Evaluation of non-intrusive systems for internal corrosion monitoring

Avaliação de sistemas não destrutivos para monitoramento de corrosão interna

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Abstract

Internal corrosion is one of the major problems affecting the integrity of pipelines and process equipment. For this reason, the internal corrosion monitoring becomes essential to anticipate eventual problems and to select the most appropriate strategy to mitigate the corrosive process. Due to the problems related to the cost, logistics and safety inherent to coupon and electric resistance probe retrieving, it is very important to seek alternatives to the current methods, to optimize the monitoring tasks. The use of non-intrusive equipment to monitor internal corrosion is an alternative that aims at optimizing this step. Additionally, the non-intrusive equipment has easy installation and maintenance, higher data reliability and faster results. These systems consist of estimating the trend of the corrosion rate through devices installed on the external side of pipelines without the need of access fittings, unlike conventional techniques. The great advantage of using this technique is the absence of interventions for components retrieving, minimizing operational risks. To evaluate such equipment, tests were carried out under dynamic conditions, varying the fluid characteristics to verify the speed of response of some commercial devices, always comparing them to conventional methods (coupon and electric resistance probe). Experimental results showed that the trend of measured corrosion rate obtained by the non-intrusive equipment converged with corrosion coupons and electric resistance probe data.

Resumo

A corrosão interna é um dos principais problemas que afetam a integridade de dutos e dos equipamentos de processo. Por este motivo, o monitoramento da corrosão interna torna-se essencial para antecipar eventuais problemas e selecionar a estratégia mais apropriada para mitigar o processo corrosivo. Devido aos problemas relacionados a custo, a logística e a segurança inerentes à recuperação de sondas de resistência elétrica e de cupom de perda de massa, é muito importante buscar alternativas aos métodos atuais, a fim de otimizar as atividades de monitoramento. O uso de equipamentos não intrusivos para monitorar a corrosão interna é uma das alternativas promissoras. Além disso, os equipamentos não intrusivos são de fácil instalação e manutenção, apresentam maior confiabilidade de dados e são capazes de fornecer resultados mais rápidos. Essas técnicas permitem estimar com boa aproximação a tendência da taxa de corrosão por meio de dispositivos instalados na superfície externa dos dutos sem a necessidade de tomadas de acesso, ao contrário das técnicas convencionais. Uma das grandes vantagens desta técnica é não necessitar intervenções para recuperação de componentes, minimizando os riscos operacionais. Para avaliar esses equipamentos, ensaios foram realizados em condições dinâmicas, variando as características do fluido para verificar a velocidade de resposta de alguns dispositivos comerciais, sempre os comparando com métodos convencionais (cupom de perda de massa e sonda de resistência elétrica). Os resultados experimentais mostraram que a tendência da taxa de corrosão obtida pelos equipamentos não intrusivos mostrou boa correlação com as taxas obtidas com cupons de perda de massa e com sonda de resistência elétrica.

1 Introduction

Internal corrosion is one of the main problems related to pipeline integrity. The occurrence of internal corrosion is a function of the type of material and the composition of the fluids. Generally, the material used in pipelines is carbon steel which, although having a low cost and good weldability, is quite susceptible to corrosion in the presence of water and oxygen. In addition, the presence of contaminants, such as CO_2*,* H_2S*, salts and microorganisms in the transported fluids, increase their corrosivity (ROBERGE, 2007).*

For these reasons, some methods for corrosion control are employed, such as the use of protective coatings, chemicals injection, such as corrosion inhibitors, PIG launching, among others. For the application of the most appropriate control method, it is necessary to monitor internal corrosion of pipelines to determine the potential corrosivity of the fluids and to better understand the corrosive process in place (ROBERGE, 2007).

One of the most important steps in pipeline corrosion monitoring consists on determining corrosion rates to evaluate the corrosivity potential of the fluid. Currently, this step is accomplished using corrosion coupons and electrical resistance probes (ER), inserted in the pipeline (ROBERGE, 2007).

These techniques require periodic interventions, either for the exchange of the corrosion coupons and its subsequent evaluation or for the replacement of the sensor element of the electrical resistance probe. The frequency of coupon and a sensor element exchange varies according to the corrosivity of the fluid (NACE INTERNATIONAL, 2013; PETROBRAS, 2016).

The non-intrusive equipment (NIE) estimates the trend of the corrosion rate through devices installed on the external side of a pipeline. The great advantage of using these techniques is the absence of interventions for component exchange and/or maintenance, decreasing retrieval operation risks and optimizing the corrosion monitoring logistics. However, NIE usually has low sensitivity in comparison with intrusive methods (NACE INTERNATIONAL, 2012).

To evaluate such type of equipment, tests were carried out under dynamic conditions, varying the fluid characteristics to verify the speed of response of some commercial devices. The results were compared with corrosion rate measured with ordinary intrusive methods (coupon and ER probe).

2 Methodology

The corrosion tests were performed in a closed loop and the corrosion environment was aerated water with and without some contaminants, resulting in conditions with different corrosivity. The loop consists of 50.8 mm (2 inch) tubes made of carbon steel, internally coated with FBE ***(Figure 1).***

The devices were installed in a test section at a 101.6 mm (4 inches) carbon steel spool positioned at the upper region of the loop (red arrow in ***Figure*** *1). The fluid flows in the system through a pump that can operate at a flow rate up to 100 L/min. No heating system was used because the tests were performed at room temperature.*

Figure 1 - Corrosion loop used to evaluate non-intrusive techniques.
Source: Authors.

Six non-intrusive devices were tested in addition to corrosion coupons and two electrical resistance probes. Five NIE considered in the tests were based on ultrasonic method and only one was based on electrical field method.

In addition to the NIE, four corrosion coupons were used in two access fittings (multiple rod containing two coupons each) and two different probes: one of high sensitivity (HS) and one conventional ER probe. The coupons and the ER probes were installed at the initial section of the spool (blue arrow in ***Figure 1****).*

Figure 2 *shows in detail two coupon access fittings, the conventional ER probe and the high sensitivity probe (left to right). The conventional ER probe has sensor thickness of 127 µm (5 mils) which is the type currently used in the field.*

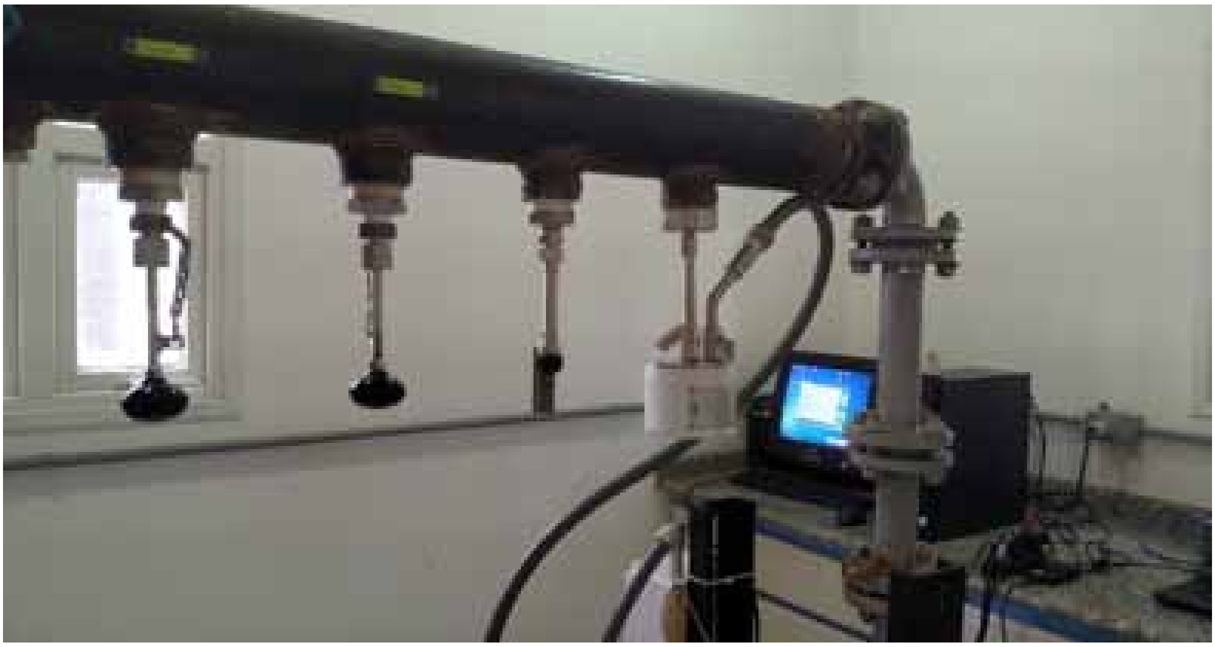

Figure 2 – Intrusive instruments used in the tests.
Source: Authors.

The main objective of these tests was to evaluate the sensitivity of each equipment when compared to corrosion coupons and ER probes. Three different conditions were simulated using aerated water with and without contaminants. ***Table 1*** *presents the test conditions.*

Table 1 – Test conditions.
Source: Authors.

Condition	Corrosion environment	Flow rate (L/min)	Duration (d)	Temperature	pH (initial)	pH (final)
A	Aerated deionized water	100	30	Room temperature	7	9
B	Aerated deionized water containing 3.5 % NaCl and 100 mg/L acetic acid	100	27	Room temperature	3.5	5
C	Aerated deionized water	100	30	Room temperature	7	5

Each condition was performed for 30 days. The first (A) and the third (C) conditions were performed using the same fluid which was aerated deionized water with no contaminants, i.e., a low corrosivity fluid. The tests were started with the aerated deionized water and were conducted for 30 days without changing the solution. After this period, the loop was drained and the deionized water was replaced with water with some contaminants (3.5 % NaCl and 100 mg/L acetic acid - see ***Table 1****). After almost 30 days, the loop was drained again and the solution was replaced again with aerated deionized water.*

This test lasted three months in total, with the corrosivity of the fluid varying every 30 days. The results of the three trials and their respective discussions is presented below.

3 Results and discussion

3.1. Test solution characteristics

Two aqueous solutions of different chemical composition (pure deionized water and deionized water containing 3.5 % NaCl + 100 mg/L of acetic acid) were considered. In the first 30 days, aerated deionized water (condition A) was used. Condition B was carried out with aerated water containing sodium chloride and acetic acid. It remained in the loop for the following 27 days and finally the fluid was again exchanged for pure deionized water which remained for the following 30 days (condition C). Complete test lasted 87 days, according to ***Table 1****.*

Table 2 *shows the pH values of tested fluids before and after each test conditions. For conditions A and B, the measured pH values were similar to those of simulated pH values. However, for condition C, the final water presented an unexpected acidification (pH dropped from 6.7 to 5.3). At the beginning, the pH was almost neutral (6.7) because the loop was filled with deionized water. Most probably, after the fluid started to move inside the loop, the circulating water was contaminated by a small quantity of the previous fluid that possibly remained in the loop. However, the thermodynamic simulation does not indicate a significant decrease in pH with a contamination of the solution of condition C with up to 10 % of the solution used in condition B (simulated pH 6.9). Another hypothesis would be that with the change of inventory of an acidic solution to a neutral/alkaline one, dissolved iron ions could undergo hydrolysis which would result in a decrease in pH.*

Table 2 – Fluid pH and iron content monitoring x simulated.
Source: Authors.

Condition	Initial pH simulated	Initial pH measured	Final pH simulated	Final pH measured	Dissolved Iron simulated (mg/kg)	Dissolved Iron max measured (mg/kg)
A	7	6.8	9.4	8.9	0.75	NA
B	3.7	3.7	6.1	5.3	45	NA
C	7	6.7	9.4	5.3	0.75	13.3

Figure 3 *shows the Pourbaix diagram obtained by OLI STUDIO ANALYSER 9.1 simulation software for the studied medium. The red rectangle indicates the corrosion potential region of carbon steel (E = +0.44 V (SHE [a]) at 25 °C). In the acid water (condition B), a wide region of corrosive process domain is favored by the presence of O_2 in the medium. In neutral and alkaline medium, the rectangle represents the region prone to precipitation of iron oxide. Thus, a higher generation of corrosion products is expected for the neutral water test (condition C). This diagram also favors the iron ion hydrolysis argument, because with the abrupt change in pH during inventory exchange, the equilibrium was displaced from the corrosion domain to the iron oxide precipitation domain.*

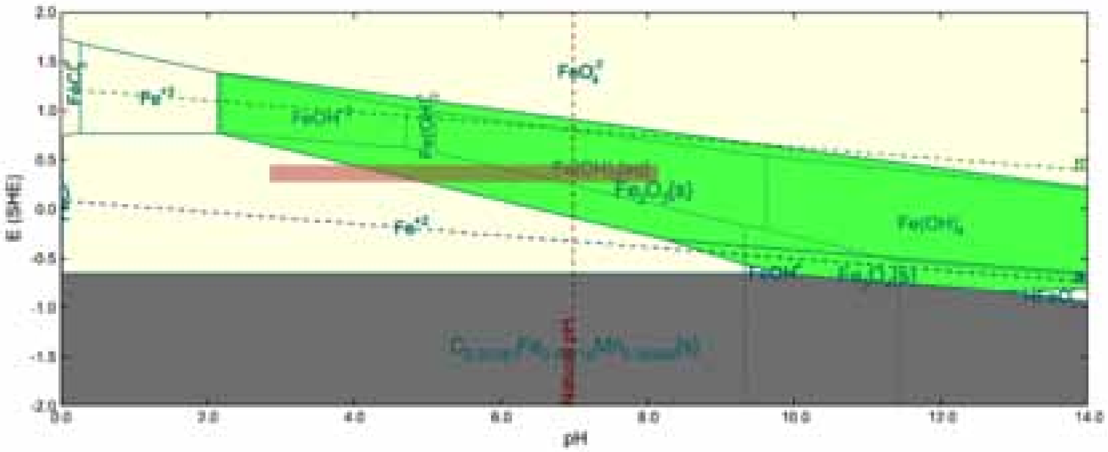

Figure 3 – Pourbaix diagram for iron in aqueous solution at 25 °C (OLI ANALYSER STUDIO 9.1).
Source: Authors.

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[a] SHE – standard hydrogen electrode

__Figure 4__ shows a photograph of the initial part of the inner section of the test tube after condition C. The corrosion products (ferric hydroxide) are distributed throughout all clock position, indicating high iron-ion precipitation rate. However, in the six o'clock position downstream the curve (red arrow in __Figure 4__), where coupons and ER probes are installed, it is possible to observe that there was considerable removal of the corrosion product.

Figure 4 – Internal view of the test section showing the corrosion product removal.
Source: Authors.

3.2. Corrosion Rate Analysis

The results obtained in the test using non-intrusive equipment and the ER probes are shown in __Figure 5__ as metal loss as a function of time. The red arrows indicate the periods when the inventory changes were carried out (Condition A, B and C). The ultrasonic methods are identified as "US" and the electrical field method as "EF". The high sensitivity ER probe did not work in condition A because there was an unexpected communication problem that impaired its results. Therefore, the result of this probe was not shown in __Figure 5__.

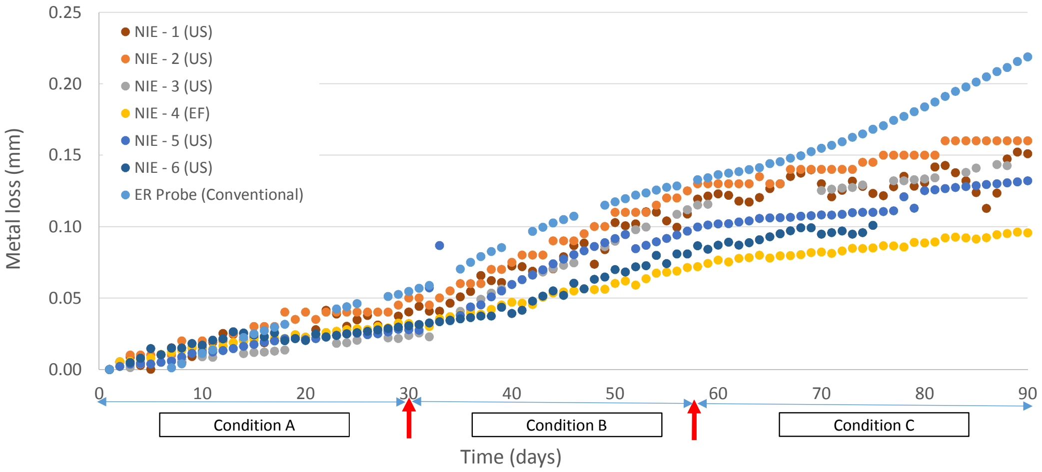

Figure 5 – Metal loss as a function of time results obtained from NIE and ER probe. Source: Authors.

In condition A (deionized water - neutral pH), all the equipment showed low metal loss (maximum of 0.05 mm in 30 d) being consistent with the simulated condition. It is possible to observe the change in curves slope between condition A and B, indicating that there was an increase in the corrosivity of the fluid detected by both intrusive and non-intrusive equipment. These results were expected, due to exchange of the neutral pH solution (Condition A) for an acid one (Condition B). ***Table 3*** *confirms that the average corrosion rate in condition B increased.*

However, as previously reported, in condition C (deionized water, pH almost 7), there was a decrease in the pH during test which may be related to iron-ion hydrolysis due to water inventory change. Through thermodynamic analysis of the fluid in condition C, the possibility of precipitation of corrosion products that could present a protective effect was observed, converging with the results presented by the non-intrusive equipment ***(Figure 5)****. In the condition C, there was a divergence between the intrusive and non-intrusive equipment, as the former showed an increase in corrosion rate and NIE showed a decreasing, in comparison with condition B.*

Table 3 - Average corrosion rate for each test condition, considering the intrusive and non-intrusive equipment tested.
Source: Authors.

Average Corrosion Rate (mm/y)		
Condition A (30 d)	*Condition B (27 d)*	*Condition C (30 d)*
	Corrosion Coupon	
0.5	0.9	1.1
	Conventional ER Probe	
0.7	1.0	1.0
	NIE – 1	
0.5	1.1	0.2
	NIE – 2	
0.6	1.1	0.4
	NIE – 3	
0.3	1.2	0.4
	NIE – 4	
0.4	0.6	0.3
	NIE – 5	
0.3	0.6	0.3
	NIE – 6	
0.4	0.7	0.3

3.3. Flow Analysis

*In addition to the protective effect caused by corrosion products precipitation in condition C, the flow variation in the loop should be considered. This is because the test section has a diameter of 101.6 mm (4 inches), but the lower part of the loop has a smaller diameter (50.8 mm (2 inches)). Considering the pump flow rate of 100 L/min and the diameter of 101.6 mm (4 inches), the average flow velocity is of the order of 0.2 m/s. As presented in **Figure 6**, in the initial part of the 101.6 mm (4 inches) section pipe, where the intrusive instruments (coupons and ER probes) were installed, it was observed some turbulence (by CFD simulation) due to the diameter variation and the 90° curve. This turbulence* *probably removed the corrosion products which were adhered in the six o'clock position causing a difference in the corrosion rate measured by intrusive and non-intrusive instruments, mainly in condition C. This analysis is quite consistent with the picture showed in **Figure 4**, where it can be seen that there was actually removal of the corrosion product in the region where corrosion coupons and ER probes were installed.*

*This may explain why, in condition C, the corrosion rate observed by the intrusive equipment, which were installed in the region of higher turbulence, remained high, while the non-intrusive devices installed at the laminar flow region showed lower corrosion rate in comparison with condition B **(Table 3)**. Thus, because there was precipitation of iron oxide/hydroxide in condition C due to the ferric ion low solubility at neutral pH, the turbulence contributed to reduce the protective characteristics formed in carbon steel at the region where intrusive instruments were installed.*

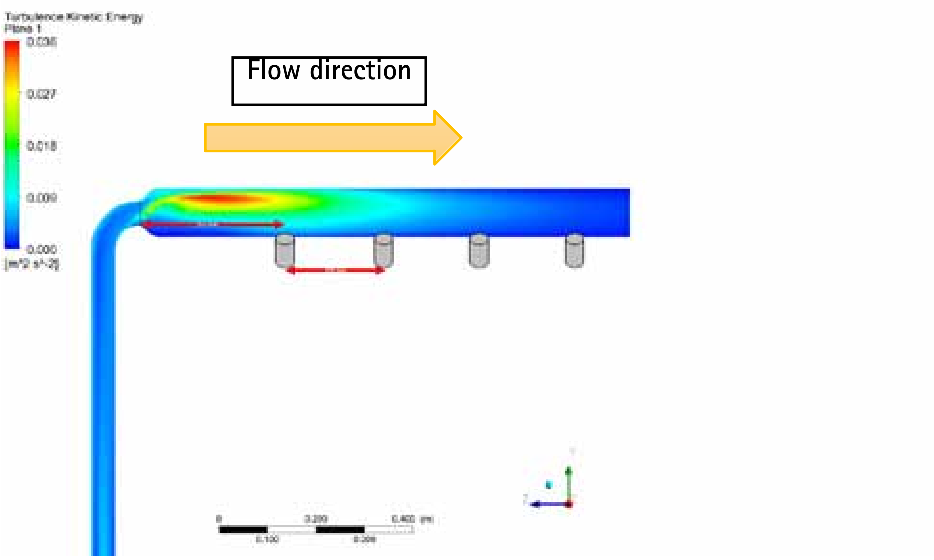

Figure 6 – CFD simulation showing the kinetics energy after diameter change.
Source: Authors.

4. Conclusions

Based on the analysis of the results obtained by closed loop tests, it is possible to conclude that:

- Corrosion coupons and conventional ER probe showed very consistent results, both in the trend of corrosion rate and in absolute values;

- All the evaluated non-intrusive equipment showed the same trend in corrosion rate when compared to intrusive equipment (coupon and ER probe). In condition C, there were some differences when comparing results obtained from non-intrusive and intrusive techniques which were related to the position of the equipment in the test circuit;

- Non-intrusive equipment showed lower sensitivity than coupons and ER probes and therefore, for applications that require immediate actions for corrosion mitigation, such as corrosion inhibitor injection control, this equipment should be evaluated before using or should be used with other corrosion monitoring techniques;

- The internal corrosion management uses several resources to warrantee pipeline integrity. This paper showed that non-intrusive equipment could be one more technique to be chosen for this proposal.

5. References

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