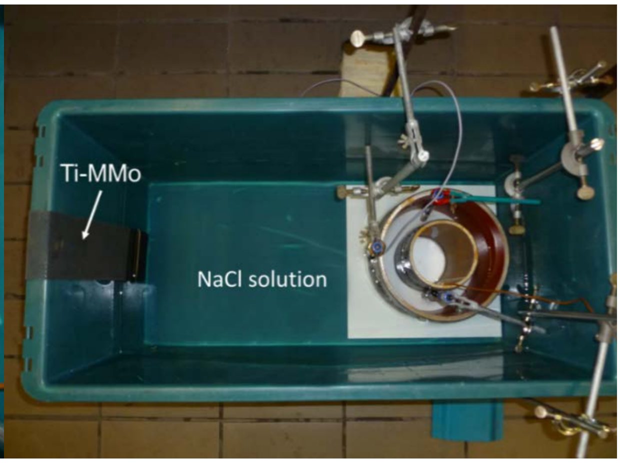

Figure 3: Cathodic protection and monitoring systems

Test conditions

Four experimental conditions were tested, changing the casing pipe:

A. Uncoated casing pipe, both on internal and external surfaces (Figure 4),
B. Uncoated casing pipe (as case A), having a through hole (diameter 1 cm) facing the coating defect of the gas pipe (Figure 5),
C. Internally and externally coated casing pipe, with a 3 cm^2 defect on both sides (Figure 6); the coating defect on the internal side of the casing faces the coating defect on the gas pipe,
D. Uncoated casing pipe electrically connected to the gas pipe by a 10 Ω shunt (Figure 4).

In all tested conditions, the gas pipe was coated on the external surface, except for a 3 cm^2 artificial defect.

Table 1 summarises the tests condition.

Figure 4: Conditions A and D

Figure 5: Condition B

Figure 6: Condition C

Table 1 Summary of the test conditions

Gas Pipe	Test	Casing Pipe		
Coated on external side, with a 3 cm^2 coating defect	**A**	Without hole	Uncoated	Not connected to the gas tube
	B	Through hole (∅ = 1 cm)		
	C	Without hole	Coated on both sides with 3 cm^2 coating defects	
	D		Uncoated	Connected to gas tube by a 10 Ω shunt

<u>Monitoring</u>

Cathodic protection was applied to the gas pipe by increasing the cell voltage by 0.5 V every 5 minutes until overprotection conditions of the gas pipe were reached (i.e. IR-free potential more negative than -1.2 V CSE, according to ISO 15589-1 [4]). For each applied cell voltage, the circulating current and IR-free potential were measured by an ammeter in series and by the reference electrodes placed according to Figure 2, respectively. After detecting the value of potential that causes overprotection, a record of the potential profile in time was performed to understand the behavior of the pipes before and after the application of such potential.

Results and Discussion

For the sake of simplicity, only the tests performed in the electrolyte 50 Ω m resistivity are discussed in the following section. The same considerations can be done for all tests carried out in the solution with resistivity 200 Ω m. In all cases, the represented diagrams show the potential profile recorded for 20 seconds, sampling 10 points per second. These are useful to understand the behavior of the two pipes when cathodic protection is applied.

<u>Cell balance</u>

The energetic cell balance of the impressed current cathodic protection system is [7-8]:

$$V = V_{min} + I \cdot R_1 + \psi_{c,casing} + I \cdot R_m + \psi_{a,casing} + I \cdot R_2 \quad (1)$$

Where:

- V is the applied voltage between anode and cathode
- V_{min} is the minimum voltage that must be applied to have circulation of current in an impressed current CP system
- IR_1 is the ohmic drop in the electrolyte between the anode and the external side of the casing
- $\psi_{c,casing}$ is the cathodic overvoltage on the external side of the casing pipe, related to oxygen reduction and eventually to hydrogen evolution
- IR_m is the ohmic drop through the thickness of the casing pipe (this is negligible because of the high conductivity of the metal)

- $\psi_{a,casing}$ is the anodic overvoltage on the internal side of the casing pipe, related to metal dissolution reactions
- IR_2 is the ohmic drop in the electrolyte between the internal side of the casing pipe and the external side of the gas pipe.

Figure 7 shows the cell balance.

It is possible to state that, in presence of an electrolyte between gas pipe and casing pipe, the application of a voltage higher than a minimum value, V_{min}, causes cathodic interference on the external side of the casing pipe, anodic interference on the internal side of the casing pipe and cathodic polarization on the external side of the gas pipe.

The absence of an electrolyte in the annulus will not allow the current to flow, therefore none of the above-mentioned phenomena would occur. In practical cases, if no electrolyte is present in the annulus, the external surface of the casing suffers from corrosion caused by soil aggressiveness, while the external side of the gas pipe undergoes atmospheric corrosion.

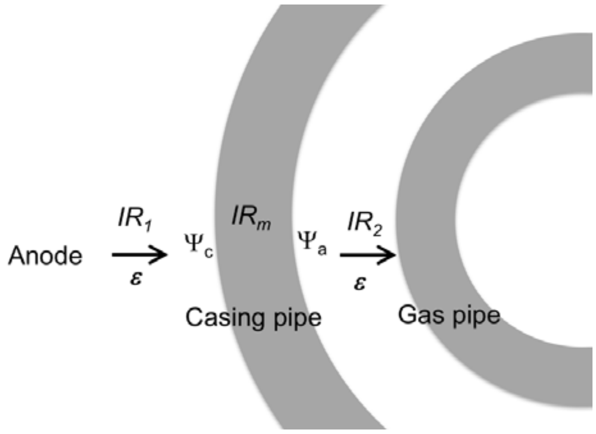

Figure 7: Contributions of ohmic drop and overvoltages to the cell voltage

Case A (Uncoated casing pipe, without hole)

In this case, overprotection conditions were reached at voltage of 2.5 V. Figure 8 shows the behavior of the three measured potentials when such a voltage is applied. For the sake of simplicity, IR-free potential measurements are referred to CSE ($Cu/CuSO_4$, +0.318 V SHE) reference electrode.

At first, both gas and casing pipe are in free corrosion conditions at a potential of -0.65 V CSE. Then, when CP is turned on, the gas pipe is cathodically polarized, reaching overprotection conditions, i.e. potential lower than -1.2 V CSE (dashed line on the diagram). The current supplied by the anode interferes cathodically with the external side of the casing pipe; therefore, the potential measured on this surface also slightly diminishes. This happens because the current density on the casing pipe is much lower than on the gas pipe, since its surface area is approximately 350 times bigger than the 3 cm^2 defect on the gas pipe. On the internal side of the casing pipe, on the other hand, anodic interference is observed: a consequence of this is the increase of corrosion rate, according to Tafel's law.

Case B (Uncoated casing pipe, with through hole)

Overprotection condition of the gas pipe was reached at a voltage of 2.5 V. The behavior of the casing pipe is slightly different from the previous case: as shown in Figure 9, the variation in potential observed on the casing pipe is smaller than for case A. This can be explained by the fact that the current can flow in two different parallel paths: across the metallic pipe and through the hole. Results show that part of the current causes interference on the casing pipe (cathodic on the external side, anodic on the internal side), while part of it finds a preferential path through the hole. The percentage of current interfering with the pipe depends on the relative position of the through hole and the defect on the gas pipe: if they face each other, as in this case, more current passes through the hole and the interference effects are limited. It should also be considered that in case B, just like in case A, the casing pipe is uncoated, therefore the current density is low and this furtherly justifies the limited effects of interference.

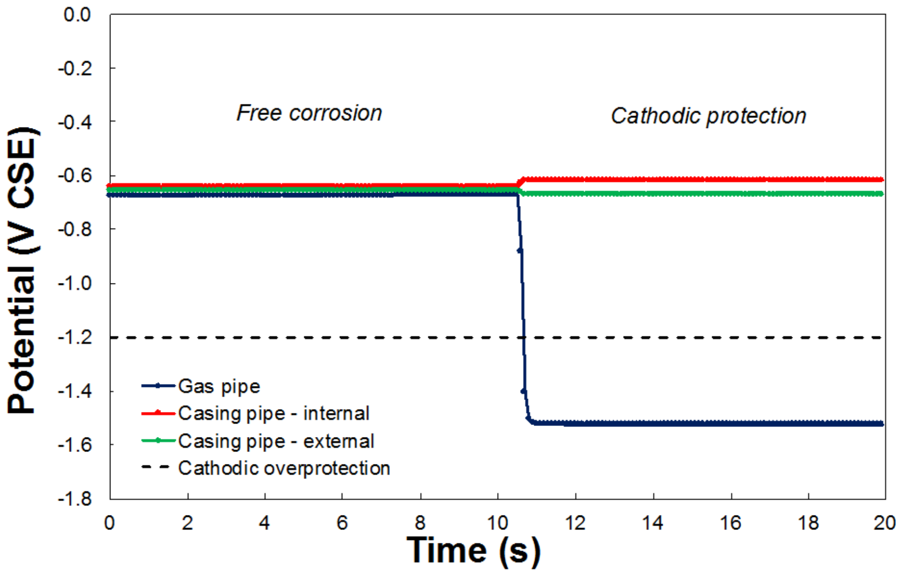

Figure 8 IR-free potential of gas and casing pipe before and after the application of a 2.5 V cell voltage (case A)

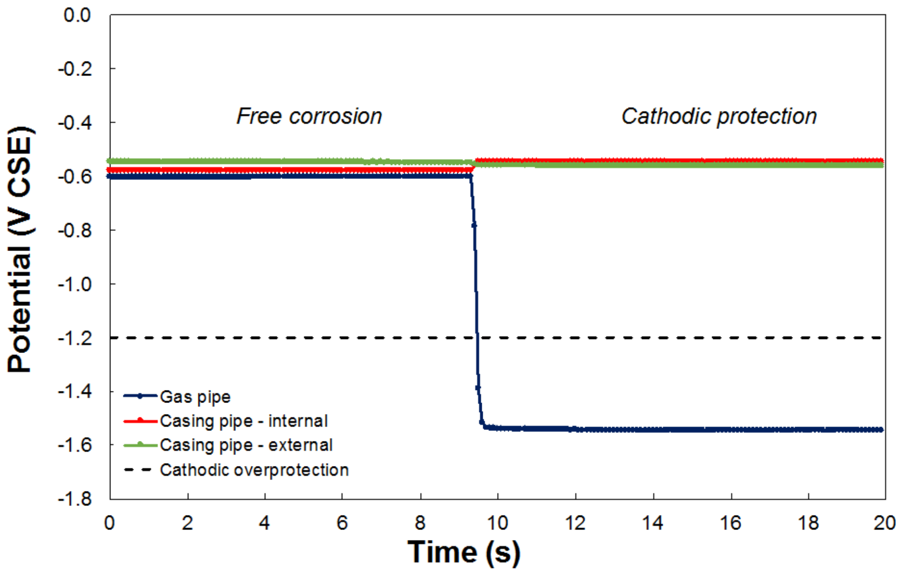

Figure 9 IR-free potential of gas and casing pipe before and after the application of a 2.5 V cell voltage (case B)

Case C (Coated casing pipe with coating defect)

The presence of a coating with a defect on the casing tube leads to a smaller current flow in the cell: the smaller the defect (i.e. the higher the current density), the higher the overvoltage $\psi_{c,casing}$ and $\psi_{a,casing}$, which means that the reactions on the casing pipe dissipate a bigger part of the voltage supplied. Since less current flows, the overprotection conditions are reached at higher cell voltage (3.5 V). In this case, the current density on the casing pipe is much higher because the current interferes on a smaller area (3 cm^2). Moreover, since the dimension (i.e. the current density) of the coating defects of the casing and gas pipes is the same, on the external side of the casing we have cathodic polarization at approximately the same potential as the gas pipe, while on the internal side we observe anodic polarization (Figure 10).

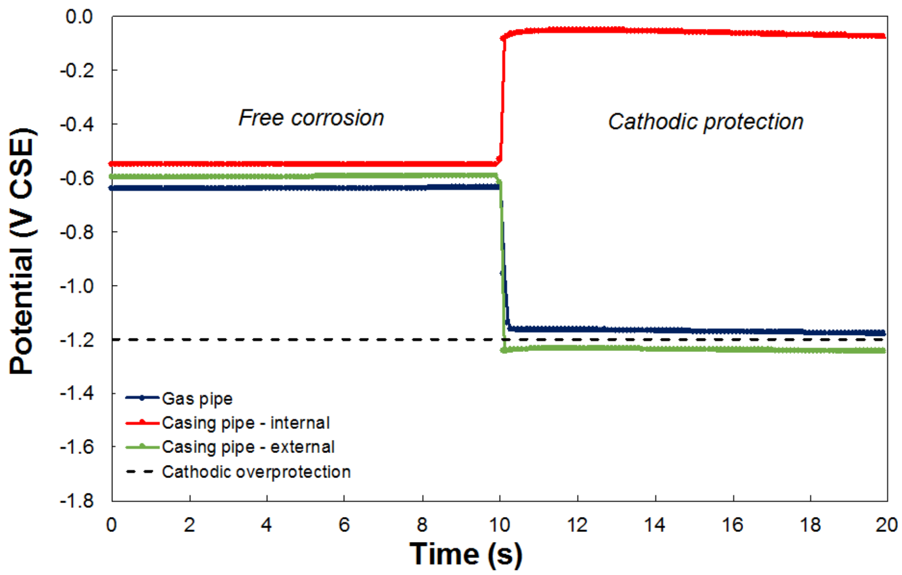

Figure 10 IR-free potential of gas and casing pipe before and after the application of a 3.5 V cell voltage (case C)

Case D (Uncoated casing pipe, connected to gas pipe by a shunt)

This time the casing pipe is uncoated and connected to the gas pipe by a 10 Ω shunt. A scheme of the circuit is represented in Figure 11. The total current supplied by the anode is indicated as I_{TOT}. In correspondence of the casing pipe, the current finds a parallel circuit: part of the current (I_{gas}) interferes on the casing pipe and, though the electrolyte in the annulus re-enters the generator. Another part of the current (I_{prot}) can follow the parallel path and re-enter the generator through the 10 Ω shunt: this current causes the cathodic polarization of the external side of the casing pipe, but does not interfere anodically on the internal side. The sole responsible for the cathodic polarization of the gas pipe, instead, is I_{gas}.

By measuring the circulating current vs. applied voltage, it was observed that $I_{TOT} \cong I_{prot}$: this means that it is easier for the current to flow through the 10 Ω shunt than through the electrolyte. It is important to note that the total current flowing in test D is much higher than in test A: at an equal applied voltage, the measured current is higher because of the addition of the parallel resistance path through the 10 Ω shunt reduces the total circuit resistance. Figure 12 shows the potential of the gas and casing pipes after the application of a 10 V potential. The gas pipe is only slightly polarized thanks to the flow of I_{gas}, but it never reaches overprotection conditions, even at 50 V. On the other hand, the major percentage of current (I_{prot}) flows through the external side of the casing pipe, which reaches overprotection conditions. The internal side of the casing pipe instead, as previously stated, is not interfered, as both I_{gas} and the current density are very small.

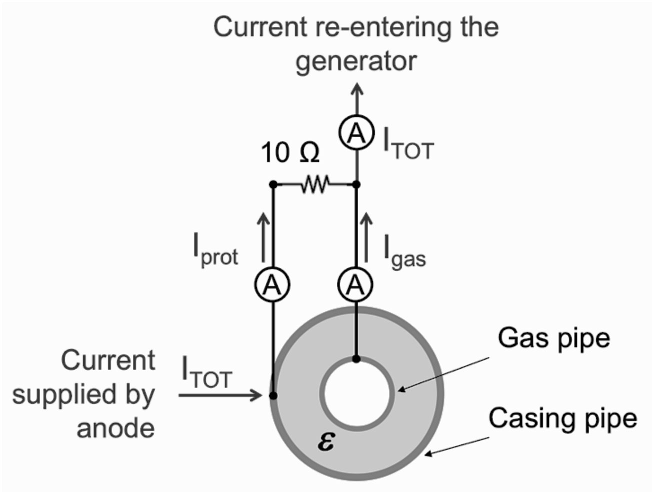

Figure 11 Electrical circuit in case D

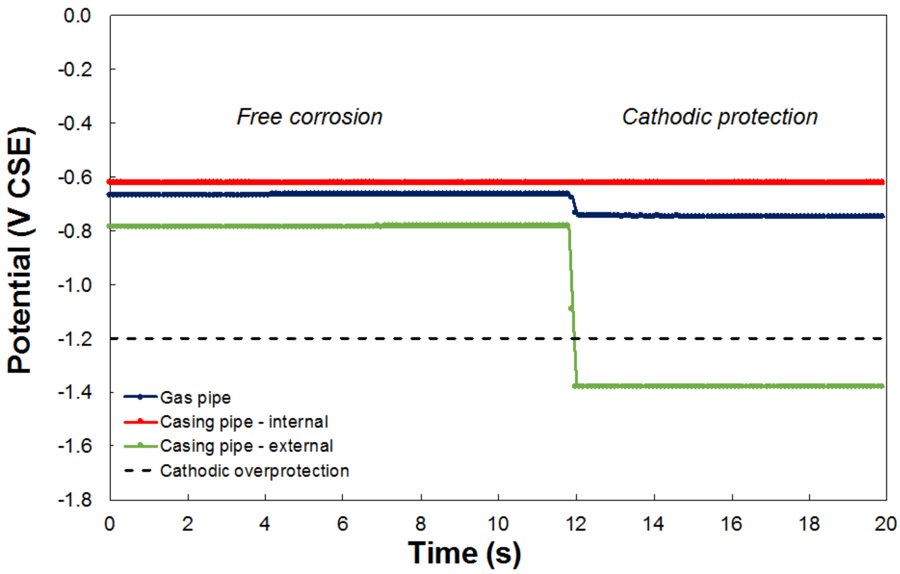

Figure 12 IR-free potential of gas and casing pipe before and after the application of a 10 V cell voltage (case D)

Conclusions

Laboratory tests have been carried out to investigate the protection (and overprotection) of a gas transportation pipe encased in a casing pipe, in case of presence of an electrolyte in the annulus. Different conditions were considered, by varying some casing pipe features.

In the ideal case, the watertight seal allows the insulation of the annulus from any external electrolyte, therefore no interference phenomena occur on the casing. The gas pipe is subjected to atmospheric corrosion, while the external side of the casing pipe withstands corrosion due to soil aggressiveness.

In case of leakage in the watertight system, interference phenomena on the interior of the casing can occur. The impressed current supplied by the c.p. system causes anodic interference and cathodic polarization on the internal and external side of the casing, respectively, and cathodic polarization on the gas pipe.

The worst case for the casing pipe is represented by the presence of a coating with defects: the anodic interference reaches high values and causes corrosion due to the high current density at the coating defect. The worst case for the gas pipe, instead, is the one with the uncoated casing pipe with a through hole: here the current flow is high and it causes overprotection of the pipe even at low voltages.

In tests where the casing pipe was connected to the gas pipe by a shunt, the current flow was split in two parts, one flowing through the electrolyte and one flowing through the shunt. This second contribution is almost equal to the total amount of current flowing, which means that the gas pipe does not reach overprotection conditions, even at high applied voltages.

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