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External Corrosion of the bottom plate of Petroleum and Derivative Storage tanks on Compacted Soils

Mauro Muniz de Castro[1], Fernando B. Mainier[2], Miguel Luiz Ribeiro Ferreira[3]

Escola de Engenharia, Universidade Federal Fluminense, Niterói, RJ, Brazil.
[1] mauromuniz@gmail.com [2] fmainier@uol.com.br; [3]miguelluiz@outlook.com

***Abstract* —Inspections carried out on petroleum and derivative storage tanks on compacted soils have shown external corrosion on the bottom plates of the tanks despite cathodic protection by an impressed current. The holes or cavities in the outer plates of the bottom of the tank (in contact with the soil) result in oil leakage, thereby having significant environmental impacts. The objective of this paper is to show, in laboratory experiments, that cathodic protection is not reliable when there are voids or spaces between the plates and the soil. In addition, it proposes the application of a thermal spray with aluminium in the parts of the bottom plates that are in contact with the soil to protect these plates from localised corrosion. It is important to note that the welding temperature was 320°C, without affecting the aluminium coating applied by the thermal spray.**
***Keywords* — corrosion, oil storage tank, compacted soil, cathodic protection, laboratory experiment.**

I. INTRODUCTION

The petroleum storage tanks evaluated in this study are subjected to near-atmospheric pressure, which is why they are also known as “atmospheric storage tanks”, made of plate carbon steel, cylindrical, vertical and supported on compacted soils. They are built from 100 barrels (16 m³) to large tanks with approximately 550,000 barrels (87,500 m³) [1-3].

Figure 1 shows a scheme of a storage tank supported on compacted soil, with the bottom plates being protected by cathodic protection system by an impressed current (inert anode).

The most widely used technique for tank bottom protection is impressed current cathodic protection, being predicted in international standards of storage tanks, such as API RP 651: 2014 [4].

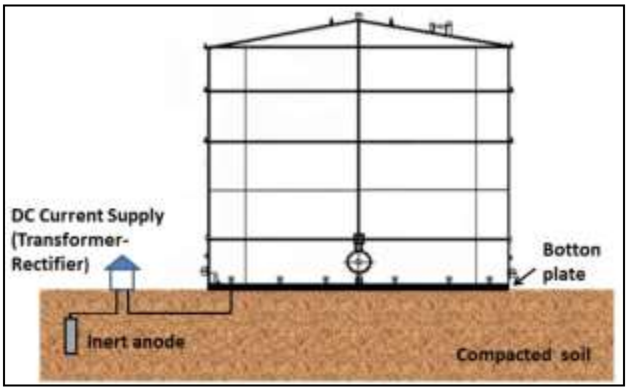

Fig. 1 - Scheme of a storage tank supported on compacted soil with the bottom plates protected by cathodic protection system

The difficult access to the area under the bottom of the tanks for the periodic measurement of the protection potentials obtained through the use of cathodic protection impedes the monitoring of its effectiveness. In order for the impressed current cathodic protection to be effective as anticorrosion protection, it is necessary that the surface is protected and the anode is in contact with a continuous electrolyte [5-7].

Corrosion in the storage tank bottom is detected through inspections carried out periodically.

Figure 2 shows the results of the loss of thickness of the bottom plate of a 40-m diameter diesel storage tank supported on compacted soil by non-destructive inspection, the so-called MFL (Magnetic Flux Leakage). This technique consists of the detection, evaluation and measurement of the magnetic flux due to the presence of discontinuities in the carbon steel plate, such as loss of thickness and corrosion holes [8, 9].

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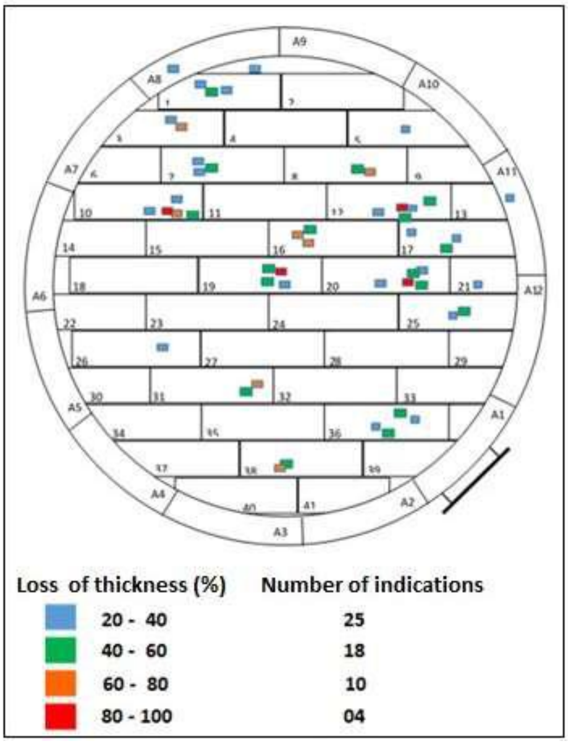

Fig. 2 - Loss of thickness (%) in carbon steel plates of the bottom of a diesel storage tank by the non-destructive inspection (method Magnetic Flux Leakage).

Figure 3 shows the circular cut made on the bottom plate, which reveals that there are voids or gaps between the plate and the soil due to the undulating behaviour of the bottom plates and any possible soil settling.

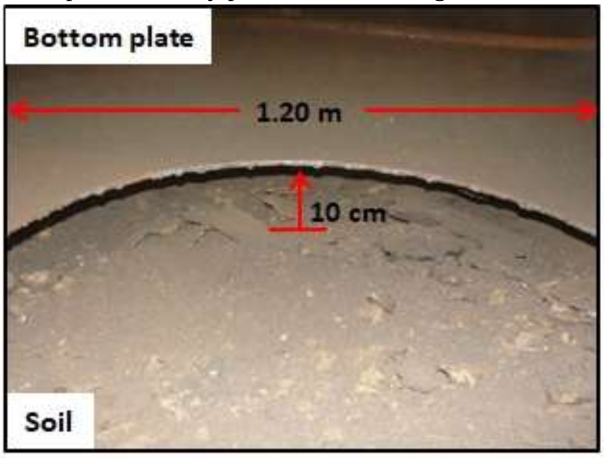

Fig.3: The void or gap between the bottom plate and the soil.

Figure 4 shows the external localised corrosion and the loss of the thickness of the cut carbon steel plate, demonstrating that cathodic protection was inefficient.

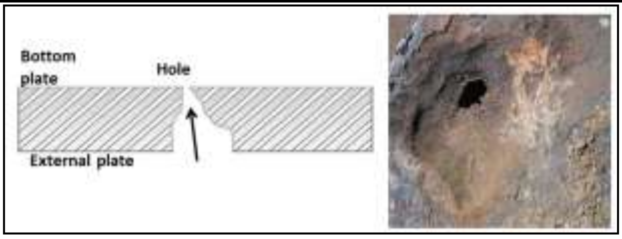

Fig. 4: External localised corrosion and loss of the thickness of the cut carbon steel plate.

This paper aims to demonstrate the inefficiency of impressed current cathodic protection when there are voids or spaces between the bottom plates and the compacted soil. It was also evaluated the application of the aluminium thermal spray on the outer faces of the bottom plates to inhibit or interrupt the localized corrosion.

II. MATERIALS AND METHODS

For practical verification of the possible reason for the ineffectiveness of the cathodic protection system by impressed currents, and to analyse the use of aluminium thermal spray as anticorrosion protection for the external face of the bottom plates of oil storage tanks, the laboratory tests described below were performed.

2.1 Evaluation of impressed current cathodic protection

This experiment consisted of the application of an impressed current on a carbon steel plate (20 x 30 cm, thickness 6.35 mm) uncoated and supported on sand moistened with 3.5% sodium chloride solution. The use of the wet sand, representing the compacted soil, had the purpose of increasing the conductivity, aiming at the development of accelerated tests. For the application of the electric current to the carbon steel plate, a DC rectifier was used and a graphite anode was inserted in the sand (Fig. 5). As seen in Figure 5, the sand was removed from underneath the steel plate to simulate a space or void without electrical conductivity to demonstrate the lack of cathodic protection in this region

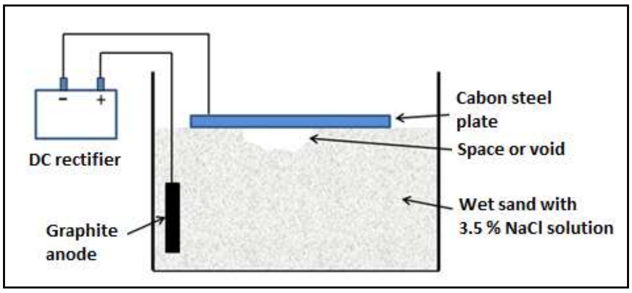

Fig.5: Evaluation of impressed current cathodic protection.

After assembly of the steel plate on the wet sand, the direct current was applied through a rectifier until a

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potential plate/electrolyte of 0.91 V was obtained, which was more negative than -0.85 V, measured with the reference electrode ($Cu/CuSO_4$) as shown in Figure 6, illustrating the experiment in progress. The duration of this experiment was 30 days. After the experimental period, the carbon steel plate was evaluated.

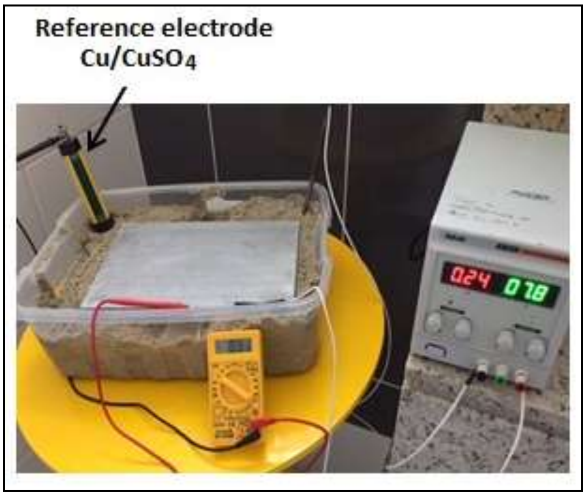

Fig. 6: Evaluation-impressed current cathodic protection

2.2 Determination of the temperature in the overlapping plate during welding

This experiment was performed in the workshop and on a small scale, consisting of the welding of the overlapping plate to represent the tank bottom in order to verify the maximum temperature reached on the outer face of the plates. Via measuring this temperature, was able to determine whether the applied aluminium anticorrosive coating could be damaged during the welding process, as shown in Figure 7.

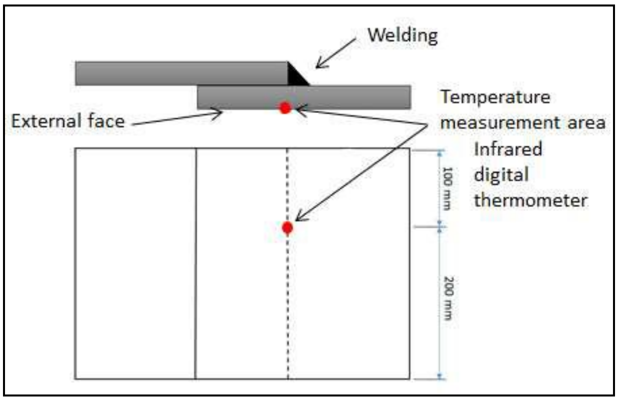

Fig. 7: Temperature measurement. Side view and bottom view of plates with overlapping joints.

Were used 6.35 mm carbon steel plates to represent the plates used at the bottom of the oil tanks. Temperature measurements were taken during the welding, using an infrared digital thermometer.

For welding, an E-7018 coated electrode was used in two passes. For the first pass, a current of 80 A and a voltage of 24 V was used; for the second passage, a current of 120 A and a voltage of 24 V was used. Welding speed was measured during the execution of the passes, with a value of 2.3 mm/s for the first pass and 2.6 mm/s for the second pass. In this way, the welding energy of the first pass was 643 J/mm, while that for the second pass was 852 J/mm, considering an efficiency of the process of 77%.

2.3 Evaluation of aluminium thermal spraying on carbon steel plates immersed in sodium chloride solution

The ASTM 283C [10] carbon steel specimens were initially prepared with abrasive blasting with aluminium oxide to achieve the Sa3 cleaning degree. Thermal sprinkling of aluminium was done via the Arc Spray Process, which consists of forming an electric arc as a heat source that can reach 4,000°C to melt and sprayed the two aluminium wires, 3.2 and 1.6 mm in diameter, with a velocity of 10 cm/min with a jet of compressed air directed to the arc area by projecting the atomized aluminium particles onto the carbon steel surface, forming a 600 µm thick aluminium coating.

A 2 cm strip was removed from the surface coated with the aluminium thermal spray to evaluate the galvanic protection exerted by the aluminium with the carbon steel plate. The other side and the sides were coated with a thick epoxy resin layer as shown in Figure 8, considering that this sample will be immersed in 3.5% sodium chloride solution. The function of the epoxy paint is to insulate the exposed surface of the carbon steel, which was not evaluated in this study.

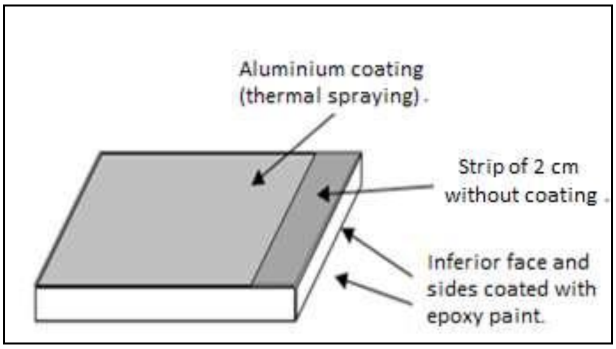

Fig.8: Aluminium-coated sample prepared for immersion in 3.5% NaCl solution.

The samples were immersed in saline solution for 3 months to accelerate the corrosive process and to provide qualitative information on the performance of aluminium-coated plates.

III. RESULTS AND DISCUSSION

As shown in Figure 9, the sample investigated after 30 days showed that the area that was not supported by the sand suffered intense generalised corrosion, while the other part was totally protected via cathodic protection by the impressed current. This suggests that the causes of

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ineffective tank bottom plates are linked to the continuity of the contact of the plate with the compacted soil. According to Gentil [11] and Mainier et al. [12], the electrical connection and the electrolyte continuity are the basic and fundamental requirements of cathodic protection. Any voids or spaces may lead to a loss of corrosion protection.

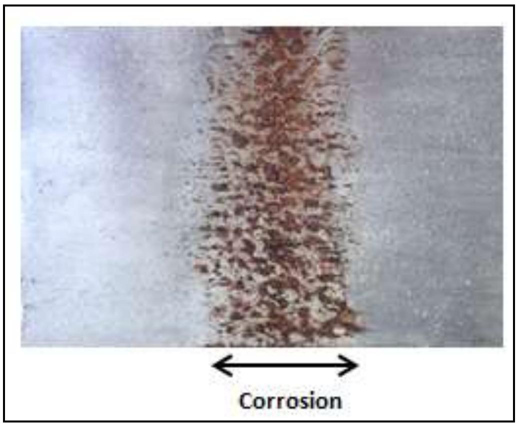

Fig. 9: Aspect of the area of the plate that was not supported in the experiment described in Figure 5.

The temperatures obtained in the welding of the carbon steel plates were 295°C in the first pass and 320°C in the second pass. This test aims to represent the welding of the bottom plates in the construction of an oil storage tank. According to the Petrobras Standard N-2568: 2011 [13], thermal spray aluminium coatings can be used at temperatures of up to 600°C, meaning that welding would not damage the anticorrosive performance of this coating.

Figure 10, below, illustrates the immersion of the aluminium-coated carbon steel plate in 3.5% NaCl solution for 3 months, showing the good performance of the galvanic protection exerted by the aluminium in relation to the 3 cm strip which was not coated and had no localised corrosion.

Figure 11 shows another plate of aluminium-coated steel, also immersed in 3.5 % NaCl solution, where phenolphthalein solution droplets were added to show the efficient cathodic protection of the aluminium as evidenced by an intense pink coloration, based on the following electrochemical reactions:

Anodic reaction: $Al^{3+} + 3e^{-} \rightarrow Al^{3+}$

Cathodic reaction: $2\ H_2O - 2\ e^{-} \rightarrow H_2 + 2\ OH^{-}$ (intense pink colour).

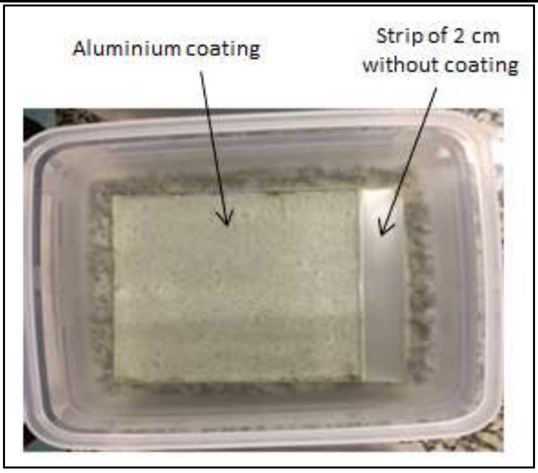

Fig. 10: Carbon steel plate coated with aluminium in 3.5% NaCl solution.

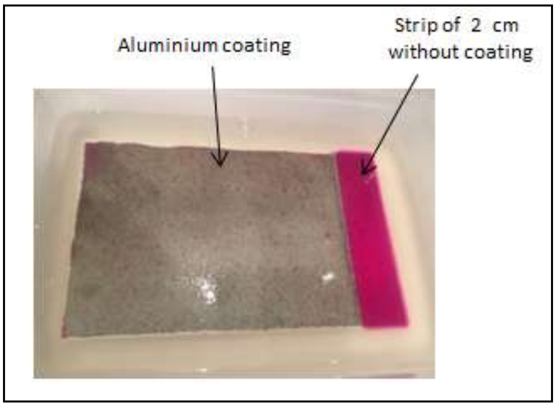

Fig.11: Carbon steel plate coated with aluminium in 3.5% NaCl solution with phenolphthalein solution droplets.

IV. CONCLUSIONS

Analysis of the cathodic protection by impressed current as anti-corrosion protection for the outer face of the bottom plates of oil storage tanks indicates that a possible reason for its inefficiency is the absence of a continuous electrolyte in contact with the entire surface of the bottom plate. Such a scenario can be generated by distortions of the bottom plates as a function of welding; causing some areas of the plates not rest directly on the compacted soil, impeding cathodic protection.

The highest welding temperature of 320°C was observed during the execution of the second pass. This allows the use of plates coated with aluminium thermal spray that are not altered by welding temperatures and at the same time are protected against corrosion.

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