Corrosion monitoring techniques and benefits of newer methods

By leveraging the power of AIoT, industry can overcome the hidden challenges of permanent ultrasonic sensor solutions and achieve superior operational performance

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The oil and gas production industry is facing substantial financial challenges attributed to corrosion, incurring annual costs estimated at $1.372 billion.[1] These costs, along with environmental risks, are expected to rise as operations move into more demanding environments. Corrosion poses a major threat in process industries, especially in asset-intensive sectors like oil and gas and petrochemicals. It can cause leaks, reduce asset performance, and lead to unplanned shutdowns and potentially catastrophic incidents. Additionally, corrosion introduces operational risks, safety concerns, and liabilities. As a result, corrosion monitoring has become a critical aspect of plant operations and maintenance, with detection methods and procedures continuously evolving.

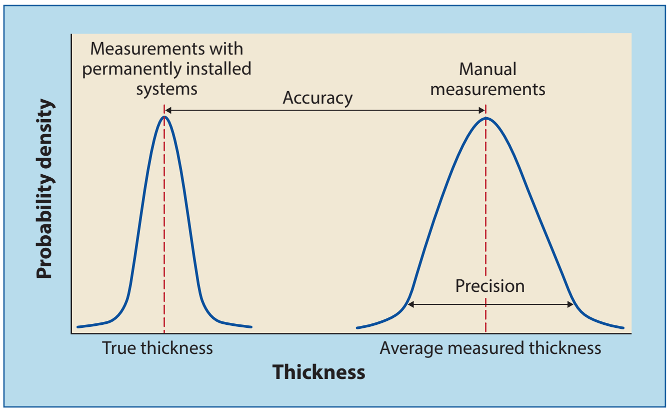

Figure 1 Accuracy and precision of ultrasonic thickness measurements[2]

Evolution of corrosion monitoring techniques

Traditionally, ultrasonic thickness monitoring has been performed manually using portable ultrasonic equipment. However, manual inspections are time-consuming and costly, and they require extensive data cleaning to address the method's limitations. To mitigate these shortcomings, permanently installed ultrasonic solutions were introduced. **Table 1** highlights the main differences between manual inspections and those using permanently installed automated sensors.[2]

Permanently installed ultrasonic solutions have been in use for more than three decades across various industries, but they present challenges regarding the accuracy and reliability of thickness measurements. These challenges can be addressed by adopting Artificial Intelligence of Things (AIoT) technology. By leveraging AIoT, industries can significantly enhance the accuracy, precision, and reliability of ultrasonic corrosion monitoring, thereby improving asset integrity and operational efficiency.

Ultrasonic measurement: accuracy and precision

The quality of ultrasonic thickness data is determined by its accuracy, which refers to how close the measurements are to the true thickness, and its precision, which refers to how consistent the measurements are around an average thickness value. This relationship is illustrated in **Figure 1.**

However, the accuracy of ultrasonic thickness measurements may not necessarily improve with permanently installed sensors. This is because the accuracy depends on a different set of factors. This becomes evident when examining the principle of ultrasonic thickness measurements and the essential equation used to calculate thickness. Both portable and permanently installed ultrasonic instruments measure the time-of-flight (ToF) of ultrasonic waves in a part.

The precision of ultrasonic thickness measurements is enhanced by using permanently installed ultrasonic sensors, as they eliminate factors contributing to the variability of manual measurements. These factors include the exact

Corrosion monitoring methods: Manual inspection vs automated inspections

Aspects	Manual inspection	Automated inspections
Method prevalence	Predominant method	Minor method
Instrument reliability	Reliable portable instruments	Reliable temporarily/permanently installed systems
Accuracy and precision	Limited accuracy and precision	High accuracy and precision
Subsequent analysis accuracy	Limited accuracy of subsequent analysis	Highly accurate subsequent analysis

Table 1

location of the probe, probe handling, differences in temperature compensation, and standardisation.

The thickness t is determined using **Equation 1** by multiplying the ToF data by the temperature-dependent material velocity $v(T)$ and dividing by two:

$$t = \frac{ToF \times v(T)}{2} \quad (1)$$

Industry standards and literature offer the necessary correction factors for various materials across different temperature ranges. Both portable and permanently installed instruments exhibit high accuracy in terms of ToF measurements and signal processing, with up-sampling further enhancing precision. However, the material velocity is typically estimated, with standard values provided in industry guidelines.

Since material velocity is temperature-dependent, additional corrections are needed to determine thickness at room temperature when measurements are taken at temperatures above or below room temperature. Industry standards and literature offer necessary correction factors for various materials across different temperature ranges. An important note is that, like material velocity, these temperature corrections are approximate, as they do not account for variations in material properties due to the production process or changes caused by environmental conditions over the part's service life.

Corrosion impact on ultrasonic accuracy

Permanently installed solutions that rely solely on traditional methods for material velocity and temperature correction do not inherently enhance the accuracy of thickness measurements. Furthermore, another source of variation arises from the nature of ultrasonic waves and their interaction with irregular surfaces. Corrosion and erosion not only lead to metal loss but also cause the affected surfaces to become more irregular and rougher. As a result, ultrasonic echoes reflected from a corroding surface are usually smaller in amplitude and broader compared to echoes from clean surfaces.

In extreme cases, these irregular surfaces can create double or triple peaks in an echo, as illustrated in **Figure 2.** Echoes from a relatively smooth surface are usually narrow with a relatively high amplitude (top panel). In contrast,

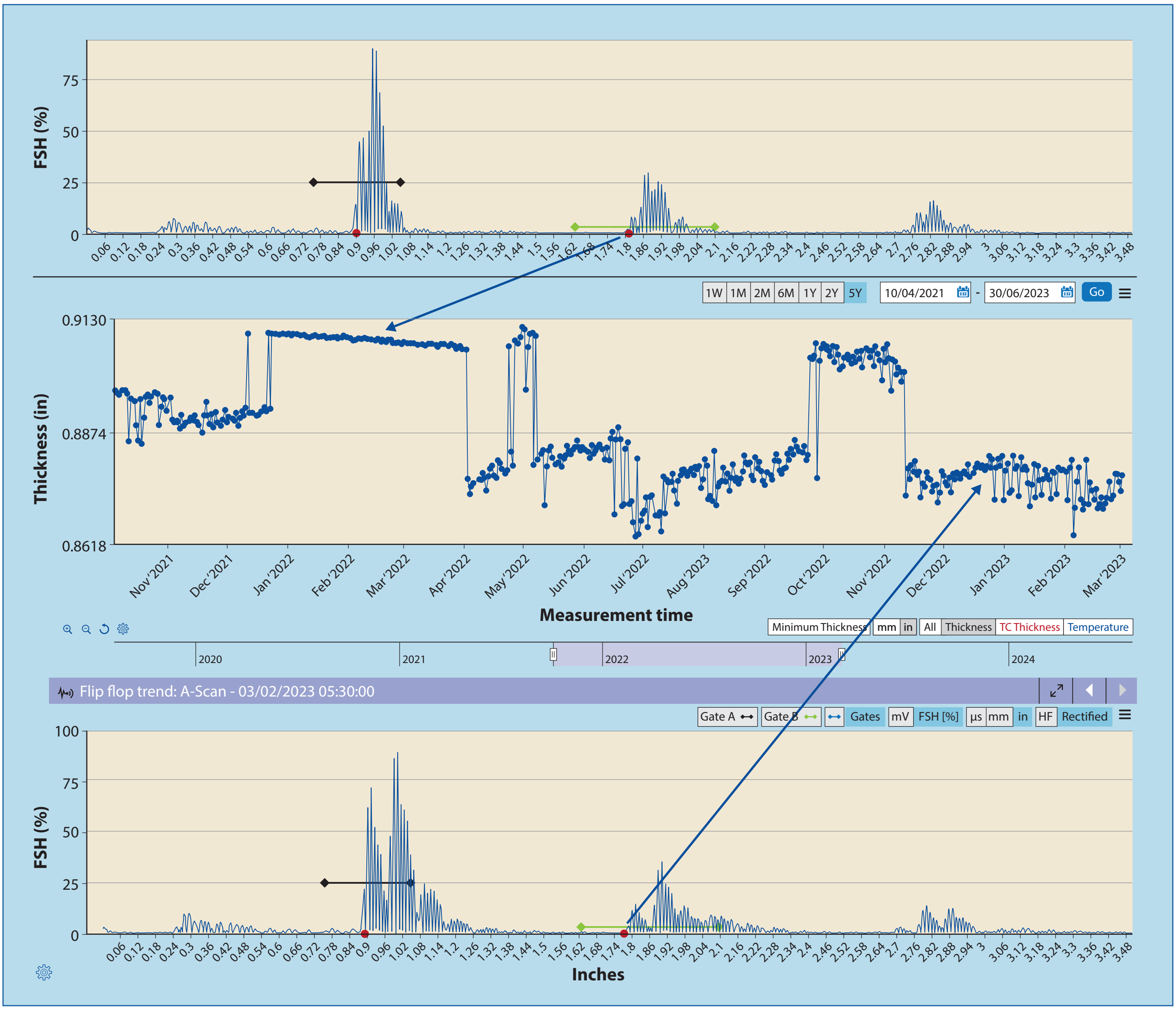

Figure 2 Effect of actively corroding surfaces on ultrasonic waveforms

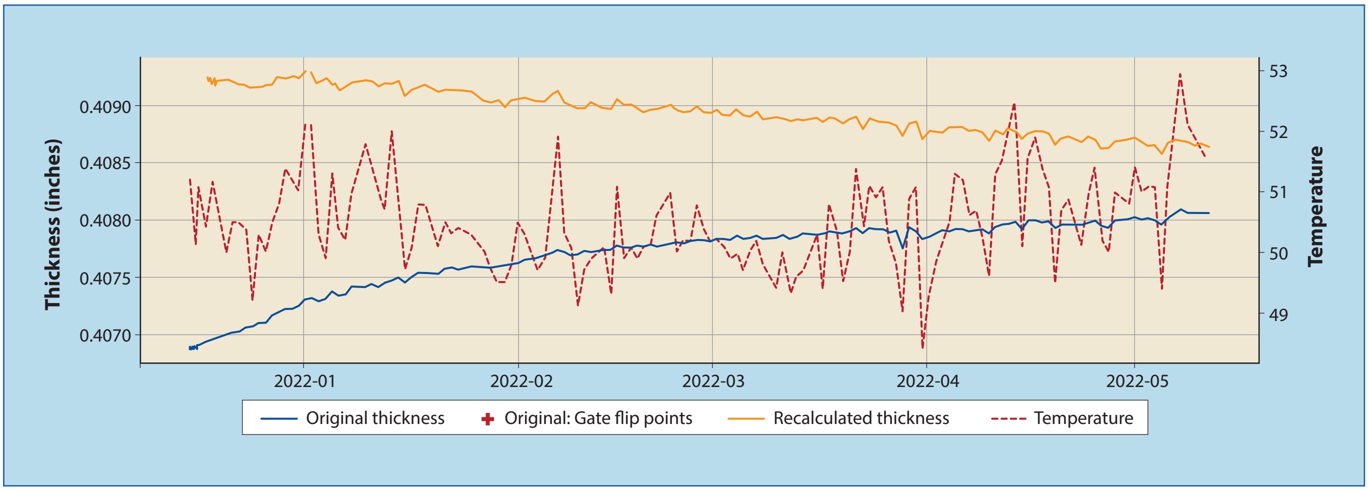

Figure 3 Apparent increasing thickness due to active corrosion

echoes reflected from a corroding surface typically have a smaller amplitude and are broader (bottom panel). In some cases, the echo splits into two or more peaks.[3]

Echo deterioration and ToF variability

The challenge with echo deterioration due to corroding surfaces is the accurate identification of ToF reference points, as depicted by the red dots in Figure 2. As ultrasonic echoes deteriorate, these reference points shift, causing uncorrelated variations in their positions. Consequently, the ToF values change over time, leading to alterations in the thickness trends according to Equation 1. These variations often manifest as distinct multiples of the half-wave distance, resulting in step-function-like changes in the thickness trendline.

In some instances, these changes produce a steady increase in ToF, which can be misinterpreted as an accumulation of deposits on the internal surface of the part being examined, as shown in **Figure 3**. Such misinterpretations can lead to critical situations that impact the safe operation of the plant.

The blue line in Figure 3 illustrates the apparent thickness trend, which is unaffected by temperature changes and results from shifting ToF reference points caused by active corrosion.[4] In contrast, the orange line represents the actual corrosion trend, determined using machine learning techniques to account for variations in the ultrasonic waveform.[3]

Enhance sensor accuracy

Advances in machine learning and the AIoT are helping to improve the limitations of permanent sensors. The actual material velocity at Corrosion Monitoring Locations (CMLs) can be measured directly, estimated using models, or a mix of both. While industry guidelines often describe the relationship between temperature and material velocity as linear, it is usually more complex – non-linear or quasi-linear in certain temperature ranges.

Permanent sensors can measure thickness frequently, ranging from minutes to days, which is far more often than the months or years between manual inspections. This frequent data collection, often during low-corrosion periods, allows machine learning to find the best temperature coefficient for the material at each CML.

Additionally, ultrasonic material velocity is affected not just by temperature but also by perpendicular stresses, known as the acoustoelastic effect. This effect is smaller compared to temperature changes and can only be detected with permanent sensors due to their stability and sensitivity. Manual inspections typically miss this effect.

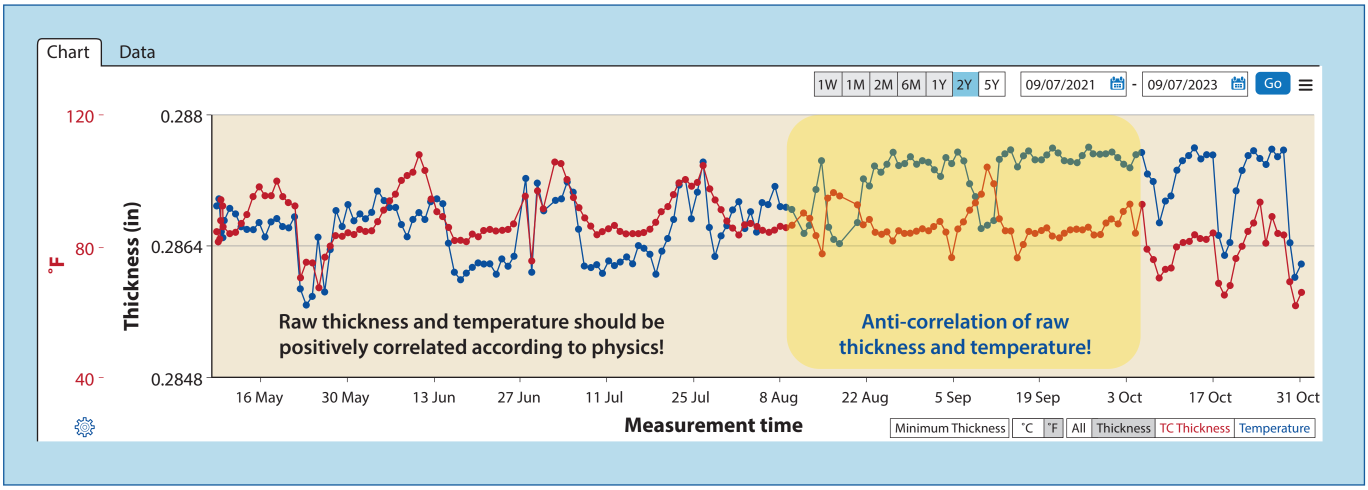

Figure 4 Acoustoelastic effect on ultrasonic wave material velocity

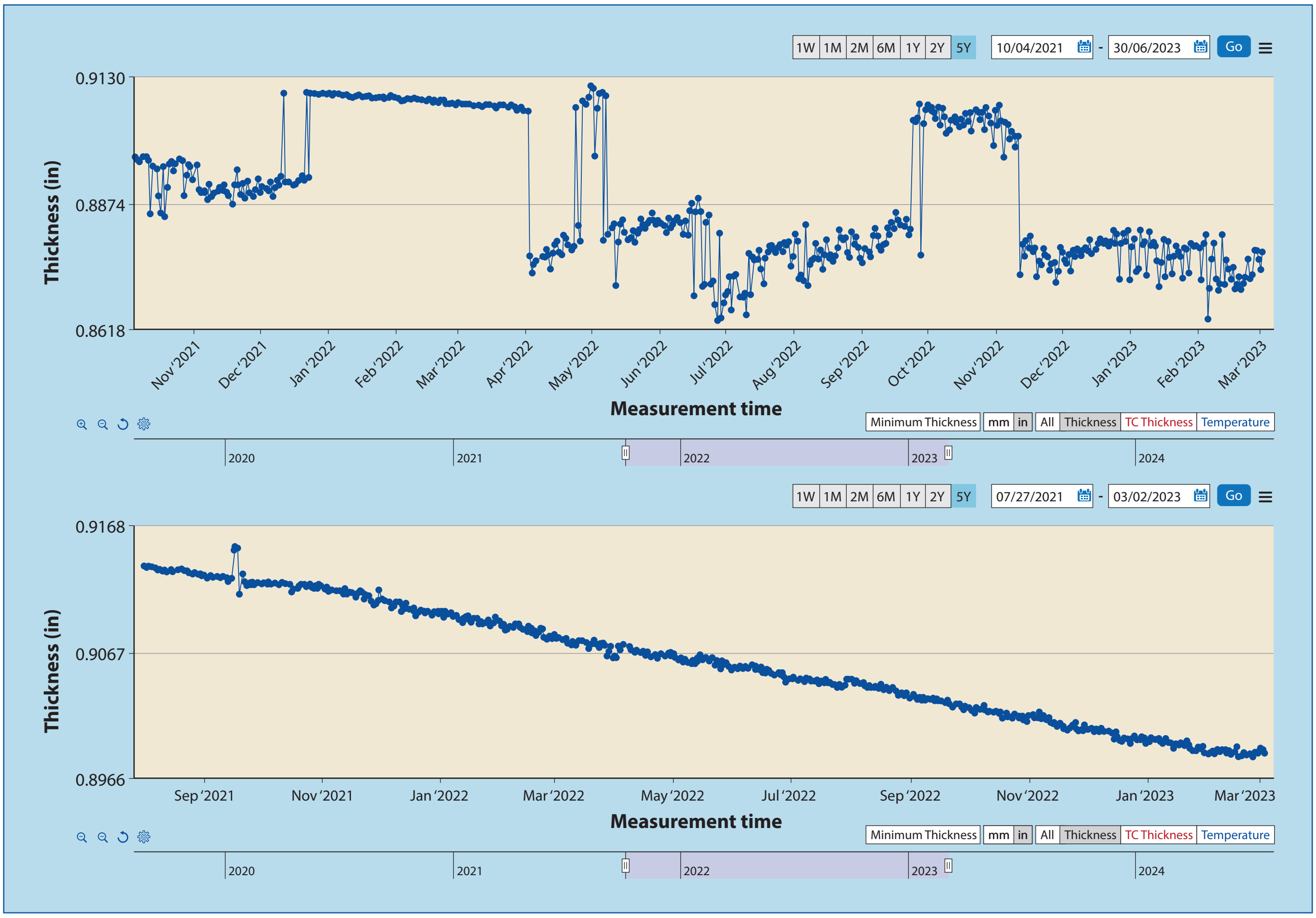

Figure 5 Comparison of thickness trends: Static gates vs dynamic gates

High-stress periods should be avoided when optimising the temperature coefficient, as they can skew the results (see **Figure 4**).

Figure 4 displays a time-series of temperature and thickness over approximately six months. While temperature variations generally correlate with changes in thickness, stress (evident in the highlighted section) can overshadow this temperature dependence, resulting in an anti-correlation between thickness and temperature. These periods of anti-correlation should be excluded from the optimisation of the temperature coefficient.[3]

Dynamically adjust for corrosion effects

As previously discussed, corrosion can create an irregular and rough surface, leading to reduced amplitude and broader ultrasonic echoes. This deterioration can affect the determination of ToF reference points using static gates, potentially resulting in a step-function-type thickness trend (Figure 2) or, in more severe cases, an increasing thickness trendline (Figure 3), which may be incorrectly interpreted as material deposits.

To overcome this issue with permanent sensors, machine learning algorithms can adjust the gates in real-time to match changes in the ultrasonic waveform. **Figure 5** shows how dynamic gates can avoid misleading thickness trends. The top section of Figure 5 illustrates how static gate algorithms produce unusable step-function-type thickness trends, while the bottom section demonstrates how machine learning algorithms provide accurate and usable thickness trends.

User-friendly circuit-level dashboards

Machine learning enhances the accuracy of thickness measurements, but artificial intelligence (AI) is key to turning vast amounts of data into actionable insights. This enables effective management of corrosion monitoring across many ultrasonic sensors.

Traditional dashboards provide detailed views of individual CMLs, focusing on corrosion, material properties, or sensor health. However, they often lack a broader view of the entire circuit or unit. To address this, a new type of dashboard is needed for a clear and comprehensive overview of asset status.

Figure 6 illustrates the new dashboard. AI processes data from trend lines and A-Scans to create a visual summary at the circuit level. Coloured markers indicate each sensor's location and health. If a sensor's measurements exceed a user-defined threshold for thickness, temperature, corrosion rate, or remaining life, its colour changes from blue to red, providing an easy-to-understand overview of the entire circuit. Additional details about CMLs, such as corrosion rates and remaining life, are listed on the right side of the dashboard. The figure includes a graphical map of the sensors (blue dots) and a list of CMLs ranked by highest long-term corrosion rates and shortest remaining lifespan.

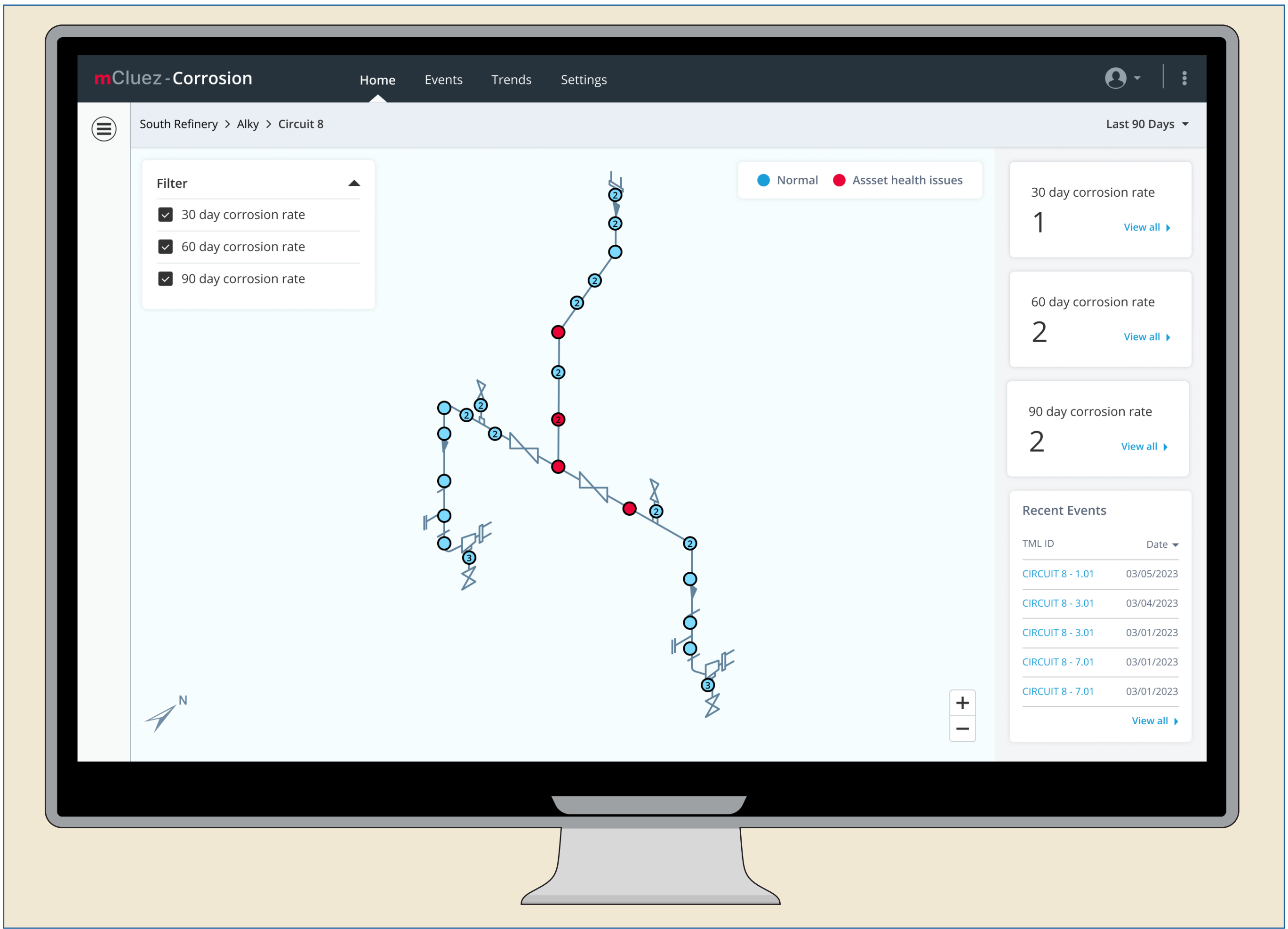

Figure 6 Circuit-level dashboards: Sensor status and CML rankings

Simplified dashboards with critical insights

The number of CMLs varies significantly between different industries. Oil and gas plants typically have hundreds to thousands of CMLs, while refineries manage hundreds of thousands of CMLs grouped into thousands of circuits. Managing thousands of circuits manually is impractical, necessitating machine learning tools to simplify the information into a human-manageable overview at the unit or plant level.

An example of such a dashboard is shown in **Figure 7**. This dashboard uses a mixture of event widgets and list widgets to provide a simple overview of the status of a unit or plant, helping asset owners focus on what matters. Internal links allow users to drill down into circuit and trend views for more detailed information about critical CMLs. This dashboard helps asset owners quickly identify and focus on the most critical CMLs. It is linked to other dashboards, enabling users to drill down for more detailed information on these critical CMLs.

Case study: Enhancing corrosion management with AIoT technology

One of the largest US refineries faced severe corrosion issues in its degassing system, particularly affecting a critical 2in elbow pipe. This component endured extreme conditions, including chemical exposure, high temperatures, pressure, moisture, oxygen, and impurities, posing serious risks to system integrity. Traditional monitoring methods struggled with the pipe's complex conditions and geometry, heightening the risk of equipment failures and safety hazards.

Conventional methods proved inadequate in accurately capturing the subtle effects of fluctuating environmental conditions on corrosion. This monitoring gap raised concerns about undetected equipment degradation and potential safety incidents.

To overcome these challenges, the facility adopted mCluez, a proprietary advanced AIoT-based corrosion and monitoring solution, combining AI with IoT sensors to deliver precise, real-time insights into asset conditions. By deploying mCluez sensors, the facility achieved continuous monitoring of the elbow pipe, capturing crucial data on thickness, corrosion rate, and environmental factors. The system's sophisticated dashboard provided detailed trends and alerts, enabling the team to monitor changes and respond promptly.

Key findings from the mCluez dashboard revealed a sharp decrease in pipe thickness and an alarming increase in the corrosion rate, reaching 400 mils per year (mpy). Further investigation linked these issues to a temperature drop below the dew point, which coincided with a process line-up change. This temperature drop directly contributed to the increased corrosion rate.

In response, the team adjusted the temperature in the affected section of the degassing system. The real-time data

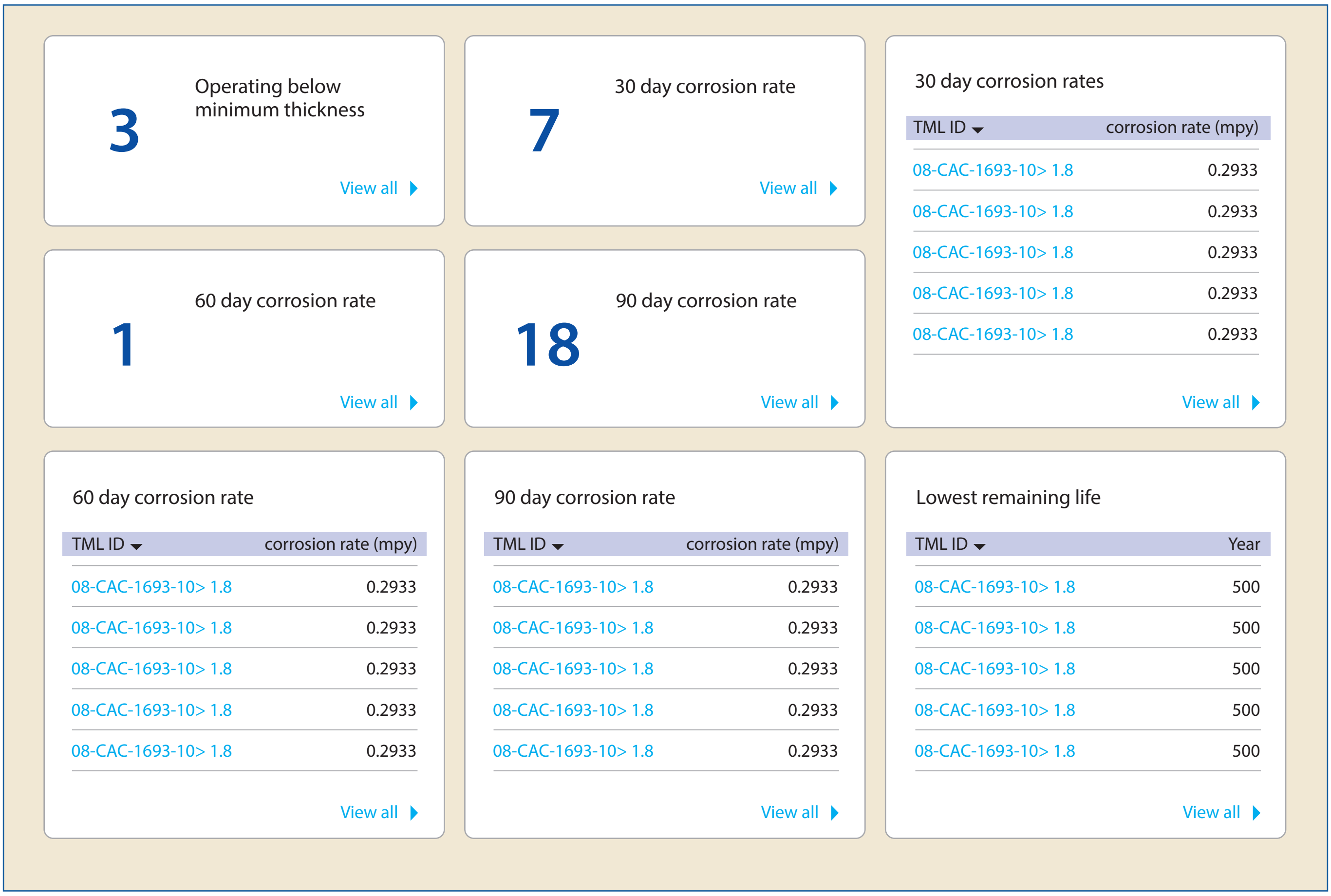

Figure 7 Simplified status dashboard highlighting critical assets

from mCluez enabled informed decision-making, allowing for timely adjustments and a reassessment of equipment longevity. Raising the temperature effectively mitigated the heightened corrosion rate, stabilising the asset's condition and improving overall safety.

The implementation of mCluez with AIoT technology transformed corrosion management for the facility. By providing accurate, real-time data and facilitating quick responses to environmental changes, AIoT technology significantly enhanced monitoring accuracy and operational decision-making. This case study highlights the transformative impact of integrating advanced technologies to optimise asset management and ensure long-term reliability.

Using AIoT

Corrosion poses significant safety risks in the refining and petrochemical industry. Traditional manual ultrasonic thickness monitoring is fraught with errors and inefficiencies, and even permanently installed sensors struggle with accuracy due to surface irregularities and material velocity limitations.

The proven approach of AIoT technology has fundamentally transformed corrosion monitoring. By combining artificial intelligence with IoT sensors, AIoT enhances measurement precision, dynamically adjusts parameters, and delivers real-time analysis. AI algorithms significantly improve data quality by addressing variations in temperature and stress, ensuring more reliable results. Modern AIoT-powered dashboards offer a clear, real-time view of asset health, enabling rapid focus on critical areas and informed decision-making. These innovations dramatically improve accuracy and efficiency, revolutionising corrosion management practices across industries.

References

1 www.ampp.org/technical-research/what-is-corrosion/corrosion-reference-library/oil-gas

2 Schieke S, Geisenhoff M, *Ultrasonic Corrosion Monitoring – It's time for a Paradigm Shift*, presented at the API Inspection Summit 2022.

3 Schieke S, Geisenhoff M, *Ultrasonic Corrosion Monitoring – Real World Examples*, API Inspection Summit, 2024.

4 Schieke S, Geisenhoff M, *Ultrasonic Corrosion Monitoring – It's time for a Paradigm Shift*, Inspectioneering Blog, 2021.

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