IBP 1026_06

CATHODIC DISBONDMENT IN HIGH PERFORMANCE COATINGS: EXPERIMENTAL AND NUMERICAL RESULTS

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Abstract
Segments of aged cathodic protected buried pipelines can be damaged as a consequence of soil movement, third-party-damage and corrosion processes. Therefore, high performance coatings have been applied when some replacement is necessary. Attention has to be taken to cathodic disbondment of these new coatings due to overprotection, especially in regions where the bed of anodes are located. If there is any failure in the replaced pipe section, exposing the metal substrate, it is believed that the current density in that region can be very high leading to serious damage in the coating. The aim of this investigation is to determine experimentally the behaviour of four different coatings, regarding cathodic disbondment. The cathodic protection system is assessed involving new and aged coatings. They are used as boundary condition to determine the potential distribution along the pipeline by means of numerical simulation. This assessment also aims determine the level of protection in the new segment of pipe and in the interface of aged and new coatings. It will be consider parameters such as physical-chemistry and corrosivity of soil.

1. Introduction

During the lifetime of pipelines, corrosive processes are likely to occur. These processes are due to natural aging of coating allied to damage resulting from transportation, installation and even during operation. As a consequence, the replacement of pipeline segments is necessary. These are coated, in plant, with high performance coatings, such as Fusion Bonded Epoxy (FBE) and Polyethylene Adhesive Tape (PE3L).

The pipeline replacement has to be accessed in relation to the cathodic protection applied in the pipeline network. It is especially relevant because the cathodic protection system is projected to attend the tubes with aged coatings, such as coaltar enamel, bituminous coatings, etc, most common in Brazil. Therefore, the current required to protect the old pipelines can easily overprotect the new segments. The potentials in this region can reach very negative values.

Attention has to be given to cathodic disbondment of new coatings as a consequence of overprotection, especially in regions close to where the anodes are located. If there is any failure in the replaced pipe, exposing the metal substrate, it is believed that the current density in that region can be very high leading to serious damage in the coating. In this case, a progressive disbondment of coating from the metal substrate is expected. The literature has reported this process in buried pipelines coated with high performance coatings [1-3], corroborating with this research.

The high current density is not necessarily the only factor responsible for the cathodic disbondment. The association with other parameters can magnify this effect and has to be taken in account. It is widely accepted that the loss of adhesion of the coatings is related to the formation of a high alkaline environment in the metal/coating interface. However, there is not a final agreement about the mechanisms involved in the disbondment. Some parameters can influence the process, such as soil resistivity, wet/dry cycles of soil, treatment of metal surface, etc [4,5].

The aim of this investigation is to determine by computer simulation the most probable potential of the new segments of pipe and test in lab the behaviour of the coating regarding cathodic disbondment. However some real

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systems have been numerically simulated [6,7], this kind of cathodic protection problem has not been reported in literature.

2. Experimental procedure

In order to understand the role of cathodic protection systems in real buried pipelines with aged and high performance coatings, a joint research was carried out using tools as computer simulation of the actual system and investigation of soil characteristics in the laboratory. Parameters such as curves and resistivity values of soil samples, taken from regions nearby the segment of the replaced pipe (high performance coating), were experimentally obtained.

The aim of the investigation is to determine, by computer simulation, the most probable potential developed over the new segments of pipe and test in lab the behaviour of the coating regarding cathodic disbondment. Here, the methodology employed in this research and some cathodic disbondment tests are presented.

2.1. Laboratory methodology

In order to improve the numerical simulation and to define parameters to study cathodic disbondment, a research on the soil sample was done. The first step was to analyse the physical-chemistry properties of soil samples, taken from the region of the new segments. Then, the resistivity values of the soil samples, as a function of the humidity content, were determined. After that, the behaviour of the metal (bare pipe) in soil as a function of the water content was obtained. These results defined the resistivity and the polarisation curves adopted for numerical simulation, which in turn will provide the proper potential used in cathodic disbondment tests. The coatings used in tests are representative of field conditions.

2.2. Real Pipelines Simulations

As a means to evaluate the presence of pipe sections with high performance coatings in old buried pipelines, numerical simulations have been carried out using software based on the Boundary Element Method [8]. Two real pipelines were simulated, here represented as PIPELINE A and B. The pipelines are protected by impressed current anodes and there are three sections with new coatings (99.9% of efficiency) in each pipeline. Cylindrical quadrangular elements were used to model the pipelines.

The following boundary conditions have been considered for the numerical simulations: anodes as impressed current point sources and cathodic polarisation curves, experimentally obtained for different humidity contents: 35% and 15%.

Figure 1 and 2 show PILELINE A and B, as schematically represented for numerical simulation. The positioning and the distance between the real anode beds and the pipeline are described in the figures. The total current was supplied in order to keep the potential over the whole pipe in, at least, -0.85VCu/CuSO4.

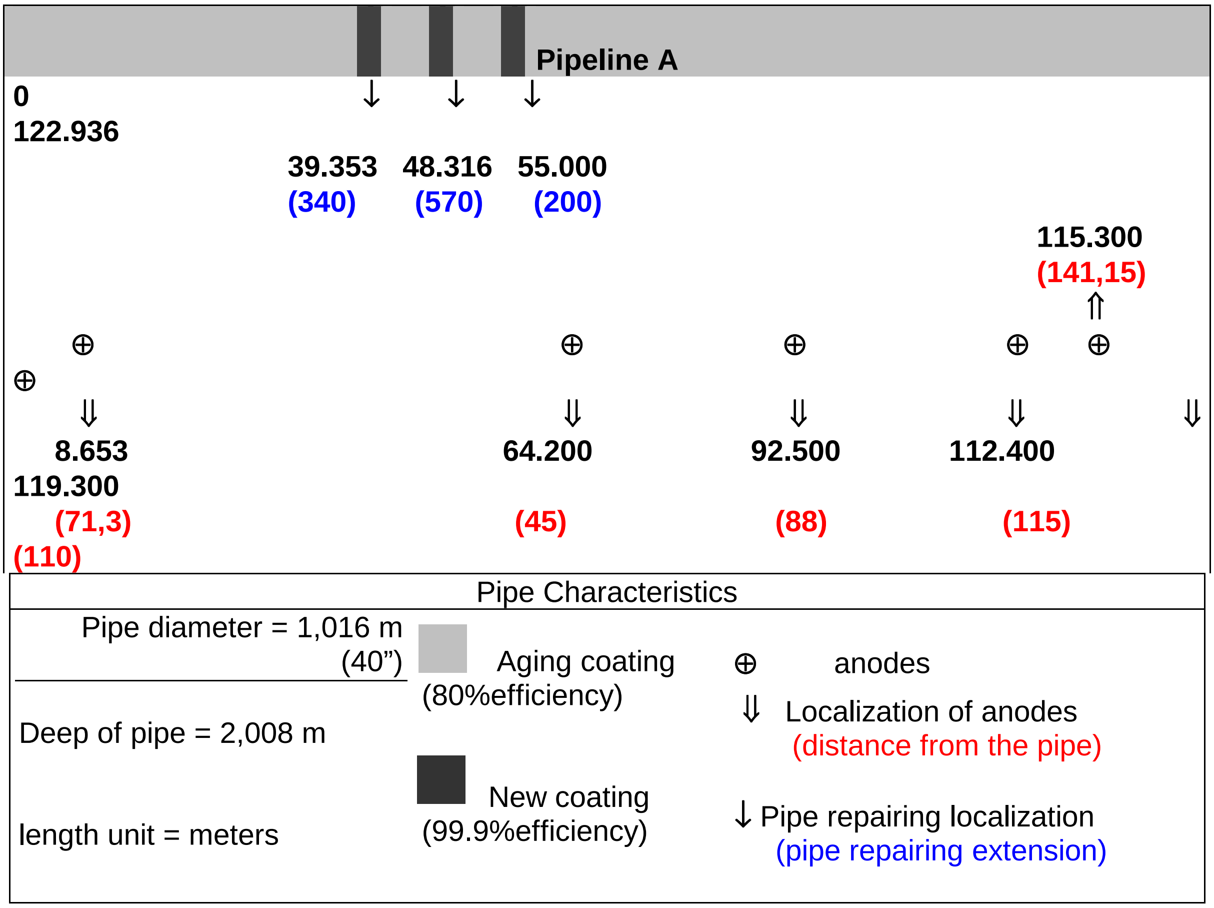


Figure 1 – Schematic representation of PIPELINE A

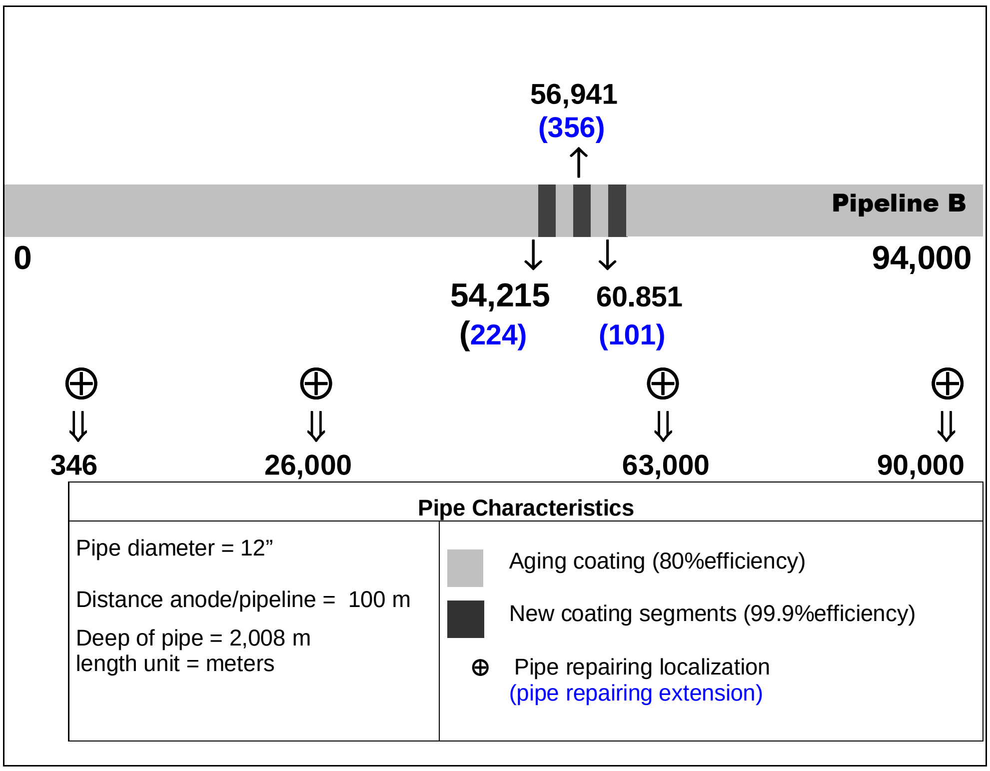


Figure 2 – Schematic representation of PIPELINE B

3. Results and discussions

3.1. Experimental results

3.1.1. Soil analysis

The soil samples taken from the region of the new segment of pipe were analysed. Table I and II show these characterisation for PIPELINES A and B. It can be observed that the soil resistivity alters from one sample to another. Therefore the variation of resistivity as a function of humidity content was determined. The methodology used is described elsewhere [9] and consists of drying out the soil and to add the percentage, in weight, of water progressively. Figure 3 and 4 present the behaviour of the samples in relation of humidity.

It can be observed in these figures that the resistivity does not vary after certain humidity content values.

Table I: Characterisation of soil samples as received – PIPELINE A

SOIL	SAMPLES – AS RECEIVED		
	Kilometer 39	**Kilometer 48**	**Kilometer 55**
Humidity Content (%)	27,81	28,78	29,34
Resistivity (Ω.cm)	87000	4950	31500
pH	6,40	7,16	5,71

Table II: Characterisation of soil samples as received – PIPELINE B

SOIL	SAMPLES – AS RECEIVED		
	Kilometer 54	**Kilometer 57**	**Kilometer 60**
Humidity Content (%)	35,35	48,06	32.99
Resistivity (Ω.cm)	24000	8000	33000
pH	6,69	6,17	8,51

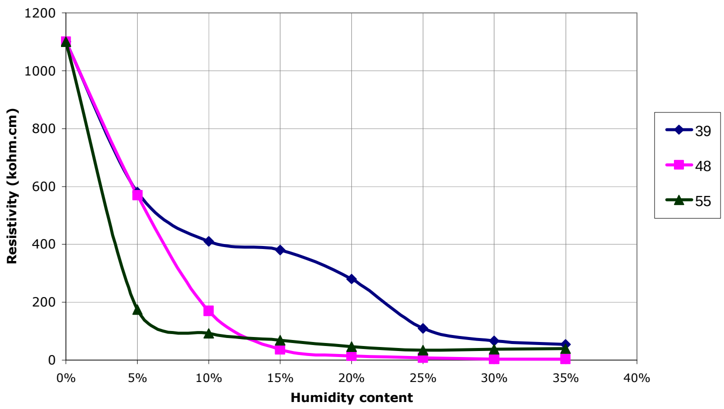


Figure 3 – Resistivity x Humidity content - PIPELINE A

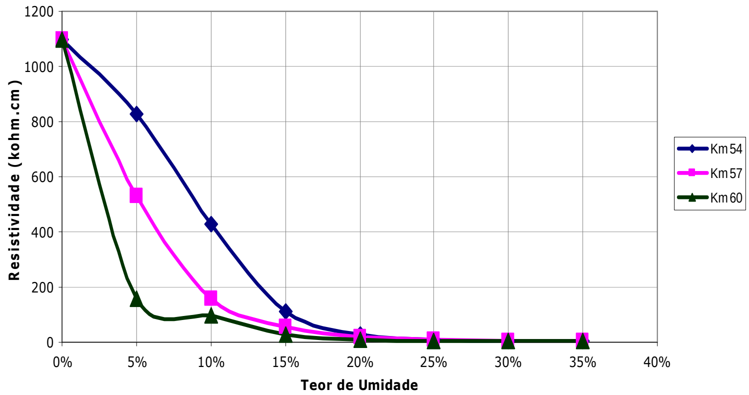


Figure 4 - Resistivity x Humidity content - PIPELINE B

3.1.2 Polarization curves

Polarization curves were obtained to be used in the numerical simulation and also had the objective to define the electrochemical conditions of the pipe in the soil. The methodology employed was a three electrodes cell, where the working electrode was a steel sample, a saturated calomelan electrode (SCE) as a reference and a graphite rod as an auxiliary electrode. The soil with various humidity contents was the electrolyte. The curves are shown in Figures 5.

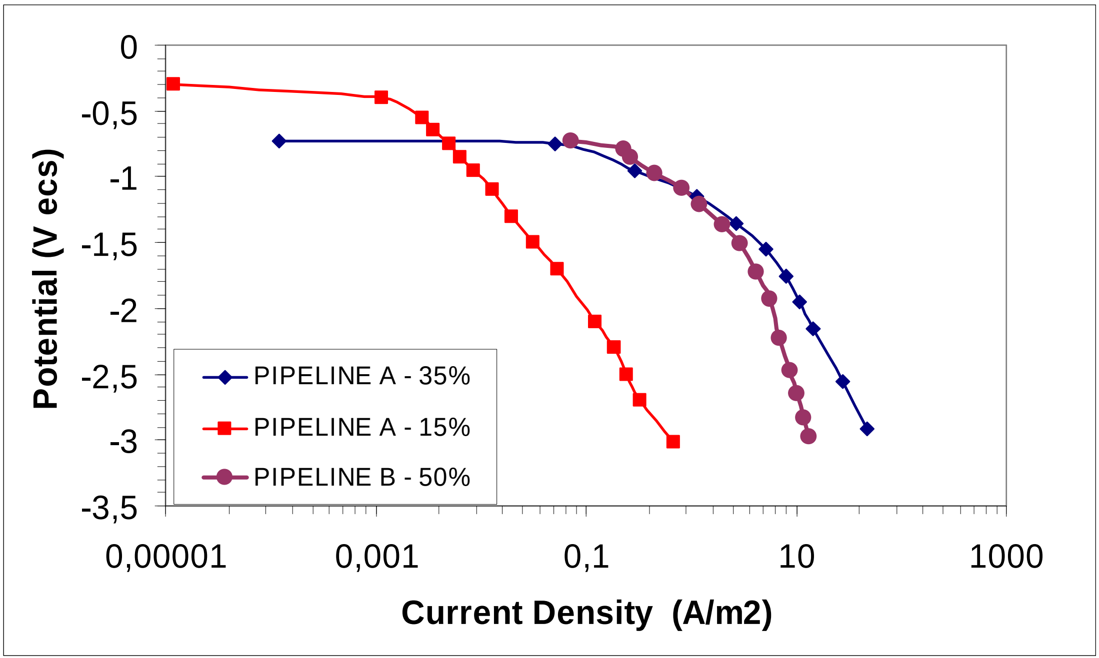


Figure 5 – Cathodic polarisation considered as boundary conditions

3.2. Numerical results

3.2.1. Pipelines potential distribution

Considering the boundary conditions mentioned above, Figures 6 and 7 present the potential distribution on PIPELINE A, for two humidity conditions. The real distances between anodes and pipeline are indicated in Figure 1.

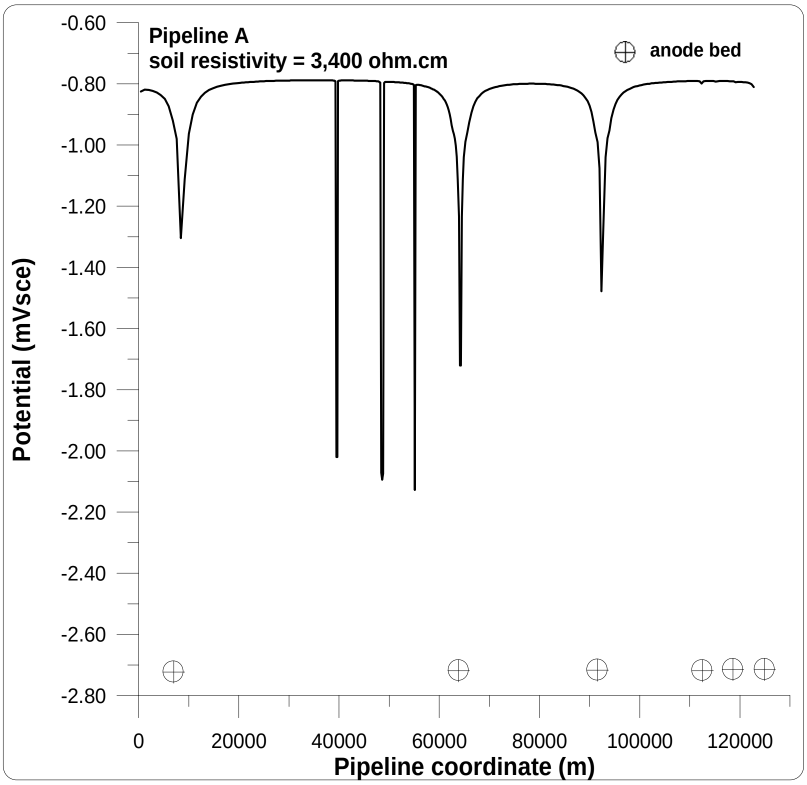


Figure 6 – PIPELINE A. Numerical simulation considering 35% humidity content cathodic polarization curve (resistivity = 3,400 ohm.cm)

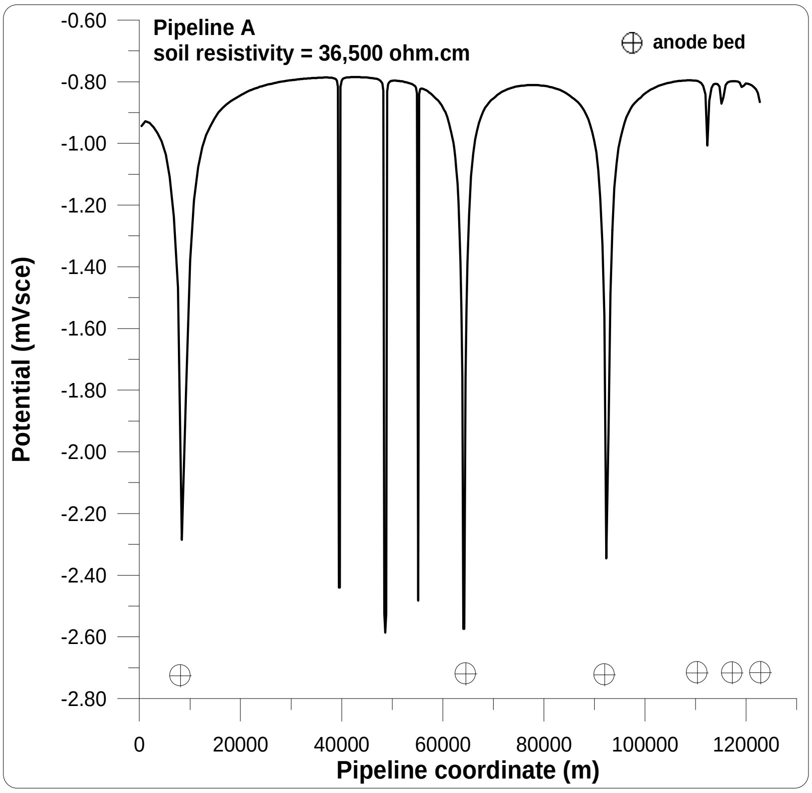


Figure 7 – PIPELINE A. Numerical simulation considering 15% humidity content cathodic polarization curve (resistivity = 36,500 ohm.cm)

In these simulations the influence of the distance between anode beds and pipeline is noticed. It is also observed the great influence of the new coating segments, where the potential reach cathodic values. This situation is even more pronounced in higher resistivity soil (Figure 7).

Figure 8 presents the potential distribution in PIPELINE B, for high humidity soil (50%). The anode beds are located at same distances from the pipeline (100m). As observed for PIPELINE A, the anodes influence the potential distribution in regions nearby and the presence of new coating segments generate higher cathodic potentials, reaching values of about -3.4Vsce.

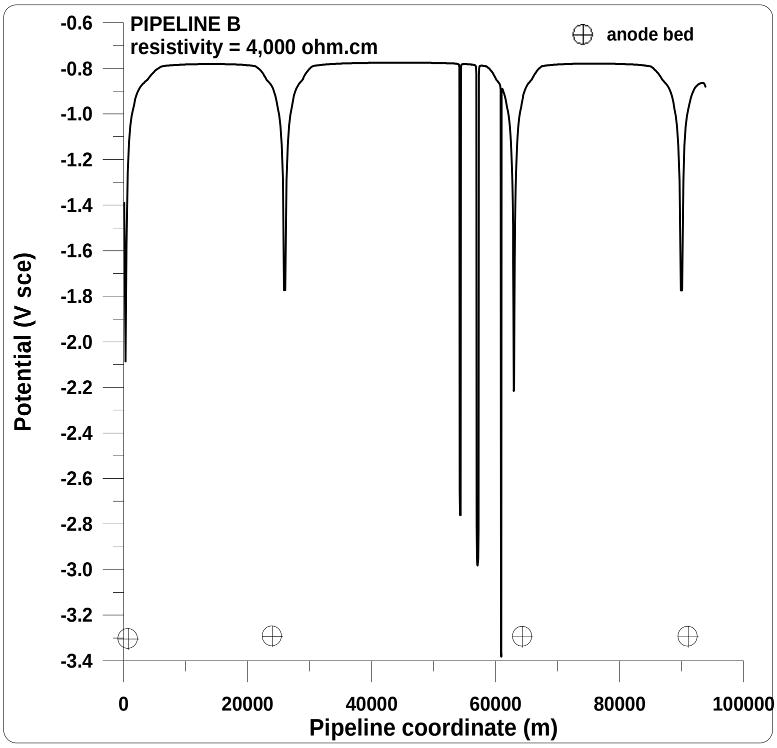


Figure 8 – PIPELINE B. Numerical simulation considering 50% humidity content cathodic polarization curve (resistivity = 4,000 ohm.cm).

In order to define the influence of the old pipeline coating efficiency on the potential distribution, other simulations were carried out, considering 70% and 90%. For the new segments, 99.9% of coating efficiency was admitted. In the Figure 9, the region of the pipeline with new segments was magnified in order to make easier to observe the influence of this parameter. The increase in the efficiency of the coating promotes more cathodic potential values in the whole pipe (new and aged coatings). The current was applied in order to maintain the whole pipeline cathodically protected.

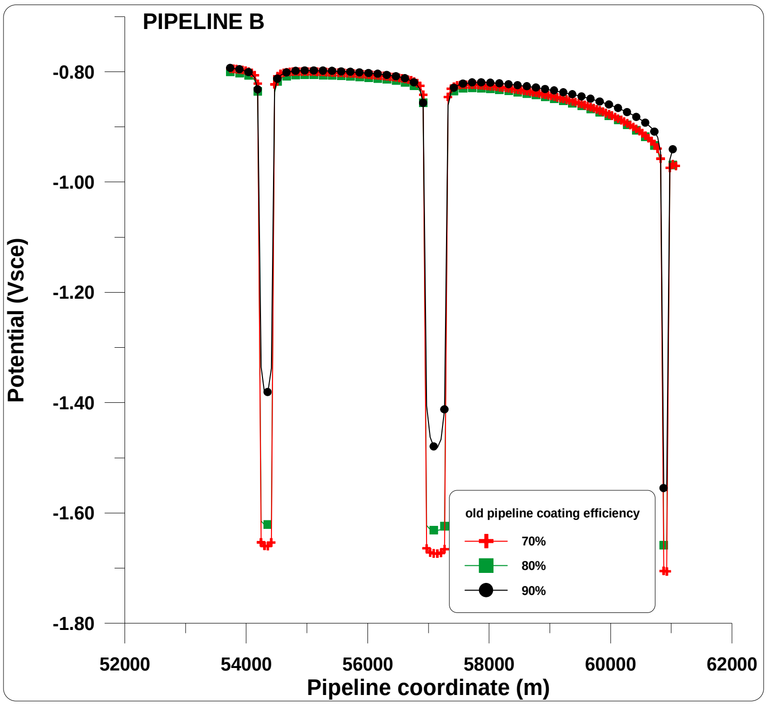


Figure 9 – PIPELINE B. Influence of the old pipeline coating efficiency (resistivity = 4,000 ohm.cm).

3.3. Disbondment Tests

The cathodic disbondment tests were carried out in 4 different coatings: Fusion Bonded Epoxy (FBE), Polyethylene Three Layer (PE3L), Liquid Epoxy and Heat Shrink Sleeve. FBE and PE3L are used as high performance coatings, while the Epoxy Liquid is applied for field repair and Wrap-around heat-shrinkable (WHS) is used as a weld joint coating.

The tests were set up employing real soil taken from PIPELINE A and B as electrolyte. The potential applied was obtained from numerical simulation and was in the range of -3V vs. SCE. The experiments ran for 28 days and used Canadian Standard Z245.20-02 and 21-02 as a base for the experiments. The schematic set up of the cathodic disbondment testes are shown in Figure 10 and Figure 11 presents the experimental tests using the 4 different experiments.

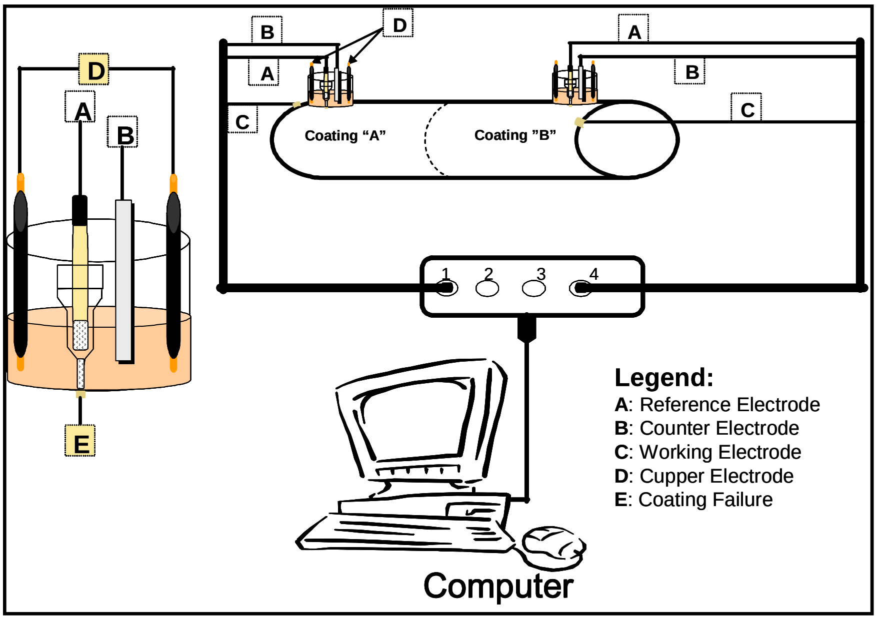


Figure 10: Schematic set up of the cathodic disbondment tests

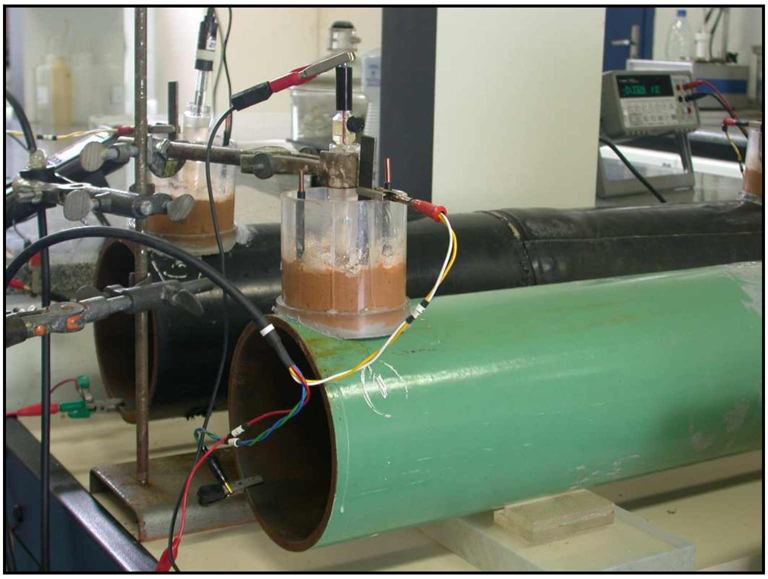


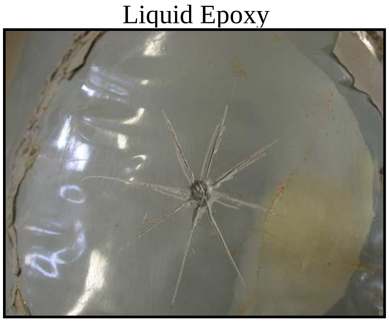
Figure 11 – Experimental set up for the cathodic disbondment test using 4 different coatings

Figure 11 presents qualitative results found for the cathodic disbondment in the analysed condition. It can be observed that there are differences between the 4 coatings. The FBE and PE3L presented a certain degree of disbondment. HSJ showed a completed failure after the tests while the Liquid Epoxy did not evidence any delamination.

FBE

PE3L

Liquid Epoxy



WHS

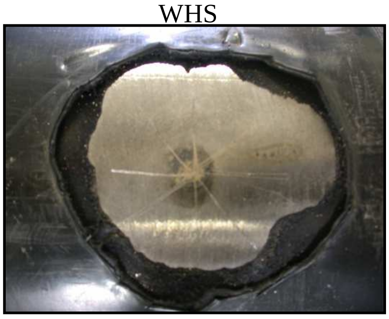


Figure 11 – Experimental set up for the cathodic disbondment test using 4 different coatings

4. Conclusions

There are two causes for the developed potential peaks over the pipeline: the proximity of the anode bed and the difference between coating efficiency values.

The negative potential peak in the new pipe segment has been found to be a direct function of the difference between new and aged coating. It was observed that this behaviour become more pronounced as the original coating deteriorates.

The HSJ showed the worse performance for cathodic disbondment test in the analysed conditions. On the other hand, the epoxy presented no disbondment.

5. References

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