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Development of a non-destructive tool for inspecting the integrity of HDPE lined pipes

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Abstract
A recurring issue in the oil industry is internal corrosion within oil, water, and gas flow lines. In the offshore sector, a strategy to lower maintenance expenses and replace segments of pipelines carrying saltwater involves using carbon steel pipes internally coated with HDPE. However, the presence of dissolved gases like CO_2, H_2S, and O_2 can permeate through the coating, leading to disbond and subsequent displacement of the entire liner. This study aims to develop a methodology and construct a non-destructive ultrasonic inspection tool capable of identifying liner integrity. Analyzing the A-Scan signal obtained in ultrasonic inspections revealed a variation in its behavior. This variation facilitated the identification of regions with disbonded of the HDPE liner in carbon steel pipelines. This insight guided the development of the multichannel inspection tool, which comprises a collar with 16 transducers covering the entire internal perimeter of the selected region. Utilizing this tool will minimize unforeseen production shutdowns on FPSO platforms, thereby reducing corrective maintenance expenses and enabling the scheduling of damaged section replacements before clogging or leakage occurs due to corrosion.

Keywords
Pipeline; HDPE Liner; NDT

Introduction
In the oil industry, both in offshore and onshore operations, the use of carbon steel pipes for transporting oil, water, and gas is common. However, these pipes are susceptible to corrosion, leading to thickness loss. According to KHALID *et al.* [1], this issue accounts for 70% of pipe failures in the oil and gas industry, with 58% of them originating internally. In more advanced stages, corrosion can result in fluid leaks such as water or oil. In severe cases, besides production interruptions for replacing damaged sections, leaks can cause economic losses and serious environmental damage [2, 3, 4].

In offshore fields, lines containing seawater are common and, consequently, are prone to severe damage from internal corrosion [5]. These lines can supply different systems on the platform, such as cooling, freshwater production, water injection into wells, and treatment of produced water from oil separation and stabilization process. Only the latter can circulate between 16.000 to 25.000 m^3 of water per day [6]. As production fields age, fluids become more corrosive, exacerbating corrosion problems in the facilities [7].

Internal corrosion in these pipelines can be caused by the flow of fluids containing not only free water but also the presence of gases (CO_2, H_2S, O_2) and/or by bacterial action, especially under stagnant conditions. Other factors such as pressure, temperature, and the condition of the pipeline surface also influence this process [1, 4, 8].

Practices such as the use of corrosion-resistant alloys, corrosion inhibitors, cathodic and anodic protection, as well as the use of metallic and non-metallic linings, are adopted to reduce corrosion in pipelines. Internal lining has been widely explored as an alternative to corrosion-resistant alloys, aiming to isolate the inner wall of the carbon steel pipe from corrosive agents [5]. This approach using HDPE lining represents significant savings for the industry, with around 60-80% reduction in costs compared to replacement with new stainless steel pipes [4, 5].

According to specifications, the HDPE lining can be classified in terms of operating temperature, ranging from -40°C to approximately 82°C [9], above this temperature, cracks begin to appear in the lining [1]. However, for application in flow lines containing aromatic hydrocarbons, cyclic solvents, and multiphase fluids, it is recommended that the operating temperature with the lining does not exceed 60°C [1, 2]. Additionally, certain gases such as CO_2, hydrocarbons, and H_2S can diffuse into the polymeric structure, causing swelling, softening, and reducing the strength and thermal performance of polyethylene [7]. This permeation promotes the confinement of these gases between the host pipe wall and the coating, increasing the annular pressure, resulting in lining disbond. However, if the host pipe exhibits external damage, a pressure differential can also promote disbond [10]. Other effects to be considered in the lining collapse process are the thermal expansion of the coating associated with swelling and softening caused by the presence of hydrocarbons or exposure to fuels that generate stresses in the material, which can also cause coating deformations [1, 11]. Lining collapse, identified by its displacement, can lead to pipe and valve blockages, necessitating immediate shutdowns for repairs.

Currently, the assessment of integrity and estimation of the service life of HDPE used in liners are conducted through destructive tests that characterize changes in the mechanical, thermal, chemical, and structural properties of the polymer. These tests include tension, differential scanning calorimetry (DSC), Fourier-transform infrared spectroscopy (FTIR), among other techniques [1, 8]. They are conducted on samples that have undergone aging in the laboratory or on test coupons installed in industrial lines, acting as sensors. However, these coupons are difficult to apply due to accessibility to the pipelines of these lines. These results are qualitative and do not provide real-time information on coating damage [1, 8, 12]. Therefore, the use of non-destructive testing inspection techniques emerges as a new perspective in the assessment of coating integrity in the field.

This study aims to develop a methodology and build a localized non-destructive inspection tool to be employed in topsides pipeline, allowing the identification of the integrity stage of the HDPE liner used in FPSO-type platforms in the transport of saltwater. To achieve this, the ultrasonic non-destructive testing technique will be used to assess whether the lining is intact, disbonded, or if there is no coating (uncoated) in the pipeline, indicating total lining collapse.

Methodology

Sample Description

In this work, a flanged carbon steel pipe with a length of 4 m and an internal HDPE liner was used. The external radius of the pipe is 57,5 mm, the internal radius of the carbon steel pipe is 49,5 mm, and the liner thickness is 3 mm. A half-pipe with a length of 900 mm was extracted from it for bench tests. Figure 1 shows the drawing of the half-pipe with the insertion of defects simulating thickness loss, an uncoated region, and another with coating disbond.

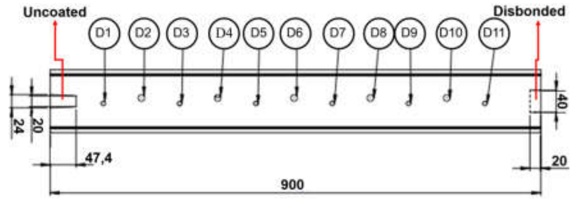

Figure 1. Schematic representation of the half-pipe showing the location of the inserted defects.

Experimental Procedure

For the bench tests, the setup shown in Fig. 2 was used, employing the ultrasonic equipment ISONIC 2005 from SONOTRON NDT®, responsible for generating and receiving the ultrasonic signal, coupled with the oscilloscope, model MSOX4024A from KEYSIGHT®, for digitizing the ultrasonic signal allowing it to be exported in .CSV format. A single crystal transducer with a central frequency of 4 MHz and oil as a ultrasonic couplant were used.

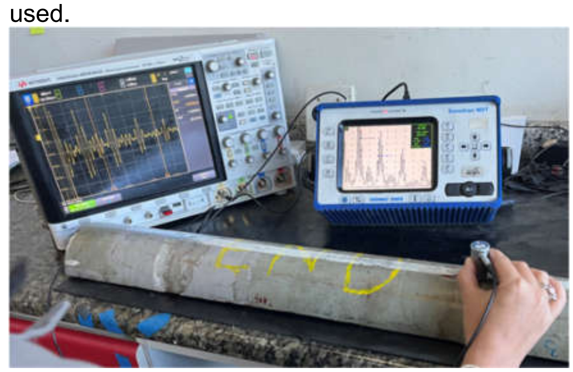

Figure 2. Bench setup used for signal collection in the half-pipe.

Three regions of the half-pipe were selected for the acquisition of ultrasonic signals in A-Scan mode and defined as uncoated and disbonded, near the ends, as indicated in Fig. 1, and a region where the liner is intact. The signals were collected in triplicate by different operators and on different days to verify the repeatability of the results.

For each A-Scan signal obtained, the interval corresponding to the first back echo was selected, and the Fast Fourier Transform (FFT) was applied to it, converting the signal from the time domain to frequency. The processing was performed using MATLAB®.

Development of Inspection Tool

Based on the obtained results and the external diameter of the evaluated tube, the development of a collar of transducers arranged alternately on two generatrices was proposed. Based on the sonic beam, this collar is capable of covering the entire internal perimeter of the pipeline, the Fig. 3 shows the design of this prototype.

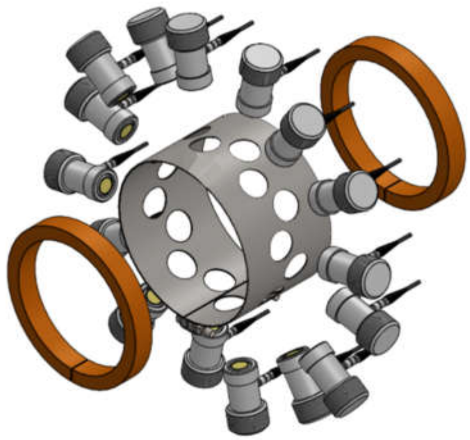

Figure 3. Design of the prototype of the ultrasound inspection tool.

Multichannel electronics was also developed to manage the tool and acquire the signals. These electronics allows the connection of up to 32 transducers simultaneously, the adjustment of inspection settings such as gain and window size with the acquired echo interval, and the saving of signals. All these mentioned points are performed remotely through the electronics' own Wi-Fi network, without the need for external internet access.

Results and Discussion

Initially, the A-Scan signal was acquired with the bench setup for each of the three regions, as shown in Fig. 4. In these images, it is possible to identify a clear distinction in the behavior of the A-Scan signals. In Figure 4.a, corresponding to the intact liner region, it is possible to observe in the 1st echo a more "widened" signal, indicating a possible delay of the signal due to the difference in propagation velocity between the materials, steel and HDPE. When the coating is disbonded, Fig. 4.b, the background echoes are presented in a narrower time interval compared to the signal from the intact liner region. In the uncoated region, Fig. 4.c, the observed signal refers only to the steel layer, with the interval corresponding to the echoes being "narrower" and a better signal-to-noise ratio among the echoes.

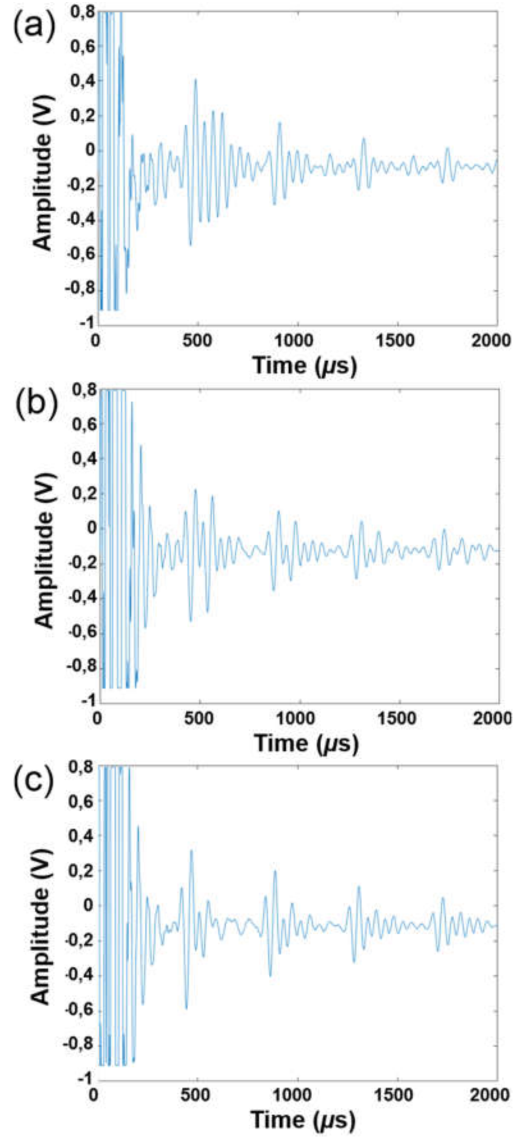

Figure 4. Ultrasonic A-Scan signals considering the stages of integrity of the polymeric lining (a) intact, (b) disbonded, and (c) uncoated.

Next, using Matlab®, the A-Scan signals from the three regions were plotted together, as shown in Fig. 5.a, allowing for a comparison of the signal behavior differences. From the complete signal, the interval from 400 μs to 700 μs, corresponding to the first response echo, was selected, as shown in Fig. 5.b. In this comparison, besides the variation in signal behavior, it is possible to observe a time lag in the intact liner signal compared to the others, as well as a more subtle lag between the disbonded and uncoated signals. Figure 5.c shows the FFT of the A-Scan signal in the same time interval as Fig. 5.b. In this case, the difference in signal behavior in the analyzed regions becomes more evident due to the difference in amplitude.

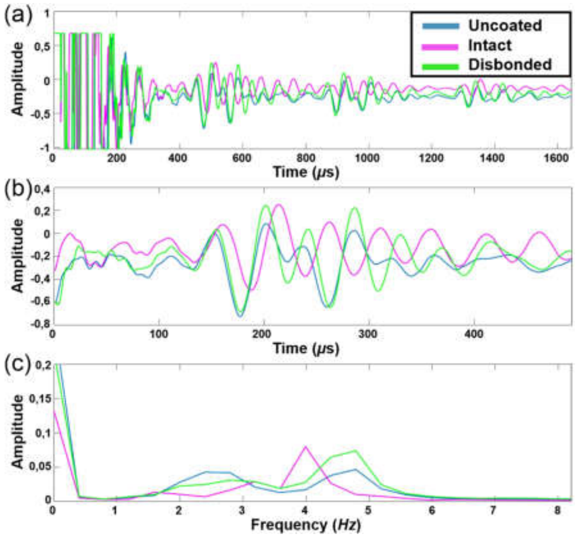

Figure 5. (a) Comparison between the ultrasonic A-Scan signals in the intact, disbonded, and uncoated regions. (b) A-Scan signal of the three regions considering the first back echo in the interval from 400 μs to 700 μs. (c) FFT of the A-Scan signal of the three regions in the interval from 400 μs to 700 μs.

Thus, the successful ability to detect the integrity state of the HDPE internal polymeric lining in a carbon steel pipe was confirmed. Both the A-Scan and FFT signals demonstrated a clear distinction between the states, indicating a promising effectiveness in the inspection of this material. From this stage, testing of the inspection tool began on the remaining part of the pipe from which the half-pipe was removed. Figure 6.a shows the tool adjusted to the pipe body to be inspected, while Figure 6.b depicts the inspection setup with the tool in the background and the acquisition of A-Scan signals from the electronics and software developed for this project.

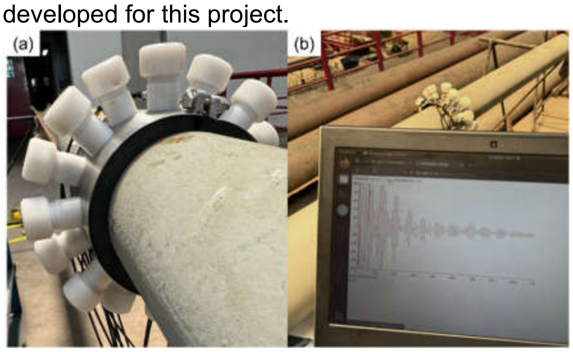

Figure 6. (a) Assembly of the inspection tool and (b) collection of A-Scan signals using the developed electronics.

Conclusions

The A-Scan signal obtained during the ultrasonic inspections of the half-pipe revealed a variation in signal behavior within the labeled regions, indicating the integrity of the liner as intact, disbonded, and uncoated. This variation enabled the identification of regions potentially experiencing coating disbond, suggesting an initial failure in the integrity of the HDPE liner in carbon steel pipelines. Consequently, the use of the tool will help minimize unplanned production shutdowns on FPSO platforms, directly reducing operating costs associated with corrective maintenance. It also allows for the scheduling of shutdowns to replace degraded sections before line clogging or corrosion-induced leaks occur.

Acknowledgments

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Responsibility Notice

The authors are the only responsible for the paper content.

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