Corrosion rate in pipelines due to varying currents and its dependency on the electrical resistivity of the soil.

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This paper was prepared for presentation at the 8th International Congress of The Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 14-18 September 2003.

Abstract

Laboratory tests were carried out to study corrosion rates in pipes embedded in environments with lateral electrical discontinuities, due to the effect of induction currents.

Scale models were designed to simulate pipes buried in soils with 2D electrical discontinuities, and corrosion process conditions due to different external sources were compared. The buried pipes were electrically isolated using a polyurethane cover and sacrificial anodes were connected to the pipe; then, corrosion rates were estimated by measuring the mass loss in each anode. The results indicated an increase in the corrosion rate when the pipe was under the effect of induction currents, being also noticeable the dependence on the electrical contrast of the soil.

Introduction

The interaction between solar wind and the Earth's magnetic field with time produces varying currents in the ionosphere and in the magnetosphere; such currents cause variations in the geomagnetic field and induce an electric field capable of producing currents along pipelines [(1 - 3)]. These geomagnetic induced currents (GIC) can contribute to the increase in corrosion of underground pipes, which is one of the main problems in oil and gas pipelines [(4 -5)] .

Variations in the magnetic field of the Earth can be classified according to the solar activity, depending on whether they are produced on geomagnetically quiet or active days. The periods of such variations can range between seconds and minutes (micro-pulsations), up to days (daily variations).

In active days, the intensity sharply increases, and can even produce magnetic storms, the ones with the highest intensity whose frequencies range from 10^{-5} Hz to 10 Hz. In practice, these intense variations can produce induced currents of several hundreds of amperes, increasing the risk of corrosion in the pipeline [(5 - 6)]. However, there is another effect that is usually disregarded: induced current dependency on soil resistivity distribution.

Previous papers indicate that when induced currents are modeled as a function of soil resistivity, assuming that it uniformly surrounds the pipe, the currents increase for soils with higher resistivity [(5 & 7)]. When the pipes runs through stretches of land with sharp contrasts in resistivity, electrical discontinuities can produce a current escape through the defects in pipe coating, thus becoming a corrosion current [(5)].

In this context, scale models were built to study corrosion rate in pipelines embedded in resistivity contrastive soils affected by external low frequency magnetic fields (1 Hz), compared to the case of identical pipes in the absence of magnetic induction

Soil Corrosion

Corrosion Causes

Given its variable content of moisture, salts and organic matter in decomposition, the soil is the most complex corrosive medium it can be found, and it is generally a heterogeneous environment that gives way to many processes generating variations in corrosion rate for the metals in contact with it.

It is a known fact that corrosion rate is directly related to soil resistivity (the lower the resistivity, the higher the corrosion), and that resistivity, in turn, is dependant upon soil structure features such as porosity, permeability, moisture level, ion content and pH (the higher the acidity, the bigger the aggressiveness). Also when the pipeline runs through stretches of land with different characteristics there is differential aeration due to the presence of anodic and cathodic areas.

If atmospheric oxygen cannot penetrate the soil, as is frequently the case in clay or peat soils, the hydrogen produced as a consequence of the cathodic reaction in the underground structure can be eliminated (oxidized) due to microbial factors. This process is the result of the metabolic activity of bacterial microorganisms that develop in conditions of total lack of free oxygen (anaerobic conditions). Microbial corrosion is due to the presence of a biofilm on the metal surface between the metallic substratum and the surface liquid; such biofilms influence corrosion since they bring about chemical changes in the metal surface proximity.

It is also known that in biotic anaerobic systems, sulfate-bacteria can considerably increase corrosion due to the production of hydrogen sulfur, which can act as an electron acceptor instead of the oxygen. [(8)]

Finally, the presence of errant or parasite currents produces alterations in corrosion rate. These currents are predictable in some cases but in others they are not and they vary in intensity depending essentially on the nature and function of their source. One type of such current, the one generated by electromagnetic induction, is the type concerning us in the present paper. [(9)]

Anticorrosion Protection

In order to avoid or reduce corrosion damage in embedded metallic structures, pipes are in general electrically isolated from their surroundings, and complementarily some other active protection system is provided, such as sacrificial anodes. Metal isolation is achieved through some coating material, such as asphalt paint, protective tape, plastic sheaths or a combination of them. The sacrificial anodes are metallic or alloy pieces with a chemical potential lower or equal to the one corresponding to the metal in the structure, electrically joined to the pipe in areas suspected of corrosion and in direct contact with the soil so that they act as extensions to the pipe that take the corrosion by sacrificing the anodes.

Test Desing

In order to quantify the increase in electromagnetic induced corrosion rate in an underground structure, scale models of buried pipelines running along soils with different resistivity levels were built and currents were induced through a low frequency variable magnetic field.

In order to quantify corrosion according to the stretch of land crossed by the pipe, metal samples connected to the pipes as sacrificial anodes, weighted before and after the test, were used to measure the metal loss due to corrosion. In each case, special care was taken to minimize the corrosive effect of all other factors, thus avoiding masking the measurements corresponding to the desired phenomenon.

Soil Selection

Tests were conducted with three different types of soil: sand, clay and humus, each with a different moisture level to facilitate electrical conduction, since it is known that in a watery environment with presence of organic matter the likelihood of bacterial corrosion increases. The samples (sacrificial anodes) exposed to wet sand presented in all cases a type of uniform non-localized corrosion, whereas the ones in contact with humus presented a type of more localized corrosion of a darker shade, and in the case of clay, corrosion was very localized and a considerable contribution of bacterial corrosion was noticeable, with characteristic symptoms such as local blackening of the soil (formation of iron sulfur) and the characteristic hydrogen sulfur smell.

In order to avoid the possible corrosion increase due to the presence of sulfate reducing bacteria, clay was discarded, and soils composed of sand and humus were preferred. Before the test, both humus and sand were sifted to get a homogeneous material and both soils were subjected to a 250ºC temperature treatment during 30 minutes so as to get microorganism free environments.

Acidity

As regards acidity, very acid soils (pH<5.5) can determine a fast corrosion in naked metal, and soil aggressiveness increases with acidity, but such pH values are not generally normal. Most soils have a pH level ranging from 5 to 8, and therefore corrosion depends on other factors. For our test, acidity measurements in the different soils used fell within the alkaline range, thus ruling out increase corrosion due to soil acidity.

In consequence we can assume that under these experimental conditions, the prevailing corrosion factor is soil conductivity, free from acidity, microorganism activity and presence of anions that can increase corrosion risk, e.g. Cl^- , S^{2-} or SO_4^{2-}. Therefore, we can consider that there is a good correlation between conductivity and aggressiveness

Soil moisture level

Having reduced the corrosion driver to solely conductivity of the environment, two types of soils were prepared: one with resistivity characteristics and a particularly conductive one. In order to model conductive soil, we mixed conditioned sand with demineralized water in a proportion of 0.1 m^3 of sand and 0.01 m^3 of water (an approximate moisture level of 10%); the mixture was homogenized and it was kept in an air-tight container for 24 hours before use. Similarly, a mixture of humus was prepared to model conductive soil, mixing 0.05 m^3 of humus with 0.02 m^3 of demineralized water, stored in identical conditions as the other mix.

Recipients

In order to contain the soil/ pipeline models, two identical 5-mm thick rectangular parallelepiped glass recipients opened at the top were built; these containers were designed to easily contain the 0.90 m x 0.40 m x 0.30 m pipes, and they were joined by their sides through silicone rubber.

Pipes

Metallic pipelines ordinarily used for oil or gas transportation are typically made of steel, low in carbon content. For this test we used SAE 1010 steel pipes (see table 1), lined with expanded polyurethane used to avoid internal corrosion and to seal the ends so as to avoid soil entrance.

In order to avoid possible electricity leaks outside the anode area, the set was isolated (pipes, welding and ends) with layers of asphalt paint up to a thickness of 1 mm.

Anodes

Sacrificial anodes are generally made in the industry with elements that are more electronegative than the material to be protected (Zn, Al or Mg) in order to guarantee an easy reaction with the environment, and sometimes it is possible to use anodes made out of the same material as the pipe[9] For the present test, we decided to work with steel presenting the same characteristics as the structure, thus avoiding the possibility of additional corrosion due to high reactivity with the environment that could mask the natural corrosion of the steel.

STEEL SAE 1010				
	C	Mn	P	S
%	0.08-0.13	0.30-0.60	0.04	0.05

Table 1. Chemical composition of the steel used in pipes and anodes.

Sacrificial anodes were weighted before and after the experience with a Sartorius BP 210 S precision scale (error margin of 0.0001 g).

Generation of the magnetic field

In order to induce current in the pipes, it was necessary to generate a low frequency variable magnetic field under 10 Hz, uniform enough to exert influence over pipes of acceptable length. In order to generate such magnetic field a coil was built using a 90cm x 40cm x 30cm parallelepiped rectangle, around which 250 copper wire strands of 2 mm^2 section were coiled up; additionally a power source was design with a power differential of 30 Vpp, capable of generating a 2A current.

As the power source, a Kenwood FG272 generator was used to ensure that frequency was maintained low. This source was connected to a high power amplifier (up to 150 W), especially designed and assembled for this test. Fig. 1 shows an assembly outline and the amplifier circuit.

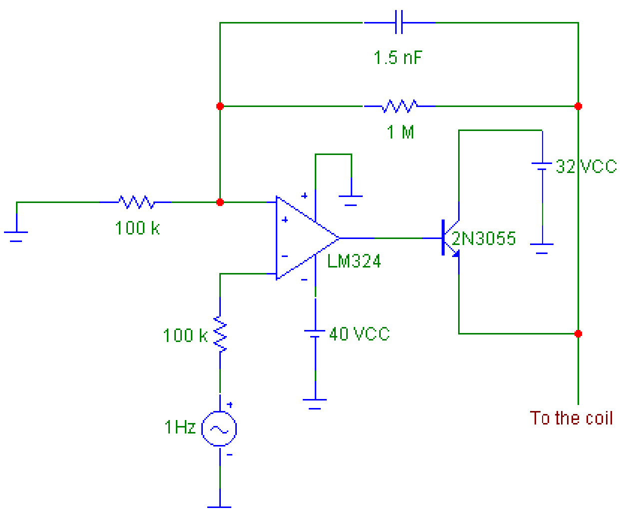

Figure 1. Assembly outline and amplifier circuit.

Tests

Sand and Humus

For this first test, only one discontinuity was set up in the soil composition (sand and humus), and two SAE 1010 steel pipes (40 cm long, 2.2 cm of external diameter, and 0.1 cm thick) were installed under identical conditions in two different recipients.

Fig 2 shows the configuration in a soil with 2D lateral discontinuities that generate resistivity contrasts.

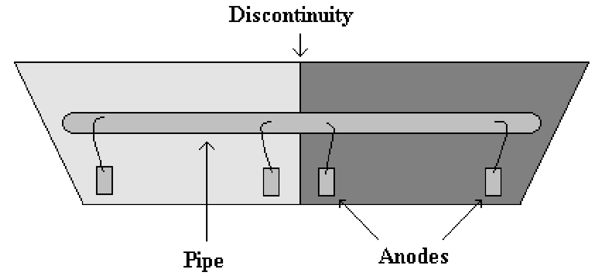

Figure 2. Diagram of the set up

In order to obtain resistive discontinuity of around one order of magnitude, dry sand, with a resistivity of around 600 Ωm and wet humus, with a resistivity level under 10 Ωm were used.

Geoelectrical tests were made in order to verify that requirement. Dipole-dipole configuration was used(10), with distance between electrodes of 1 cm.

Data were colected with a Scintrex Automated Resistivity Imaging System (SARIS) and were inverted by means of program RES2DINV developed by Loke(11) and based on the Occam inversion method. Applying this code, the electrical tomography of the subsoil can be obtained. The result can be seen in Fig 3. The required electrical contrast can be clearly seen.

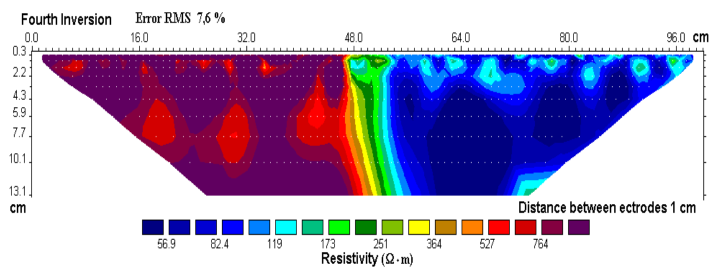

Figure 3. Electrical tomography of the soil.

Four anodes were welded to each pipe so that anodes 1 and 2 in each recipient were in sand, while anodes 3 and 4 were in humus.

SAE 1010 steel sheets (2.5 cm x 4 cm x 0.07 cm; approx. 6.7 gr) were used as sacrificial anodes.

One recipient was put inside the coil that received a current of 2A with a frequency of 1 Hz, exposed to its low frequency magnetic field, while the other was used as the control specimen in order to compare the different corrosion processes.

In both cases, the above-mentioned conditions were maintained during 28 days, and then the anodes were removed and cleaned with a copper brush so as to remove soil particles adhered to the surface; they were washed with HCl diluted in water first, and then with distilled water in order to eliminate any trace of rust or medium.

Figures 4 and 5 show the lost weight relation (with and without induction) on the anodes embedded in sand and the anodes embedded in humus.

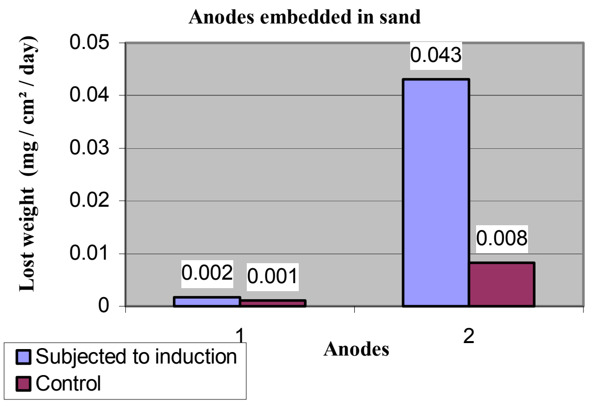

Figure 4. Weight loss in the anodes embedded in sand.

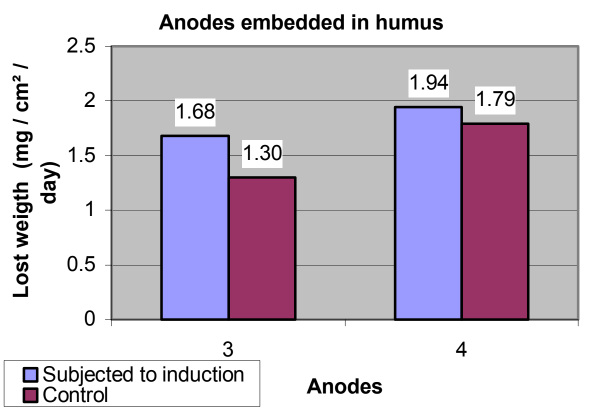

Figure 5. Weight loss in the anodes embedded in sand.

It was verified that the most corroded anodes were the ones in the soil with higher conductivity (humus). The largest weight difference was in the anodes on the pipe under the influence of the magnetic field.

The corrosion rate for the most affected anode was 1.94 mg/cm^2/day in the case of the pipe under the influence of the magnetic field and 1.79 mg/cm^2/day for the control pipe.

Sand-Humus-Sand

In the second test, two discontinuities were set up in the soil composition (humus-sand-humus), and two SAE 1010 steel pipes were installed under identical conditions in two different recipients.

The pipes has 4.8 cm of diameter and 0.2 cm of thickness and a length of 70 cm; each one of them was welded to nine copper cables of 2mm of diameter and approximated length of 20 cm, covered with plastic.

For the construction of the anodes steel with low carbon content, SAE 1010 (sheets of 5 cm x 3.5 cm x 0.2 cm; approx. 25 g) were used.

The anodes 1, 2, 3, 7, 8 and 9 were embedded in in sand while the 4, 5 and 6 were in humus.

The geoelectrical profile of the recipient was obtained in the same condition of the first experience, the resistivity profile can be shawn in the Fig 6.

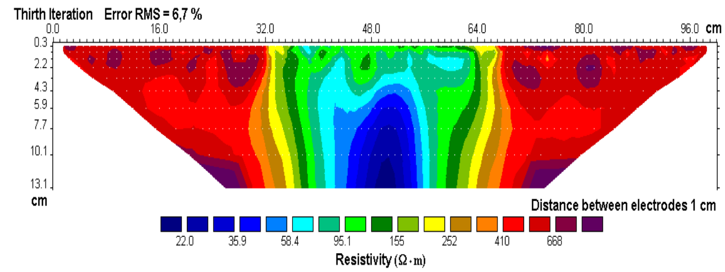

Figure 6. Electrical tomography of soil.

Like first experience one recipient was put inside the coil, while the other was used as the control specimen in order to compare the different corrosion processes.

In both cases, the same conditions were maintained during 14 days, and then the anodes were removed and cleaned.

Figures 7 and 8 show the lost weight relation (with and without induction) on the anodes embedded in sand and the anodes embedded in humus.

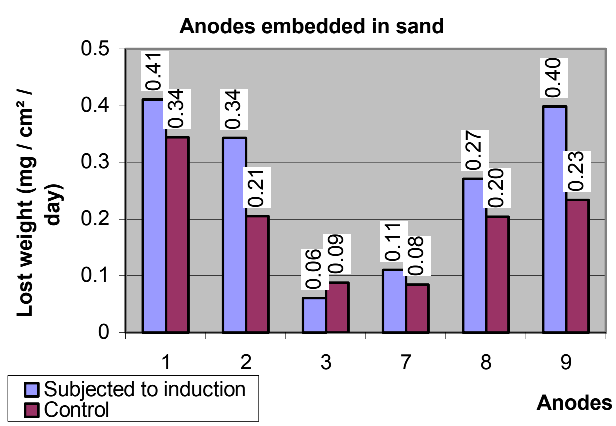

Figure 7. Weight loss in the anodes embedded in sand.

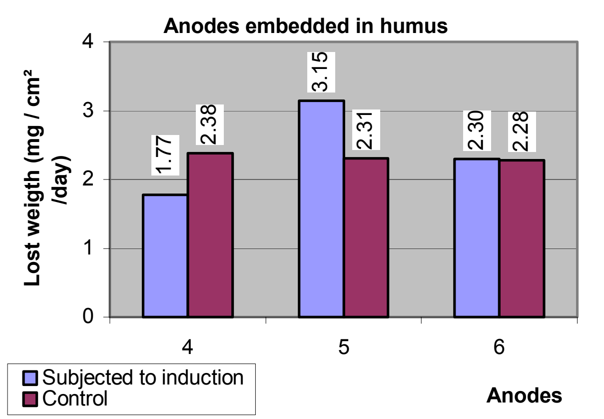

Figure 8. Weight loss in the anodes embedded in humus.

The corrosion rate for the most affected anode was 3.15 mg/cm^2/day in the case of the pipe under the influence of the magnetic field and 2.38 mg/cm^2/day for the control pipe.

Conclusions.

In both cases, pipes affected by induction currents and control pipes, the most corroded anodes were in the soil with higher electrical conductivity, due to the fact that the area behaves as an anodic area, enabling electron loss.

In the anodes on the pipe affected by the magnetic field, a higher corrosion rate was verified as compared to the anodes on the control pipe. We can conclude that low frequency magnetic fields (1 Hz) increase the corrosion rate in underground pipes. For the contrast sand-humus, we observed that the more affected anode (under the humus) were corroded 18.3% more than the corresponding to the control pipe, while in the contrast sand-humus-sand, the increase was of 8.4 %.

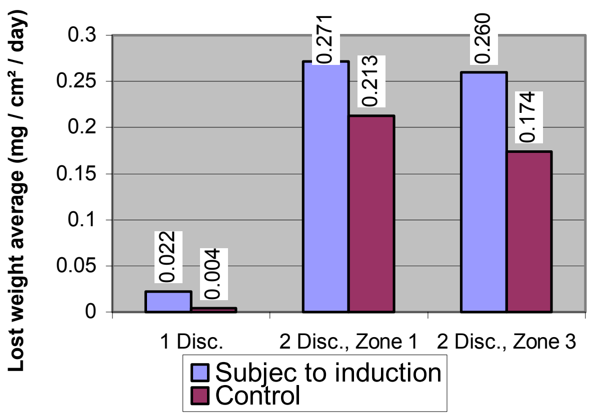

Figure 9. Lost weight average for the anodes embedded in sand.

Fig. 9 shows the lost weight average for the anodes embedded in sand. For the first discontinuity case, the corrosion of the anodes under induction currents was 5.5 times more than without induction. In the second discontinuity experience, the increase was 27% and 49% in each zone, respectively.

We can conclude that for pipes subjected to inductive currents, there was an increase in the percentages of lost mass in underground anodes in the proximity of resistivity contrastive areas, observation that confirms previous results.

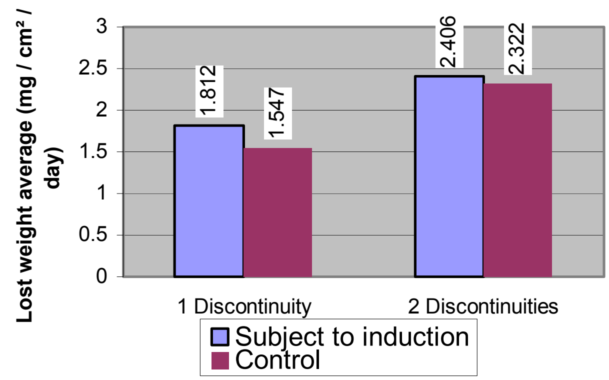

Figure 10 Lost weight average for the anodes embedded in humus.

These results are important because it verifies that an alternating current increases corrosion rates and, also and more interesting, that this increase is larger in resistive zones. It must be remembered that usually the pipes are specially protected in conductive zones because they are considered more aggressive than resistive zones. Nevertheless this result, in agreement with theoretical predictions, shows that the presence of alternating fields in resistive zones (usually with low protection) increases the corrosion in near 50 %.

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