Protection of Corrosion under Insulation using Vapor Phase Corrosion Inhibitors, Corrologic V_pCI-658

For

CORTEC Corporation

by

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Summary

For Corrosion under Insulation (CUI), the highly aggressive environment beneath insulation materials, in combination with the lack of visibility, can lead to major problems for oil and gas pipelines in refining, power and chemical processing industries. CUI is blamed for production declines, extended plant shutdowns and pipe leakage. Maintenance and plant inspection become labor and time intensive when large quantities of insulation have to be removed. Despite advances in materials and inspection technologies, CUI remains a serious and costly industry problem. In this investigation, four API 5L X65 steel pipes were insulated to determine the effectiveness of a commercially available vapor phase corrosion inhibitor (Corrologic VpCI-658). Electrochemical potential and corrosion rate were monitored under isothermal and cyclic wet/dry test conditions. Test results have demonstrated that Corrologic VpCI-658 can successfully reduce corrosion attack under insulation even in a chronic wet environment. When VpCI was used, the corrosion rate was reduced by a factor of 30. These results showed that protective coatings under the insulation are critical and require the inclusion of corrosion inhibitors like Corrologic VpCI-658 to prolong the pipe integrity and reduce inspection and maintenance cost.

Introduction

Corrosion under Insulation (CUI) is one of the major problems for oil and gas pipe lines in refining, power, and chemical processing industries, as well as marine environments. CUI is blamed for production declines, extended plant shutdowns and pipe leakage. Part of the problem stems from the difficulty of detection due to the corrosion occurring beneath the insulation. Complete removal of insulation to thoroughly inspect the materials is time consuming and expensive. Much of maintenance costs are spent on external piping inspection, insulation removal and replacement, painting and pipe repairs [1]. From the numerous case studies highlighting catastrophic failure, pipe leakage, explosions and massive cost incursions due to corrosion under insulation [2-5], it would seem that the best way of avoiding CUI is to not use insulation, which was the practice prior to the 1970 [6]. This avoidance however, in 2014, is not feasible in most cases since insulation is now used for heat conservation, fire protection, noise reduction, freeze or condensation prevention and other protective measures. Many adjustments were made in the 1970s and 1980s to correct for changes in design, materials and technology. Pipes were being insulated to save energy; however, coatings were not being used in the process [6]. A large number of corrosion failures resulted from the change in practices and inadequate solutions. Policy standards were written to address the increased amount of corrosion in the US and Europe. Numerous nondestructive methods were implemented to improve early detection of CUI, including sonic techniques (acoustic emission, ultrasound), radiography, electromagnetic techniques and electrochemical sensors [7-9]. In 1998, inorganic zinc silicates were recommended for coatings. However, several years later, zinc silicates proved to have poor performance against wet insulation and were unable to provide an effective barrier when used in a low oxygen/low carbon dioxide environment [2, 10]. Other publications suggested coatings for use under insulation that included epoxy phenolic and special coal tar epoxies (even though, benzopyrenes are considered to be carcinogenic) [9]. These standards have been modified several times since. Not surprising then, that even as CUI inspection strategies were put into the field, the annual costs continued to increase as aging facilities and equipment remained in operation without effective protective coating systems [4].

Water or moisture must be present for an electrochemical reaction to initiate and can come from the insulation, leakage, slipped jackets, seal deterioration or from temperature differentials between insulation and piping that facilitate condensation. The restricted area at the pipe/insulation interface traps moisture that then combines with oxygen and eventually develops into an electrochemical cell. In practice, CUI tends to occur where water is likely to collect, such as at low points (six o'clock position on pipes) and around discontinuities.

Systems with fluctuating temperatures are more susceptible to CUI, especially in the pipelines with repetitive cooling and warming of the insulated pipes. CUI can occur in temperatures ranging from 20-175°C [11], more severe conditions are seen in the range of 50-100°C. Chlorides and sulfides are the most likely contaminants and generally increase the rate of corrosion. There are multiple sources for chlorides coming from rain, ocean mist and even from some thermal insulation materials [6]. The insulation materials should limit the likelihood of creating an acidic environment (to maintain the pH level above 4-5 for steel pipes) [3]. Both carbon steel and stainless steel are susceptible to CUI. For carbon steel piping, water trapped under the insulation combines with chlorides and sulfates becoming more concentrated with any evaporation and sets up corrosion cells. The contaminants will lower the pH and cause corrosion (general or localized corrosion) on the carbon steel. In austenitic and duplex steel substrates, these contaminants will damage the protective chromium oxide film and cause pitting or stress corrosion cracking [12-13].

Not surprisingly, locations with significant rainfall or warm marine environments are more susceptible to CUI than facilities in cooler, drier regions. Though, CUI is affected by external environment and process conditions, it is also highly dependent on the quality of insulation and protective coatings. During the construction phase of a facility, CUI prevention should be implemented. Examples of CUI have been seen in the chemical industry (specifically, an ammonia plant) where poor quality insulation materials were used to wrap piping and the insulation did not adequately isolate the pipe from water exposure. This same piping system had undergone previous inspection, but the quality of the insulation had not been given any attention [3]. Subsequent wall thinning (due to corrosion) of the pipe resulted in rupture and leakage.

In CUI prevention, the objective is to minimize condensation of water between the insulation and the metal piping or equipment. But even when moisture is on the metal surface, there are effective methods to prevent CUI. Paint and coatings can physically prevent water contact with critical components. Conventional CUI prevention practices that are used in oil, gas and petrochemical industry consist of standards that include proper design, insulation installation and application of organic protective coatings or vapor phase corrosion inhibitors (VCI). Vapor phase corrosion inhibitors (VCI) are an alternative protection method that is both effective at controlling corrosion and inexpensive. A vapor phase corrosion inhibitor is a volatile compound and forms a stable bond at the interface of the metal, preventing penetration of corrosive species to metal surfaces [14-19]. VCI offers an alternative way to protect stored equipment, facilities and their contents. These inhibitors are easy to apply, versatile and can be used to protect multiple metal types in a variety of industries. These materials have stable passivating properties, strong tendencies toward surface adsorption, and the ability to form a comparatively strong and stable bond with the metal surface [20-22]. VCI has also excellent wetting properties and forms a clear, dry, hydrophobic film of roughly 6.35 micron on the surface that is stable up to 176°C. Adsorption of the inhibitor on to the metal surface provides a protective hydrophobic inhibitor layer to slow corrosion significantly. Compared to other methods of corrosion prevention such as gas blanketing and dehumidification, vapor phase corrosion inhibitors (VpCI) provide substantially better corrosion control at lower cost and require very low dosage rate. The VpCI used in this investigation is a chemical additive that is formulated for rapid transport throughout the insulating jacket or thermal insulation to reach the pipe surface. Application is by injection into the insulating jacket either through a gravity feed system or a portable injection pump.

Materials and Methodology

In this investigation, the effectiveness of commercially available vapor phase corrosion inhibitors against CUI was determined. API 5L X65 mild steel piping (110 cm length x 5 cm diameter) was insulated with (2.0 cm) thermal insulation and (1.25 cm) thick foam. All pipes were sand blasted and polished to 600 grit using silica carbide (SiC) abrasive papers and rinsed with alcohol prior to use (SSPC-SP 5/NACE No. 1, White Metal Blast Cleaning condition). Figures 1-4 show the assembled CUI test samples before and after covering with a 10 cm diameter PVC pipe (CUI Shield) and caps at both ends. To avoid crevice corrosion, the first 15 cm of each end was wrapped with corrosion resistant tape. A wetness sensor made of copper and aluminum strips (galvanic cell) was applied to the lower side of the pipe prior to adding the insulation as seen in Figure 2. The sensor monitored the surface wetness and duration of wetness by measuring the galvanic voltage. When water bridges between the two metal strips it generates a voltage (a galvanic potential between 500-600 mV). If the area is dry, then no voltage is recorded. Furthermore, monitoring voltage provides a nondestructive assessment of degree and duration of wetness. This method can also be used to determine specific areas that require visual inspection for corrosion attack.

Four samples were assembled, two samples were used as controls (no inhibitor applied), and two samples were wrapped with thermal insulation that was impregnated with a commercially available inhibitor, Corrologic VpCI-658. The effectiveness of this inhibitor at minimizing CUI damages was evaluated by different corrosion tests. Two samples (one with inhibitor, 1 control) were placed in in a cyclic corrosion test chamber for 4800 hours. A 24 hour cycle consisted of 8 hours salt spray, 8 hours humidity at ambient temperature, and 8 hours dry cycle at 45°C. The samples (one with inhibitor, 1 control) were disassembled every 720 hours (30 days) to evaluate their surface condition and document the extent of corrosion damage at pipe/insulation interfaces. The remaining two samples were tested in wet and dry cycles. A 200 ppm sodium chloride solution was injected by tube into the pipe/insulation interfaces every 48 hours. Hot dry air (120-140^{o}C) was blown through the pipes (inner diameter) for two hours per day and ten held at ambient temperature. These samples were also disassembled every 720 hours (30 days) for visual inspection and evaluation. Corrosion rates were continuously monitored using Metal Samples MS3500E (a data-logger for data storage) and electrical resistance probes.

a)

b)

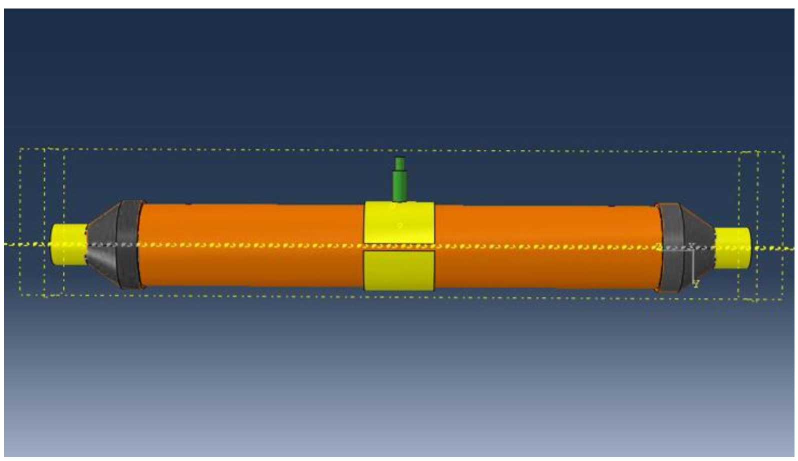

Figure 1: Schematic of (a) unassembled components: 2 inch (5 cm) diameter pipe, caps, insulation and sensor elements and (b) assembled sample for CUI tests.

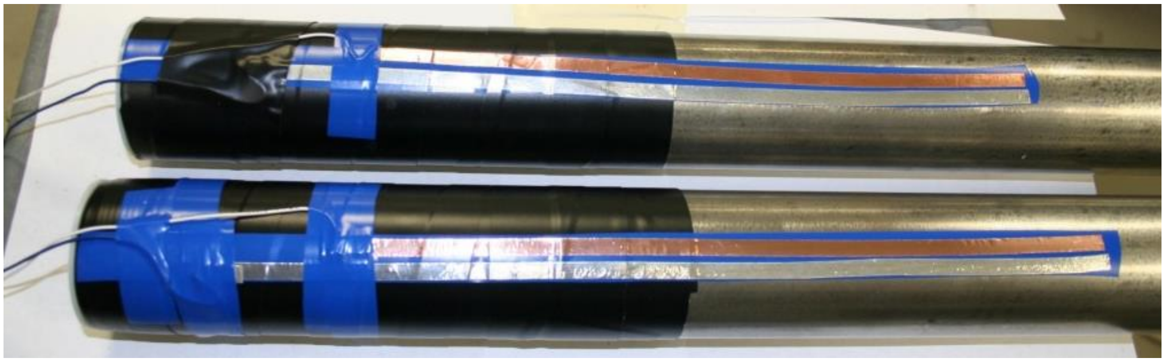

Figure 2: Wetness sensors seen on top of pipe prior to insulation.

Figure 3: Assembled test samples in test chamber showing ER test probes and salt solution feed tubes. Every 48 hours, a 50 ml solution was injected at pipe/insulation interfaces.

Figure 4: Assembled test samples in test chamber showing ER test probes and solution or V_pCI feed tubes. Corrosion rate was recorded continuously using ER and Data collectors.

Results

The effectiveness of commercially available vapor phase corrosion inhibitors against CUI was investigated. Cyclic polarization tests on the API 5L X65 mild steel piping were conducted at multiple temperatures to determine the passive regions in the Corrologic VpCI-658. Figure 5 shows the polarization behavior for API 5L X65 mild steel in the Corrologic VpCI-658 with 200 ppm chloride ions. The most noticeable changes are the positive shift in the breakdown potential and expansion of the passive range for these alloys in the presence of Corrologic VpCI-658. The inhibitor changed the reactivity by reducing the pH level, increased the passivation range significantly, and was beneficial in reducing localized corrosion damages. Wetness probes were positioned at six o'clock to determine the degree of wetness at pipe/insulator interfaces. When the probes read ~ -600 mV, this indicates that water has reached the pipe/insulator interface and corrosion is imminent. Potential measurements can be used as a corrosion gauge and location indicator where possible corrosion may exist. The coatings in areas where water has reached the pipe interface should be removed for further inspection. Figure 6 shows the wetness probe data from monitoring the surface potential throughout testing. This collection of data is for a 600 hour time frame to demonstrate how often the pipe surfaces were wet and the wetness duration cycle. The CUI warning system using the galvanic CUI sensor (wired or wireless systems) is an effective monitoring method for the wet pipe sections of long pipe systems [22]. Removal of insulation for more thorough inspection would be needed only when the wetness sensor indicates a wet surface for a long duration (as determined by voltage measurements). Once water penetrates an insulation material, a highly corrosive environment may result at the interface between the insulation and steel substrate. Moisture may collect on the surface, leading to prolonged periods of moisture contact and more corrosive contaminants. Inspection priorities in the field can be scheduled as a function of wetness duration and can significantly reduce the visual inspection cost.

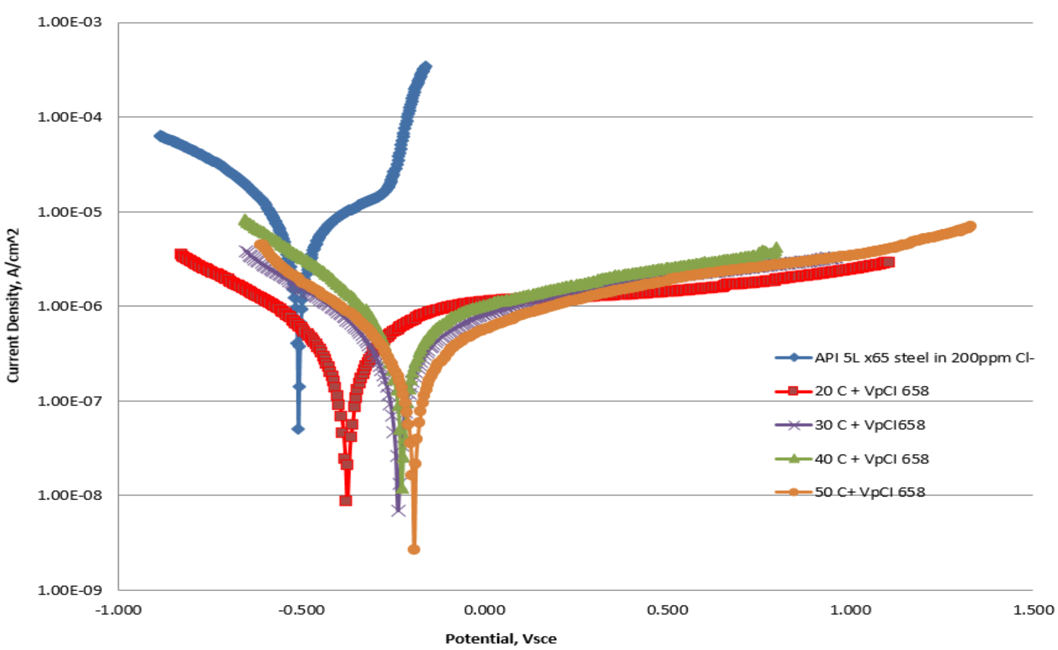

Figure 5: Cyclic polarization for API 5L X65 steel in solution of 200 ppm chloride ion solution + Vapor phase Corrosion Inhibitors, Corrologic V_pCI-658. Addition of Corrologic VpCI-658 to environment significantly increase passivity and resistance to corrosion.

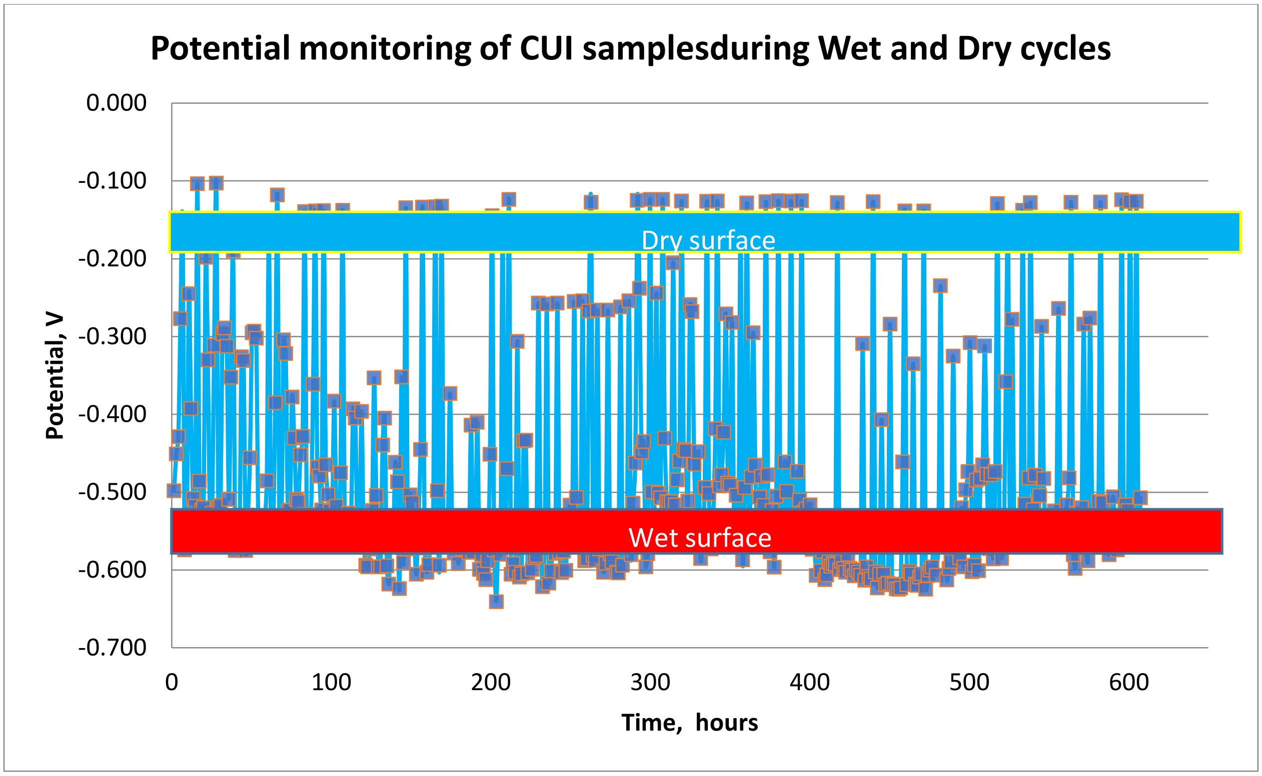

Figure 6: Monitored potential from wetness sensor during wet/dry cycling. The surface is wet when measured potential is -500 to -600 mV, and tends to be dry when potential shifted to higher than -200 mV.

As seen in Figures 7-21, the comparison of pipe interfaces after various exposure time ranging from 330 hours to 5,800 hours of testing shows significant corrosion attack and red rust formation for the sample with no inhibitor. The sample treated with inhibitor provided good protection for the pipe despite the harsh and continuously aggressive wet/dry environment inside the insulation. The inhibitor treated pipes were relatively clean and corrosion free. Further assessment of the test sample conditions were done by the ER probes that continuously measured the corrosion rate. As well, the electrode probe surface that sat flush with the metal pipe control sample, showed red rust formation (Figures 10, 19). The probe used to monitor the corrosion rate for the pipe protected with inhibitor was clean, showing no corrosion residue. Figure 21 shows clearly that addition of vapor phase corrosion inhibitor is very critical to improve life expancy of the insulated pipes. Figure 22 compares the corrosion rates; the control sample with no inhibitor measured an average of 0.96 mpy and as high as 2.2 mpy at 110 hours of testing. The inhibitor treated sample had a corrosion rate that was very low in the range of 0.03 to 0.04 mpy. The results verified that Corrologic V_PCI-658 managed to form a clear, dry, hydrophobic film on the pipe and protected the pipe surface.

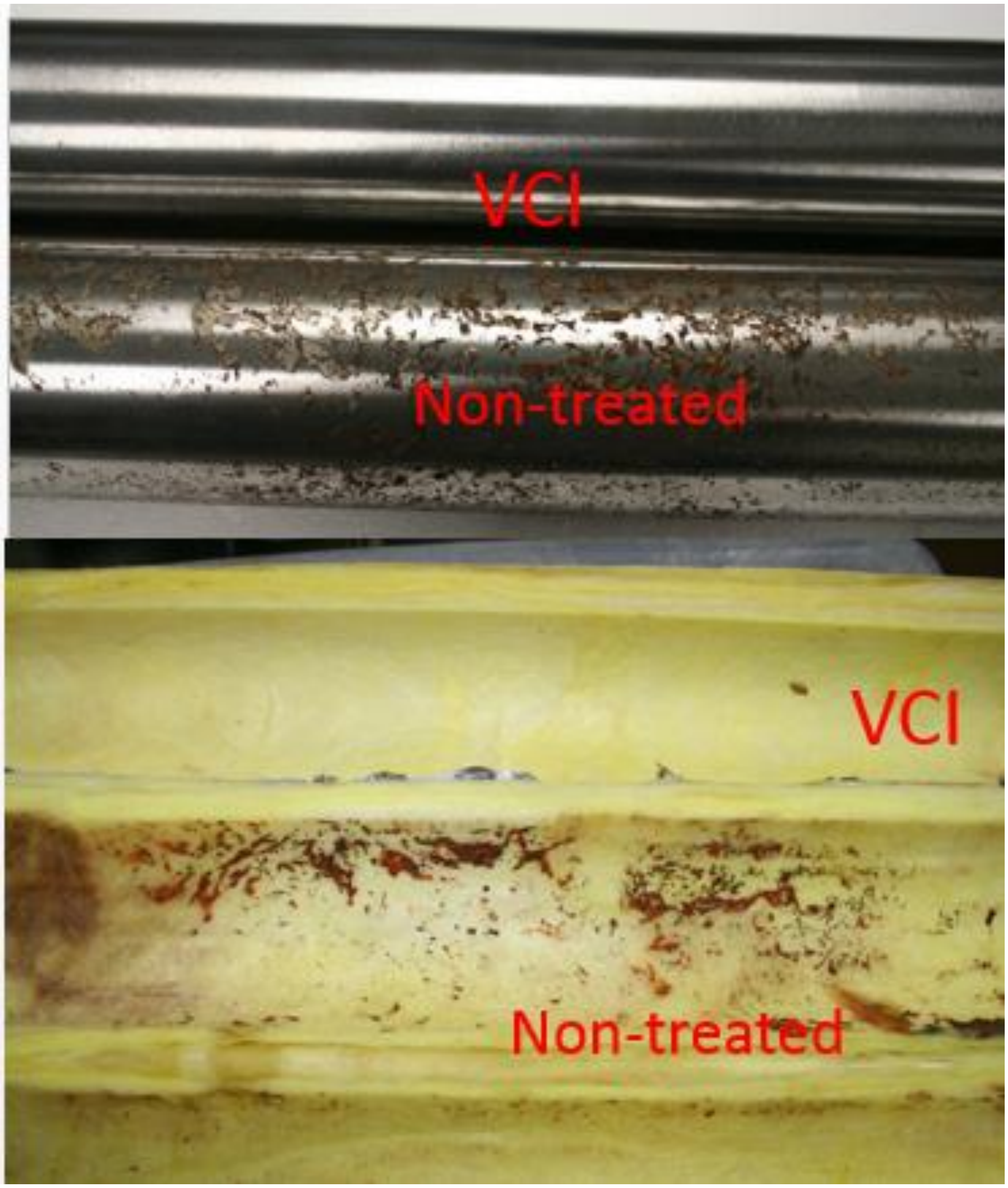

Figure 7: Comparison of surface of the insulation/pipe interfaces after 14 days (330 hours), V_pCI-658 inhibitor treated pipe shows no corrosion attack, while the control sample showed red rust formation at its interface.

Figure 8: Corrologic V_pCI-658 treated pipe shows no corrosion attack, while the control sample showed red rust formation at its interface.

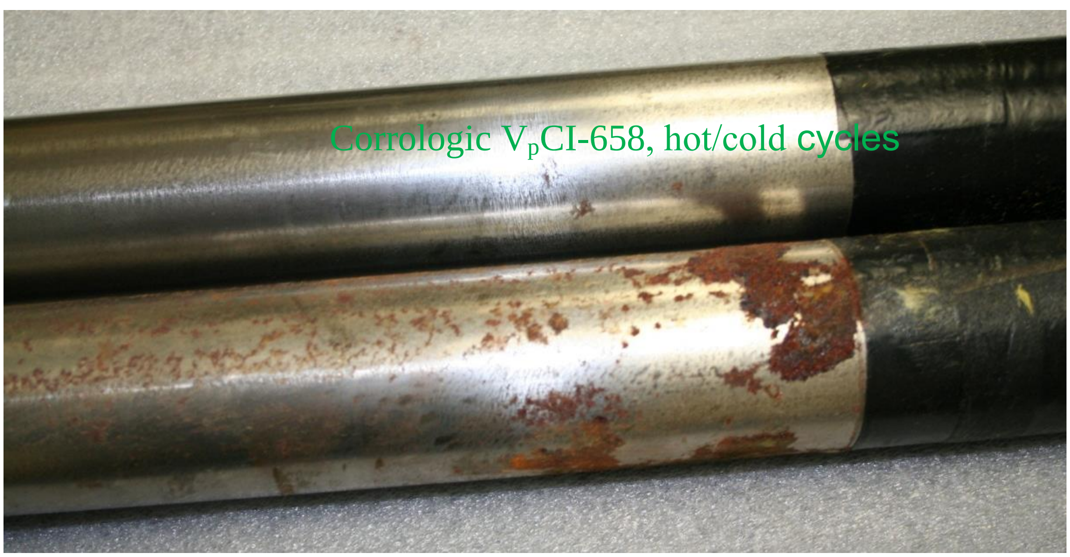

Figure 9: Comparison of surface of the insulation/pipe interfaces after 60 days (1440 hours), Corrologic V_pCI-658 treated pipe shows no corrosion attack, while the control sample showed red rust formation at its interface.

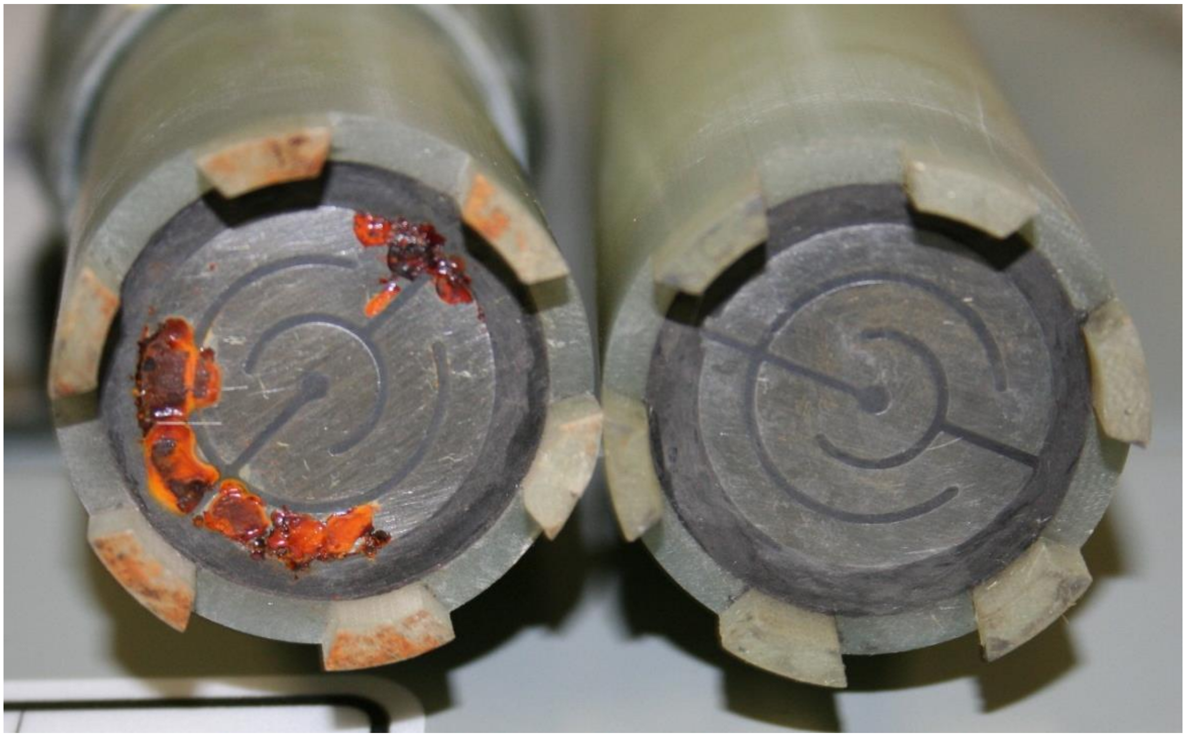

Figure 10: Comparison of electrical resistance probes used to measure the corrosion rate of the CUI samples after 60 days exposure. The control sample shows red rust formation; while sample treated with Corrologic V_pCI-658 is clean and shows no corrosion residue.

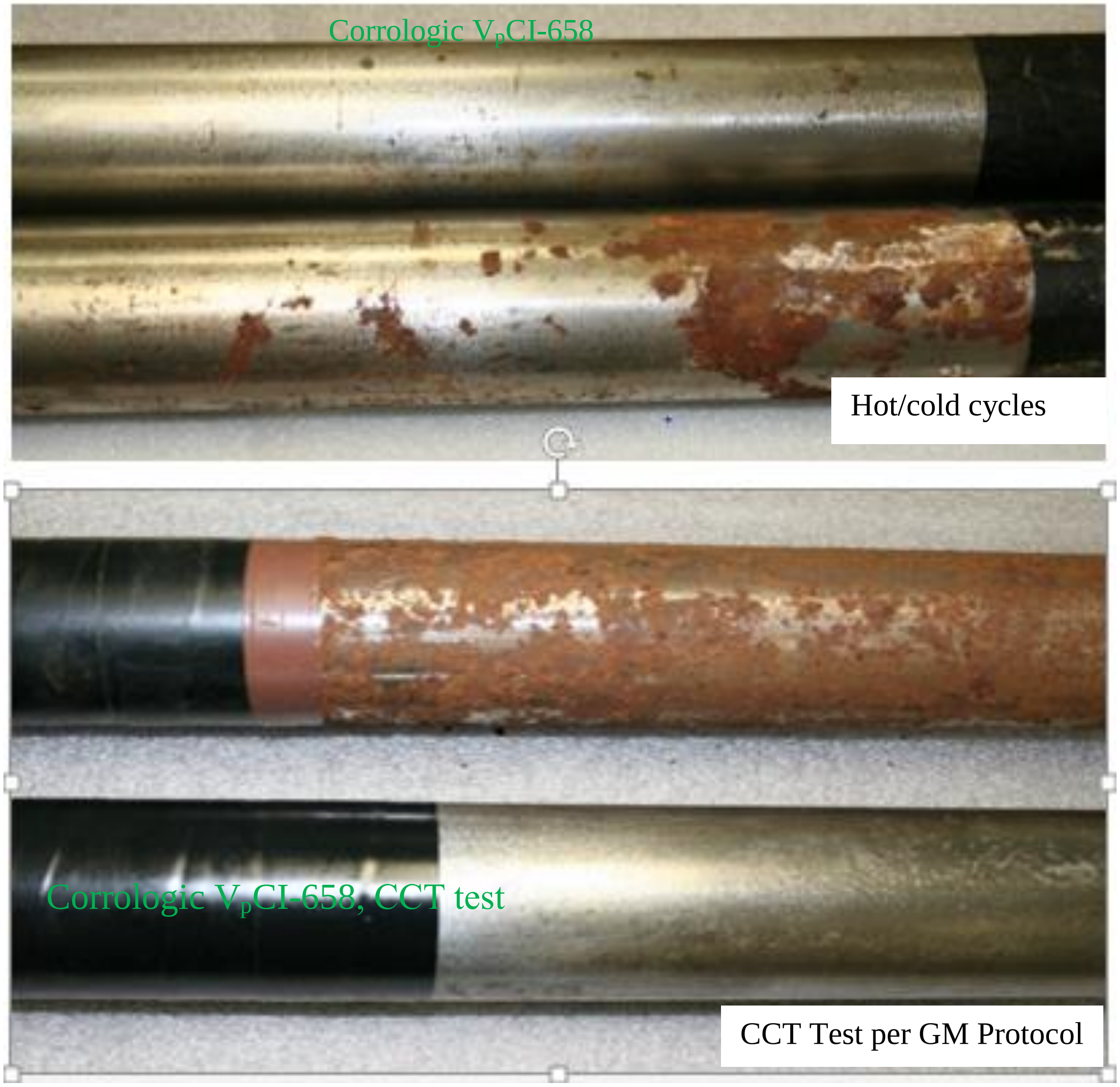

Figure 11: Comparison of surface of the insulation/pipe interfaces after 90 days (2160 hours), Corrologic V_pCI-658 treated pipe shows no corrosion attack, while the control sample showed red rust formation at its interface.

Figure 12: Comparison of surface of the insulation/pipe interfaces after 120 days (2880 hours), inhibitor treated pipe shows no corrosion attack, while the control sample showed red rust formation at its interface.

Figure 13: Comparison of surface of the insulation/pipe interfaces after 150 days (3600 hours), inhibitor treated pipe shows no corrosion attack, while the control sample showed red rust formation at its interface.

Figure 14: Comparison of insulation/pipe interfaces after 176 days (4,220 hours); inhibitor treated pipe shows no corrosion attack, while the control sample shows red rust formation.

Figure 15: Comparison of insulation/pipe interfaces after 210 days (5,040 hours); inhibitor treated pipe shows no corrosion attack, while the control sample shows red rust formation.

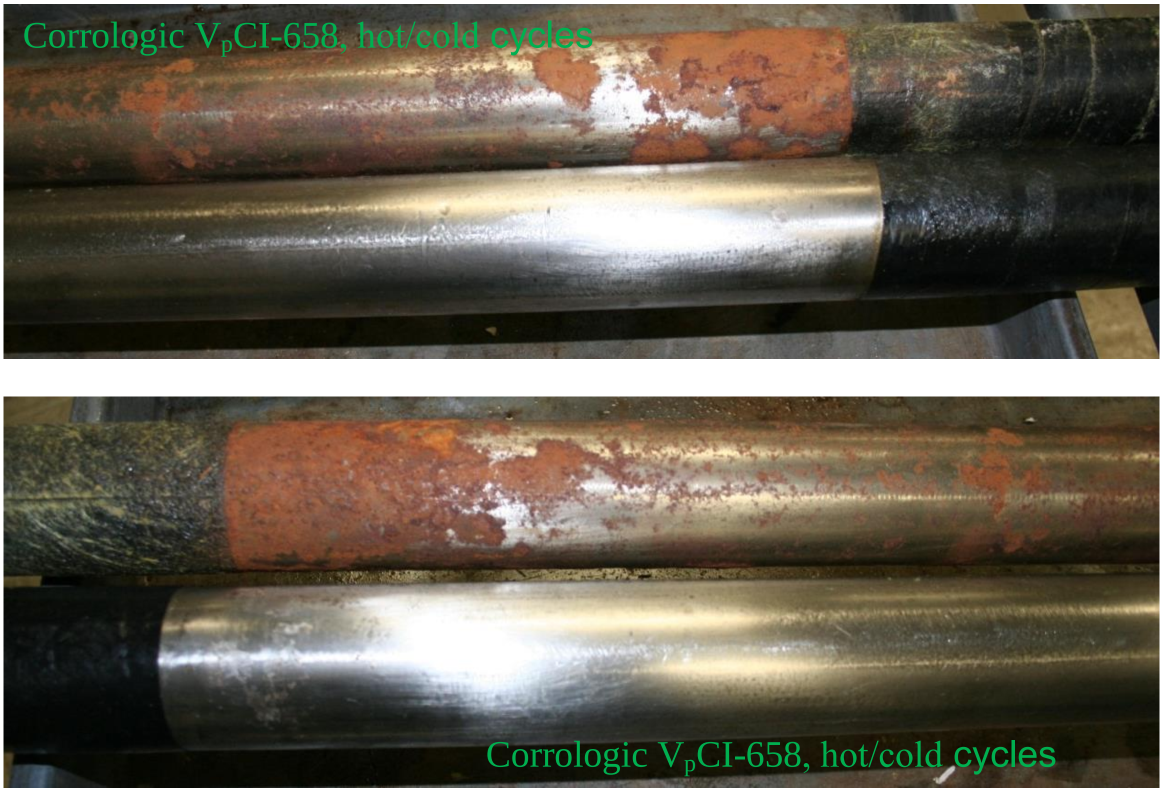

Figure 16: Hot/cold cycles - Comparison of insulation/pipe interfaces after 210 days (5,040 hours): inhibitor treated pipe shows no corrosion attack, while the control sample shows red rust formation.

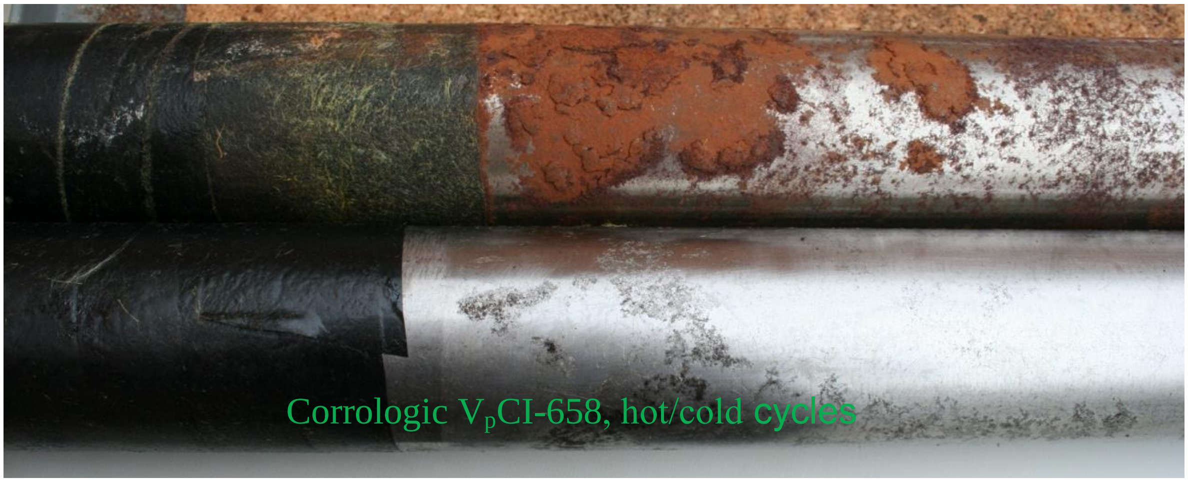

Figure 17: Hot/cold cycles - Comparison of insulation/pipe interfaces after 242 days (5,800 hours). Inhibitor treated pipe shows no corrosion attack, while the control sample shows red rust formation.

Figure 18: CCT corrosion tests - Comparison of insulation/pipe interfaces after 242 days (5,800 hours); Corrologic V_pCI-658 treated pipe shows no corrosion attack, while the control sample shows red rust formation.

Figure 19: CCT GM protocol corrosion tests - Comparison of ER test probes and insulation/pipe interfaces after 242 days (5,800 hours); inhibitor treated pipe shows no corrosion attack, while the control sample shows red rust formation.

Figure 20: (Hot/cold cycles tests) Comparison of insulation/pipe interfaces after 242 days (5,800 hours): Corrologic V_pCI-658 treated pipe shows no corrosion attack, while the control sample shows red rust formation.

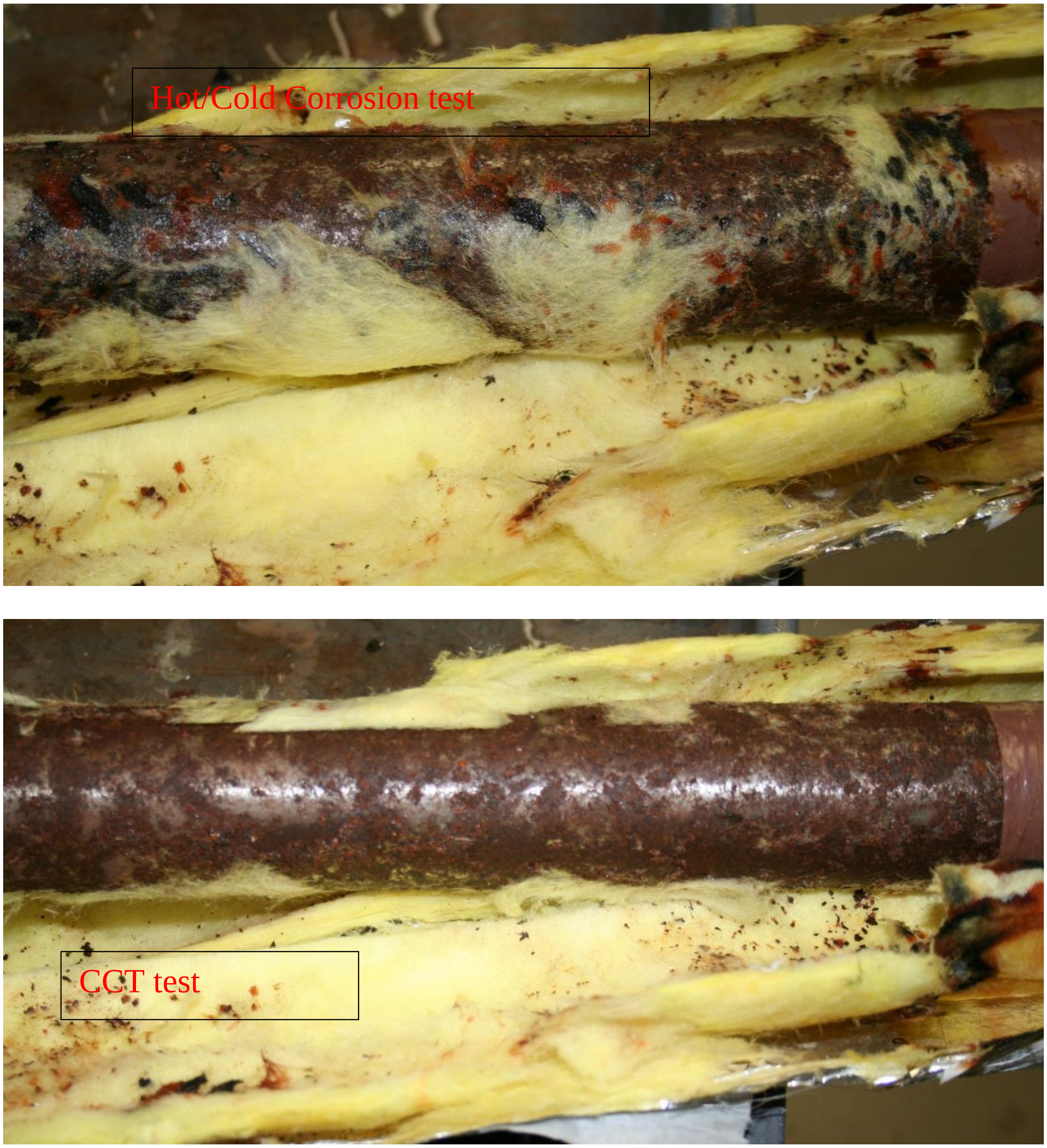

Figure 21: Photos of insulation/pipe interfaces after 242 days (5,800 hours): without Corrologic V_pCI-658 treated pipe shows severe corrosion and red rust formation.

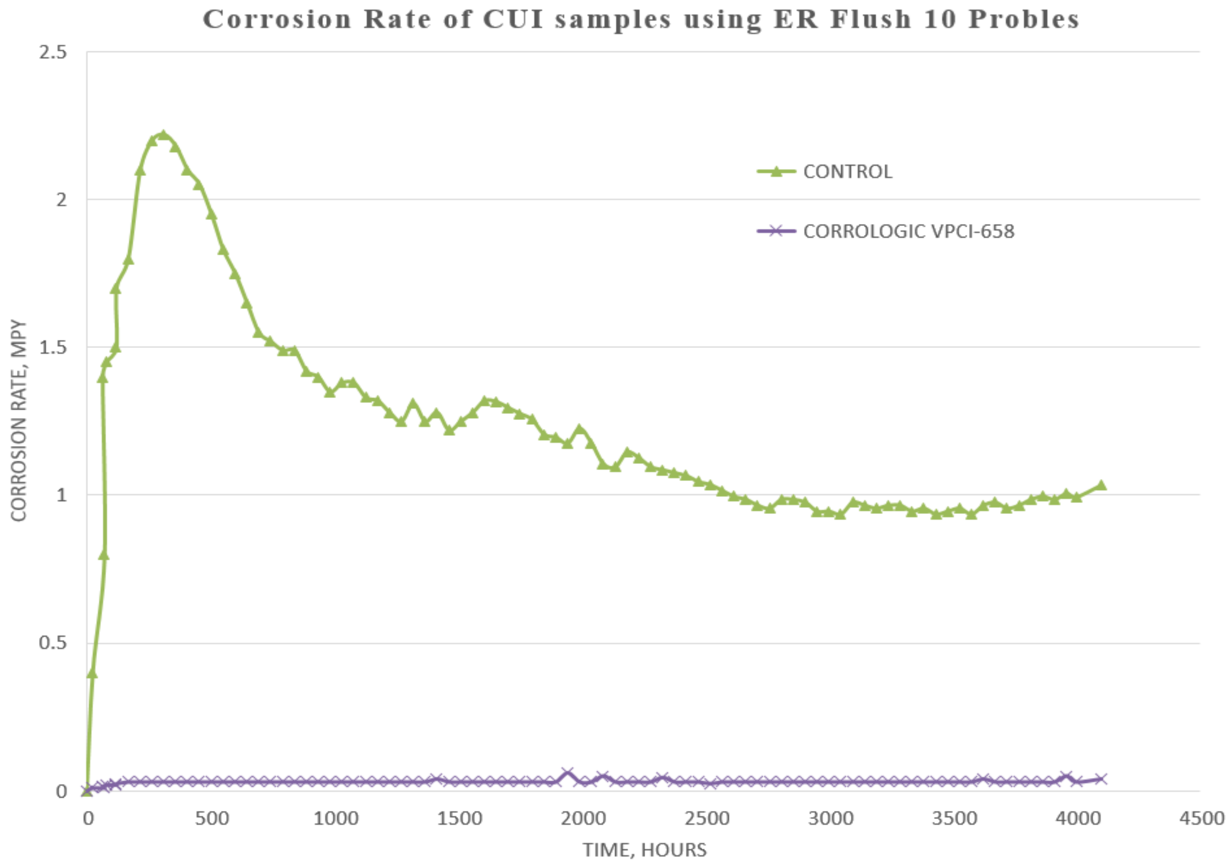

Figure 22: Comparison of corrosion rate from the ER probes. The control sample (no inhibitor) measured about 0.96 mpy and as high as 2.2 mpy at 110 hours of testing, compared to the Corrologic V_pCI-658 treated sample with a corrosion rate in the range of 0.03 to 0.04 mpy.

Conclusion

The effectiveness of commercially available vapor phase corrosion inhibitors, Corrologic V_pCI-658 against CUI was investigated using corrosion testing and corrosion rate measurements in isothermal and cyclic wet/dry test conditions. API 5L X65 steel pipes were insulated with thermal insulation, foam and placed in laboratory simulated CUI environment to monitor the degree of pipe surface wetness and corrosion behaviors. Results have demonstrated that Corrologic V_pCI-658 can successfully reduce corrosion attack under insulation despite the pipe surfaces being maintained in continuously wet/dry cyclic conditions. Electrochemical polarization behavior showed the addition of Corrologic V_pCI-658 to the environment expands the passive film stable region. The passive film breakdown potential Corrologic V_pCI-658 treated steel samples increased by nearly 1.0 volt, indicating less susceptibility to localized corrosion.

The ER probe corrosion rate was reduced from ~2.2 mpy for the control samples to less than 0.03 mpy for the Corrologic V_pCI-658 treated pipes, a change of corrosion rate by a factor of 30 for the pipes protected with Corrologic V_pCI-658.

Wetness probe system using galvanic sensor is a practical remote monitoring method (non-visual and non-destructive) when pipe sections are being exposed to wetness by the insulation system. Inspection priorities can be determined as a function of duration of wetness. This can significantly reduce the visual inspection cost, so that CUI reduction becomes manageable.

These results showed that an effective protective coating system under the insulation (Figure 21) is critical and requires the inclusion of vapor phase corrosion inhibitors to prolong the pipe integrity and lower inspection and maintenance cost.

References

[1]. B.J. Fitzgerald, P. Lazar III, R.M. Kay, S. Winnik, Strategies to Prevent Corrosion Under Insulation in Petrochemical Industry Piping, CORROSION/2003, NACE paper no. 03029, Houston, TX.

[2]. S. Winnik, Corrosion-Under-Insulation (CUI) Guidelines, Boca Raton, FL, Woodhead Publishing and Maney Publishing, 2008. ISSN 1354-5116.

[3]. F. De Vogelaere, Corrosion Under Insulation, Process Safety Progress (Vol.28, No.1), Wiley InterScience, March 2009.

[4]. J. Houben, B.J. Fitzgerald, S. Winnik, K. Chustz, M. Surkein, Deployment of CUI Prevention Strategies and TSA Implementation in Projects, NACE 2012, paper no. C2012-0001100.

[5]. W. Geary, Analysis of a corrosion under insulation failure in a carbon steel refinery hydrocarbon line, Case Studies in Engineering Failure Analysis 1 (2013) 249–256.

[6]. J.F. Delahunt, Corrosion Under Thermal Insulation and Fireproofing an Overview, NACE paper no. 03022, Houston, TX, 2003.

[7]. S. Caines, F. Khan, and J. Shirokoff, Analysis of pitting corrosion on steel under insulation in marine environments, Journal of Loss Prevention in the Process Industries 26 (2013) 1466-1483.

[8]. H. Cho, Y. Tamura, T. Matsuo, Monitoring of Corrosion Under Insulations by Acoustic Emission and Humidity Measurement, June 2011, Volume 30, Issue 2, pp 59-63, Springer Science & Business Media.

[9]. L. Reiner and B. Bavarian, Thin Film Sensors in Corrosion Applications, CORROSION 2007, paper #07388, Mar 11-15, 2007.

[10]. M. J. Mitchell, A. Nobel, Corrosion Under Insulation New Approaches to Coating & Insulation Materials, NACE paper no. 03036, 2003.

[11]. T. Hanratty, Corrosion under insulation is a hidden problem, Hydrocarbon Processing, March 2013, p 51-52.

[12]. M.S. Kumar, M. Sujata, M.A. Venkataswamy, and S.K. Bhaumik, Failure analysis of a stainless steel pipeline, Engineering Failure Analysis 15 (2008) 497–504.

[13]. P. Roffey, E.H. Davies, The generation of corrosion under insulation and stress corrosion cracking due to sulfide stress cracking in an austenitic stainless steel hydrocarbon gas pipeline, Engineering Failure Analysis 44 (2014) 148–157.

[14]. J. Holden, A. Hansen, A. Furman, R. Kharshan and E. Austin, Vapor Corrosion inhibitors in Hydro-testing and Long Term Storage Applications, CORROSION/2010, paper # 10405, NACE International, Houston, TX., 2010.

[15]. M. Kharshan, and C. Cracauer, Applications for Biodegradable Vapor Phase Corrosion Inhibitors, MP, NACE International March 2011.

[16]. A. Furman, M. Kharshan, Methodology of VCIs for Water Treatment, CORROSION/97, paper no. 182, NACE International, Houston, TX, 1997.

[17]. B.A. Miksic, R.H. Miller, Fundamental Principals of Corrosion Protection with Vapor Phase Inhibitors, 5th European Symposium on Corrosion Inhibitors, Italy, 1980.

[18]. C.G. Moore, B.A. Miksic, Vapor Corrosion Inhibitors, CORROSION/95, paper no. 490, NACE International, Houston, TX, 1995.

[19]. C. Kraemer, A Procedure for Testing the Effect of Vapor Phase Corrosion Inhibitors on Combined Multi Metals, paper no. 178, NACE International, Houston, TX, 1997.

[20]. M. Lagrenée, B. Mernari, M. Bouanis, M. Traisnel and F. Bentiss, Study of the mechanism and inhibiting efficiency of 3,5-bis(4-methylthiophenyl)-4H-1,2,4-triazole on mild steel corrosion in acidic media, Corrosion Science, Vol 44, Issue 3, March 2002.

[21]. F. Bentiss, B. Mernari, M. Traisnel, H. Vezin and M. Lagrenée, On the relationship between corrosion inhibiting effect and molecular structure of 2,5-bis(n-pyridyl)-1,3,4-thiadiazole derivatives in acidic media: AC Impedance and DFT studies, Corrosion Science 53 (2011).

[22]. M. Funahashi, Solution to CUI with Three Layered Control and Warning Systems, NACE paper no. 4079, 2014.