

Managing Integrity and Corrosion Through Real-Time Prediction Modeling Approach – “Software Sensor” Concept

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ABSTRACT

Corrosion and Integrity Management (CIM) covers several elements such as policy, strategy, resources etc. For effective implementation and supervision, these should be also supported by an integrated IT platform for analysis and communication. There's a lot of hype about the Digital Transformation or the Industrial Internet of Things and their roles in supporting corrosion and integrity management. Digital Transformation at its core, is a simple concept – to harness the immense power of plant and process data in a seamless, cloud enabled digital environment to achieve superior process efficiencies, productivity, and reliability. This has important implications from connectivity of real time operating data, automated predictive analytics, increased collaboration – and finally, the quantitative impact on the process of managing corrosion. Over the last 20+ years, a number of research initiatives to effectively manage corrosion assessment, damage mitigation and asset integrity management in refinery unit operations were conducted by Honeywell International Inc. sponsored by global, industry-leading refining and engineering companies. Results of these research efforts formed the foundation for corrosion prediction models for multiple corrosion damage mechanisms including naphthenic and sulfidic corrosion, ammonium bisulfide corrosion and ammonium chloride corrosion. The by-product of these comprehensive efforts is a real time corrosion software sensor framework built around industry leading corrosion prediction models.

This paper provides an overview of the real time prediction technology and implementation of software sensor solution at refinery units. The “software sensor” solution is capable of also incorporating off-line data, manually collected data such as corrosion coupon data or even laboratory analysis results to deliver an accurate and comprehensive characterization of corrosion and reliability.

Key words: corrosion management, reliability, sensors, simulation, modeling

INTRODUCTION

Safe and stable operation of the process plant through its life cycle is an ultimate target of any integrity management system. Over the last decades, a number of possible ways and systems for managing plant integrity were described and implemented.¹⁻⁴ A common path for all those efforts was to control and manage corrosion processes in a more-or-less systematic way by applying certain measures (monitoring techniques, material selection guidelines, operating procedures etc.) and performance indicators (remaining time-to-failure, inhibitor usage etc.). An effective corrosion and integrity management system, in theory, should be capable to “uncover” excessive corrosion incidents before serious damage occurs. Unfortunately, unexpected corrosion-related failures are still occurring in the petroleum industry.⁵ This situation stems predominantly from relatively poor data organization and management, leaving corrosion and key process information spread and hidden across different refinery functions and systems.

In order to integrate corrosion domain knowledge with process data and process unit design specifics, many refineries follow the recommendations from recently published API⁽¹⁾ Recommended Practice 970: Corrosion Control Documents (CCD) and API RP 584: Integrity Operating Windows (IOW).⁶⁻⁷ The CCD approach organizes available corrosion and integrity information into systems and subsequently develops corrosion circuits. Following these practices provide a level of protection against unfavorable corrosion conditions by accounting for the environment’s corrosivity, active and potential damage mechanisms, key process variables, material etc. This is followed by setting appropriate limits on each key process parameter contributing to corrosion and by relevant recommendations on monitoring, inspection techniques and mitigation steps.

IOW limits, as long as they are properly established, measured, and controlled, will eventually prevent excessive corrosion and unexpected damages. Both CCD and IOW concepts work toward the integration of corrosion knowledge with physically observed correlations between corrosion and process conditions. A critical element in the effective utilization of CCD/IOW and CIM frameworks relies on the smooth data exchange between different refinery functions. For example, if the operations department is changing certain parameters e.g., adjusting side-cut temperatures due to higher demands on a specific fraction, this action should be known to the corrosion/integrity team for verification and approval of new conditions from a corrosion perspective. The traditional “static” approach to Corrosion Management, when the process data information exchange with corrosion systems is lagging with respect to “live” operating data, will inevitably lead to “surprising” or unexpected corrosion events.

Therefore, an effective CIM system should include, where possible and available, a “real-time” integration of design, corrosion and operational data with the best industry domain expertise and insights into the damage mechanism (CCD and IOW).

The recently introduced concept of real-time, corrosion prediction framework – Predict®-RT[†] (real time), aka “software sensor”, integrates domain knowledge with corrosion data and process parameters to provide accurate quantification of corrosion rates for various corrosion damage mechanisms,⁸ has finally opened a way for real digitization of the corrosion-process as business users can immediately see not only the actual corrosion conditions but also in parallel, can view the larger scenario(s) reflecting alternate or future materials or operating conditions.

¹ American Petroleum Institute (API), 1220 L St., NW, Washington DC, 20005-4070

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In fact, only the real time software sensor approach can truly deliver the concept of Digital Twin (DT) to the corrosion management world. Digital Twin, according to the popular definition is known as a “*virtual representation that serves as the real-time digital counterpart of a physical object or process*”.⁹ It is one of the most attractive and elegant ways for process digitization, and in fact, nowadays is commonly used in process simulation and training systems. However, implementing a straightforward DT approach to the corrosion world is not possible without dedicated corrosion prediction models. Obviously, corrosion models, cannot be developed solely through mechanistic approaches, statistical analyses, and/or implementation of sophisticated mathematical functions. Their development requires deep integration of fundamental knowledge (thermodynamics/kinetics/flow dynamics), corrosion and chemical engineering principles and a solid experimental base.¹⁰⁻¹² For example, thermodynamic and ionic modeling is used to link the formation of ammonium chloride (NH_4Cl) with the presence of ammonia (NH_3) and hydrochloric acid (HCl) in the CDU overhead corrosion prediction model. Nevertheless, a model itself, when left standalone and disconnected from the stream of “live” process data, however still useful, cannot serve for Digital Twin purposes.

The software sensor framework links corrosion models with real-time data streams and as such, delivers a virtual (meaning, without any additional hardware sensors) representation of **actual** corrosion processes in a form which can be called a Corrosion Digital Twin (CDT). In further sections of this paper terms Corrosion Digital Twin and Software sensor will be used equivalently.

Supplementing the modeling part of a CDT system with traditional (hardware) sensor corrosion data as well as the laboratory data makes it possible to obtain a comprehensive corrosion picture, even in the situation where certain damage mechanisms are not covered by a dedicated prediction model. Actually, the lack of a specific model is the main drawback of the software sensor and CDT concept. However, in many cases we need to focus only on critical or active damage mechanisms, meaning those with high probability for occurrence at a reasonable rate. For example, in CDU/VDU high temperature (HT) lines, the most critical damage mechanisms would be sulfidation and naphthenic acid corrosion. Other mechanisms in HT lines like polythionic acids attack on austenitic components should be considered as “potential” damage modes because under proper operation e.g., during shut-down, when oxygen and moisture ingress is avoided, likelihood for occurrence of this damage mode is low.

This paper discusses several practical aspects (IT security, connectivity etc.) of software sensor framework application in refinery units. Some elements of the software framework, that are useful from CIM perspective, are also presented.

REAL TIME SOFTWARE SENSOR FOR CORROSION AND INTEGRITY MANAGEMENT

Using corrosion prediction in real time and consequently in CIM still is a relatively new idea. It is possible to envision real time corrosion or process monitoring but online modeling within corrosion management systems still sound somewhat unclear. Hence, many corrosion and integrity engineers may not know how to position and prepare their teams for digital transformation. In following chapters some general aspects of real time, digital software sensor framework and its interaction with CIM are presented.

Integration with Process Control Systems

Corrosion is a “live” process that fluctuates with operating process conditions. Therefore, management of corrosion and asset integrity must reflect such dynamics. Updating corrosion KPI’s, maintenance strategies, planning of replacements etc. based on turnaround-to-turnaround time frame may become insufficient when considering weekly changes of processed crude slates with consequent variations in total acid number (TAN) and active sulfur content. The first step for bringing said dynamics to CIM was initiated in the early 2000’s by the introduction of pioneering online, real time corrosion monitoring technology (SmartCET™[†]) that utilized HART communication protocol. This allowed for direct and rapid (within seconds) corrosion measurement and data transfer from transmitter to the plant control system (DCS) and further to the Process Historian database for linking and correlating corrosion with operating variables. The evolution of communication technologies and developments in corrosion sensors enabled a variety of commercially available solutions, from wireless ultrasonic thickness (UT) to super-fast electrical resistance (ER) technology. Unfortunately, direct integration of these systems with CIM and utilization of real-time corrosion data still has certain flaws. Probably the most important reason for such lack of integration is the so-called preferable solution of a “Standalone Corrosion Management Server”, which has very limited capabilities to exchange, collect and analyze data streams that are available within a plant data network. Without a “live” correlation between process variables and corrosion and/or verification and update of corrosion KPI’s, any real-time online CIM system exhibits only a fragment of its real potential.

The software sensor solution provides an integrated CIM platform that combines both hardware and software corrosion monitoring tools, ensuring distribution of corrosion and integrity data across the business functions. The software sensor network represents a digitized (or virtual) corrosion circuit with actual or potential corrosion hot-spots (Figure 1). As the number of software sensors is virtually unlimited, all areas of concern can be covered by dedicated corrosion modeling points. At the same time, only a limited number of hardware corrosion monitoring points is required for cross-checking purposes.

In the diagram shown, the CIM server is located on Level 4 plant network (often called the business level network). This approach provides several benefits to the user over traditional standalone corrosion server:

- all users which have access to the business level network can view the corrosion data (from both hardware and software sensors),
- none of the business users have direct interaction with Operation or Control Networks (Level 3 and Level 2),
- corrosion/integrity data can be presented on several layers: the Operator’s Panels in Unit control room, Corrosion Dashboard (for corrosion/integrity team) or Business Dashboard (key corrosion/integrity KPI’s presented for management),
- correlations between process conditions and corrosion can be evaluated in real-time,
- the software sensor solution can also be set up to evaluate alternative scenarios e.g., if particular critical parameter is not known, it is possible to run potential boundary cases and observe corrosion rate limits.
- The real time CIM server can run in a virtual server environment, simplifying centralized IT management and backups.

[†] SmartCET is a tradename of Honeywell International Inc.

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