CorrosionRADAR for Remote Monitoring of Corrosion Under Insulation (CUI) with Industrial IOT

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Abstract

This paper explores the utilization of digital technologies, specifically the Industrial Internet of Things (IIOT), in the context of predictive Corrosion Management, focusing on a compelling case of corrosion occurring under insulation. It discusses the implementation of digitalization tools and presents real-world examples of their application in the field. By harnessing digital data collection and predictive algorithms based on factors like moisture levels and temperature, hidden corrosion issues such as Corrosion Under Insulation (CUI) can be effectively managed.

This approach involves leveraging gathered data to comprehensively oversee assets, identify high-risk areas, and plan inspections and maintenance proactively. The paper outlines a predictive methodology enabling asset owners to manage their assets both economically and safely by identifying and addressing risks beforehand. This technology integrates sensors to assess conditions under insulation and employs predictive modeling to swiftly estimate potential risks.

The paper delves into various use-cases and practical applications, demonstrating how employing sensors and industrial IoT can revolutionize the detection and prediction of corrosion in the field. This advancement holds significant promise for ensuring the integrity of assets plagued by concealed corrosion issues like CUI. The paper also presents the latest field case studies, bolstering confidence in this monitoring approach and contributing to the ongoing development of knowledge within the corrosion industry.

Keywords: *Corrosion Under Insulation, CUI, Remote monitoring, Industrial IOT*

1 INTRODUCTION

Based on analysis by AMPP the corrosion costs countries approximately 4.2% of their Gross National Product (GNP) on average. In the United States, this figure rises to around 6% of GNP. Corrosion costs can be categorized as direct or indirect. Direct costs involve equipment failure, repair, and maintenance, while indirect costs encompass production losses. For instance, in a gas sweetening plant, the production loss due to corrosion in just one unit equals 47% of the unit's annual direct corrosion costs. Production losses can occur due to scheduled turnarounds, inspections, or worse, unplanned shutdowns resulting from corrosion failures.

Corrosion under insulation (CUI) is a significant concern in industrial plants as insulation is applied for various reasons, such as heat conservation, cold conservation, thermal protection, process stabilization, and winterizing. Additionally, insulation is used for sound control, condensation control, freeze protection (e.g., heat tracing), and fire protection. Erickson et al. identified around 175,000 vulnerable locations in above-ground pipelines on the North Slope of Alaska susceptible to CUI. CUI often remains undetected for extended periods and is only discovered when insulation and cladding are removed. The corrosion rate of carbon steel under insulation can be 20 times higher than in normal conditions, making CUI particularly challenging.

Current guidelines advise against unnecessary insulation application and propose alternatives like screens or protection bars due to the high corrosion rates under insulation. The widespread use of insulation on equipment below 150°C became common during the 1970s when petroleum costs were high. CUI also poses challenges in cryogenic services, where assets are insulated, and water condensation is possible. It affects liquid storage tanks and intermittent cryogenic transmission piping.

Given the economic impact, insidious nature, and mitigation efforts involved, CUI is a crucial topic in asset integrity and corrosion management. This article delves into the significance of CUI as one of the most challenging types of corrosion to predict and mitigate. It explores the use of Industrial Internet of Things (IIOT) technology in mitigating CUI in cold service equipment and presents a real-world field application case.

2 CORROSION UNDER INSULATION MANAGEMENT PRACTICES

2.1 CUI Risk Management

CUI is a challenge to the industry, and plants try to tackle it in many ways ranging from strict measures such as full removal of insulation, to minimal inspection accompanied by oftentimes ineffective NDT methods. This underpins the lack of a systematic approach to CUI management [7].
All the strategies in asset integrity management are founded on plan, do, check, and act (PDCA) approach. At the planning stage the parameters leading to the risk of equipment or piping are established and risk values are assessed.
In the next stage, the risk mitigation activities including the inspections are performed. Then, it is verified that the current risk mitigation activities are sufficient or require improvement. Next, the achieved results are used to update the strategy, and standardization and procedure development. This cycle goes on leading to constant improvement of the system.
A presentation of the PDCA cycle for CUI is given in Fig.1.

2.2 CUI Risk Based Inspection

With regards to CUI Risk assessment, API 581 and DNVGL RP-G109 have taken two different approaches. API 581 considers CUI as a form of thinning (in case of ferritic CUI) and Chloride SCC (in case of austenitic CUI) and applied similar approaches for damage factor calculations on them which will be discussed further below while DNVGL considers CUI situation as a form of failure for which different barriers must fail before it happens.

Fig.1 *Corrosion under insulation plan-do-check-act approach to achieve asset integrity [7]*

It is worth noting that both methodologies use the same concept of risk as the multiplication of probability of failure and consequence of failure as shown in Risk = Probability of Failure (PoF) X Consequence of Failure (CoF) Eq. 1 . Not much can be done to reduce the consequence of failure as it is well rooted into plant's operational and design conditions. However, PoF can be reduced effectively leading into risk reduction.

Risk = Probability of Failure (PoF) X Consequence of Failure (CoF) Eq. 1

2.3 CUI Monitoring

There are different approaches to monitoring of CUI. Each approach might use one or a combination of physical properties to monitor CUI progress. These include the electrical resistance, ultrasonic waves reflection by water, change in capacitance or electromagnetism with moisture presence, and measurement of electrochemical impedance of the degraded coatings [8].

Commercially available sensors for CUI monitoring and the parameters they use to detect CUI are listed below:

1. Indirect CUI measurement by sacrificial wire
2. Wall thickness measurement
3. Water accumulation
4. Moisture/humidity
5. Spot sensors
6. Electrical capacitance
7. Electromagnetic waves
8. Coating degradation
9. Fiber optics

The monitoring devices available in the market usually try to detect moisture under the insulation to monitor the conditions leading to the CUI. Also, the monitoring techniques use sacrificial sensors which can send signal when the environment is conducive to corrosion.

2.4 Industrial Internet of Things

The industrial internet of things (IIoT) is the use of smart sensors and actuators to enhance manufacturing and industrial processes. Also known to enable Industry 4.0, IIoT uses the power of smart equipment and real-time analytics to take advantage of the data. Connected sensors and actuators enable companies to pick up on inefficiencies and problems sooner and save time and money, while supporting business intelligence efforts.

In manufacturing, specifically, IIoT holds great potential for quality control, sustainable and green practices, and overall supply chain efficiency. In an industrial setting, IIoT is key to processes such as Predictive Maintenance (PdM), for condition-based maintenance in asset integrity management. Corrosion risk management have emerged as an attractive use case of remote monitoring enabled by IIOT technologies.

The core components of IIOT technology are:

- Connected devices that can sense, communicate and store information
- Data communications infrastructure including wireless networks
- Storage for the data that is generated by the IIoT devices
- Analytics and applications that generate insights from raw data
- Dashboard applications for decision making

3 USE CASES AND APPLICATIONS

3.1 Cold Service CUI cases

There are some characteristics in certain processes and operating conditions that make equipment generically prone to the CUI. Previous histories of failure are reported in the literature for molecular sieve dryers [9] and fractionation refrigerators demonstrate that cold temperature services can suffer from CUI, no matter the design measures taken to mitigate it. Even the use of resistant but costly coatings such as thermal sprayed aluminum (TSA) might not alleviate the problem.

3.1.1 Constant Cold Service

Equipment operating in cold service range such as chilling equipment and refrigerants (Fig.2) are usually assessed with lower corrosion rates in risk models, or even as immune. This is due to the common understanding that corrosion rate is low at zero or sub-zero temperatures. However, the failures that have occurred in the industry undermine this supposition.

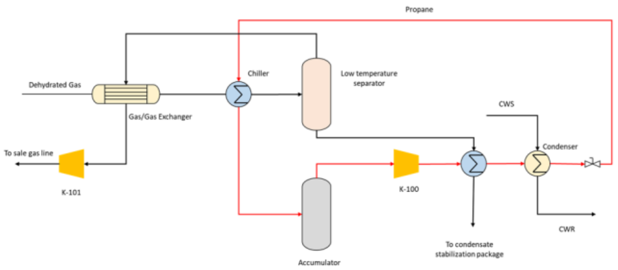

Fig. 2 *Process flow diagram of propane refrigeration system for condensate separation. The propane loop is the refrigeration loop [10].*

Equipment working at low temperatures is usually protected through vapor barrier coatings. This additional design requirement adds to the complexity and risk in comparison to their hot temperature counterparts. There are cases of severe CUI observed in fractionation units where the protection by vapor barrier is lost and water has condensed on the surface.

The requirement to keep cold service equipment isolated to avoid water ingress and condensation under the insulation due to low temperature, makes the condition for their inspection more complex.

Bear in mind that replacing insulation with metal cages or use of inspection windows as it is common for some hot insulations are ruled out for cold insulations. The plant management has no option but to inspect them fully either by non-intrusive techniques or by complete delagging during shutdowns [11].

Therefore, counterintuitively, operating under cold service, or having parts or sections of the system operating in this temperature range, can increase the CUI risk compared to hot service.

3.1.2 Cyclic Cold Operating Temperatures

Cyclic operating temperature can also exacerbate the CUI situation for cold temperature services. Constantly operating at sub-zero temperatures may only cause CUI to occur at hot fingers (areas where the temperature allows the formation of water), but in the case of cyclic operation, liquid water may form underneath the insulation.

One such example is the molecular sieve dryer and piping (e.g. in ethylene plant). Fig 3 shows a failure that occurred in this cold service process.

1. The dryer passes through three stages of operation:
2. Cold temperature when in drying mode (30 bar, -17oC)
3. High temperature in the regeneration mode (4 bar, 220oC)

Ambient temperature in the cooling mode

There are usually two dryers in the unit. When one is in service, the other dryer is in regeneration mode. In this case, the wet fluid enters the dryer which is in operation at cold temperature and the water is adsorbed on the molecular sieve resins.

In regeneration mode, however, the inlet valve is closed and now the hot stream is passed through the molecular sieve resins from the outlet. Finally, to put the dryer back to service, it should be cooled down at ambient temperature.

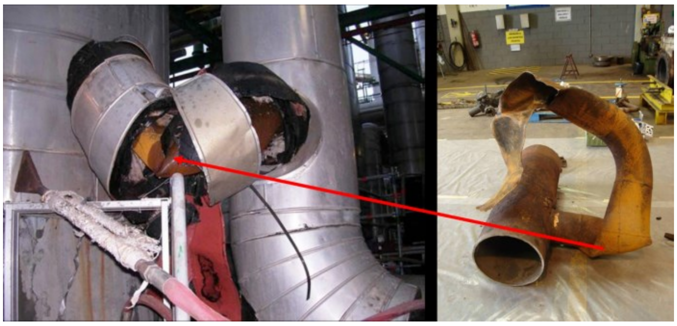

Fig 3 *Failure of a carbon steel regeneration line to a cracked gas dryer of an ethylene plant [12]*

This cyclic service temperature produces a range of micro-environments below the insulation, which can lead to severe corrosion and failure. Additionally, all the piping and equipment in such service conditions are susceptible. Only by stringent and expensive measures, such as full delagging of the insulation, can the CUI risk be controlled.

3.1.3 Cold Service Transfer Lines

Product transfer lines for liquefied petroleum gas (LPG) are another case where low service temperature can increase the CUI risk. These transfer lines are usually long insulated pipelines that stretch from the storage tanks to the loading and unloading sites or platforms. The criticality of these pipelines from business and safety aspects makes the site operators think twice when they want to conduct CUI inspections on them.

Similarly, the variations in temperature when the fluid is transported through the pipelines is one source of the risk. Their length also complicates the situation as proper design should be maintained along the pipeline route.

3.2 Gas Fractionation Columns

Low boiling point gas fractionation columns experience a temperature gradient from bottom to top. The reboiler and the reflux usually operate outside the susceptibility range for the CUI; the former above the susceptibility range and the latter below. However, areas close to the top of the columns might experience temperatures within the susceptibility range. Operational changes in the feed might also affect this operating temperature.

Difficulty in accessing to column tops, and cumbersome logistical preparations to create access to these areas, make inspections the last option for plant managers. However, there are industrial reports that CUI is a serious damage in those areas.

3.2 CUI Monitoring with Corrosion RADAR

CorrosionRADAR (CR) is a technology developed and patented to address the industrial demand for remote monitoring of Corrosion Under Insulation (CUI). It stands out as the longest-serving product in the realm of CUI monitoring. The technology relies on the Guided-wave electromagnetic principle and incorporates sensors within insulation. These CR sensors function as moisture and corrosion sensors, connected to a node that transmits data to a cloud-based repository. Designed to withstand complex field conditions like flanges, bends, and pipe supports, these sensors can carry an electromagnetic wave effectively.

It operates using permanently installed flexible long-range sensors placed on the outer surface of pipes, eliminating the need for inspection scaffolding. These sensors comprise a moisture sensor and a sacrificial corrosion sensor made of carbon steel. The moisture sensor, consisting of a pair of wires, detects moisture beneath the insulation. Both types of sensors are connected to channels on a node, which send and receive signals. Each sensor, when set up individually, can cover a length of 100 meters on the asset. The gathered data is sent to the cloud and analyzed, enabling risk assessments on the system dashboard.

CorrosionRADAR has demonstrated promising results in previous applications on cold service assets. The sensors provide real-time data on moisture ingress inside cold insulation, which is costly to address. The presence of moisture barriers in cold applications further complicates the situation. The system's installation on a cold service dryer revealed dynamic changes in risk values upon moisture detection, even when traditional Risk-Based Inspection (RBI) systems indicated low corrosion rates and recommended delayed inspection plans. By integrating the RBI system with digital monitoring, the inspection team could take immediate action upon detecting moisture within the insulation, preventing undetected failures Fig 4.

Live data from moisture and corrosivity sensors are transmitted in real-time to a cloud system, where they undergo processing. The asset's dynamic risk is calculated based on industry standards such as DNV-RP-G109 and API 581 to update risk values. An example of this integration is depicted in Figure 5, showcasing the increase in Water Probability of Failure (PoF) and Material PoF according to DNV-RP-G109 after moisture detection.

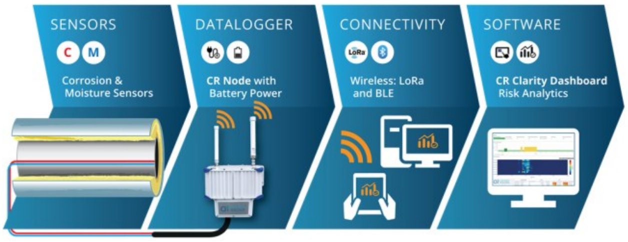

Fig 4 *CorrosionRADAR CUI monitoring system and different arrangements of the sensor appropriate for different piping or vessel types as well as the node that is capable of sending the data to the cloud.*


isture sensors ⌄

	SHE	Business		CUI PoF		Coating PoF	Material PoF	Water PoF	Design PoF
	M	M		L		VL	VH	VH	VL
	M	M		L		VL	VH	VH	VL

Fig 5 *Risk dashboard connected to CUI moisture and corrosivity sensors*

This continuous risk assessment approach kept the site's inspection and maintenance team alert to any changes in CUI conditions. By responding promptly, they were able to mitigate failures that might have gone unnoticed if only a traditional risk-based inspection methodology had been employed.

4 SUMMARY

Analysing past failures within the industry context reveals that specific equipment and processes operating under cold service conditions are inherently susceptible to Corrosion Under Insulation (CUI). This heightened vulnerability stems from active damage mechanisms linked to the service processes. Moreover, the risk associated with insulated cold service equipment might be underestimated when using Risk-Based Inspection (RBI) methodologies.

The authors argue that implementing Condition Monitoring through the Industrial Internet of Things (IIOT) can supply essential information to mitigate the risks inherent in cold service conditions, reducing the likelihood of CUI failures or damage. Solely relying on risk-based inspection methods carries the danger of underestimating corrosion rates in cold service CUI scenarios. With CUI condition monitoring, inspection teams can update risk values in real-time, enabling swift decision-making.

Furthermore, remote condition monitoring enhances data reliability. This provides the inspection and maintenance team with ample lead time to take proactive measures, preventing unexpected failures from occurring.

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