Corrosion: The New Process Variable
Online, Real-time, Saving Money

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Current estimates show the global process industries spend $50 billion annually on corrosion and its consequences. Furthermore, in many industries, corrosion often results in costly and sometimes catastrophic incidents with safety and environmental consequences.

This white paper offers a three-step plan to interface real-time corrosion measurement with process data through a plant’s distributed control system (DCS). This allows better tracking of the true economic impact of corrosion and offers the potential to minimize its negative effects. It also provides a totally new method to achieve improved process control, efficiency and cost savings while at the same time facilitating better maintenance planning and asset management.

Introduction

The paradigm of process control is changing. Control systems now bring information into process knowledge systems that directly indicate the impact of process conditions on plant assets. Integrating data and feeding it into a process knowledge system allows plant operators and engineers to view events and proactively manage the health of all plant assets and to make educated decisions more quickly—with an understanding of the cost impact—even before substantial damage occurs. This can lead directly to reduced downtime, fewer unplanned outages, better maintenance planning, increased productivity and substantial cost saving. An example of this change is the increasingly practical use of a new on-line, real-time process variable: Corrosion.

Impact of Corrosion

Corrosion deterioration results in big expenditures. In fact, it is one the largest categories of expenditure that has not been integrated into the on-line world of process control. Current estimates show the global process industries spend $50 billion annually on corrosion and its consequences with a comparable amount associated with other economic sectors such as oil and gas production, mining and metal processing and municipal water. About 20 percent of corrosion expenditures can be saved through proactive intervention implemented with new on-line, real-time corrosion monitoring technology as presented in this article. Some of this savings comes from what is mistakenly viewed as corrosion control; e.g. repairs and replacements directly resulting from corrosion. Related categories of savings arise from the ability to increase run time and reduce inspection effort and frequency.

Furthermore, in many industries, corrosion often results in costly and sometimes catastrophic incidents with safety and environmental consequences. Also, chemicals used for corrosion control are often used inappropriately (i.e. not dosed according to the immediate need for inhibition) leading to overspending or under treatment, which leads in turn to excessive expenditures or unnecessary risks.

Some examples are given below:

- **Pipeline leaks and ruptures** – Over the past decade, there have been several major pipeline leaks and explosions linked to internal corrosion. These have involved multiphase oil gathering lines, “dehydrated” gas transmission lines and even
hydrocarbon products pipelines. Results: Loss of civilian lives, major production loss and contamination of environmentally sensitive areas.

- **Amine unit bottlenecking** – Corrosion in amine gas processing units resulted in corrosion failures. Results: Need for additional standby capacity to handle unplanned outages.
- **Refinery fractionator overhead incident** – Unmitigated corrosion in a unit overhead line resulted in a failure incident. Result: $35 million in damage and lost production.
- **Municipal water facilities and service** – Corrosion without monitoring has caused substantial damage to the civil infrastructure. Result: Over 60 percent of the water distribution system in the U.S. will need to be replaced in the next ten years.

In contrast, the following points illustrate the alternatives and benefits of on-line, real-time corrosion measurement and the benefits of proactive intervention:

- **More efficient use of pipeline treatment chemicals** – At one site, corrosion was considered “under control,” before on-line, real-time corrosion monitoring was applied. Result: An immediate cost savings of 60 percent on inhibitors was realized through more efficient and confident dosage based on accurate, real-time data.
- **Process correlation hydrocarbon oxidation** – Off-line corrosion monitoring at this site failed to improve operating conditions for a process that was becoming increasingly more corrosive. But within weeks of installing an on-line, real-time corrosion monitoring system, corrosion was correlated with five process and operational conditions, allowing reduction of unit damage to acceptably low levels.

**Limits of Conventional Off-line Corrosion Measurement**

Conventional corrosion measurement is done over long time periods—months to years—via corrosion coupons (metal samples exposed to the process stream) or by inspection during turnaround periods. Long measurement cycles are the rule because corrosion damage must accumulate over time to be accurately measured with these off-line techniques. This results in only an average view of corrosion activity that cannot be correlated with process variations or upsets. In contrast, real-time monitoring shows that most corrosion damage occurs during relatively short periods of time. Figure 1 shows an example of variations in corrosion rate with time in a “dehydrated” hydrocarbon gas stream normally considered to be non-corrosive.

![Figure 1. Corrosion vs. time in dehydrated gas](image-url)
Another limitation of conventional (off-line) corrosion monitoring is that the corrosion data often requires a second data stream directed to a maintenance or reliability engineer or corrosion specialist. This often requires walking the plant to manually download corrosion data from instrument data loggers. In some rare cases, the device is on-line but sends data to a stand-alone PC or workstation where the engineers have no access to process information, greatly limiting the possibility of true root-cause analysis.

**Application of SmartCET® On-line, Real-time Corrosion Measurement**

There is new technology that operates remotely at the point of measurement using an automated sequence of electrochemical techniques that assess both general and localized corrosion on-line in real-time—an industry first.

The remote unit is connected to the probe (sensor) at the point of monitoring and provides pre-processed data directly to a plant control loop (See Figure 2).

![Figure 2. Corrosion as a process variable into a distributed control system](image-url)

The unit automatically outputs pre-processed data in the form of a general corrosion rate and a “Pitting Factor”, every seven minutes. This level of data can be uploaded directly to the plant DCS and is generally appropriate for analysis by the plant engineer or maintenance personnel. Both variables lend themselves to trending and alarming in the same way used for other process variables. One of the major benefits is that the corrosion and corresponding process data can be taken into the process knowledge system for trending, statistical analysis, root-cause investigation and for advanced applications involving cost assessment, maintenance planning and asset management. Making data available for cross-functional and cross-disciplinary analysis allows key
plant personnel to have real-time knowledge to safely enhance production levels while protecting plant assets.

This corrosion transmitter is actually an automated, multi-technique electrochemical device. The techniques applied include linear polarization resistance (LPR) in combination with two more recently developed and quantitative techniques: Electrochemical noise (ECN) and harmonic distortion analysis (HDA). This particular combination has been referred to as “Super LPR Technology” since it overcomes the many limitations of more conventional technique. Namely, the device can provide corrosion data quickly (every seven minutes), measure an important corrosion proportionality factor (B value) that is factory defaulted in other instruments, and identify localized corrosion tendencies with the simple scalable Pitting Factor. The latter is particularly important since pitting can be initiated very quickly and creates damage that is expensive to locate using off-line inspection techniques.

Another important aspect of accurate corrosion measurement is that the corrosion probe contains sensing elements made from the same type of material, grade and metallurgical condition as the equipment to be monitored. It is also possible to design the probe for specific application considerations such as heat transfer, overhead condensation or fireside conditions. Such details are usually determined by a pre-installation corrosion audit that includes a review of service environment, process flow and material selection diagrams, physical layout of the plant, and a review of off-line information such as prior failures and inspections.

**Corrosion Monitoring Makes the Difference**

*Hot organic stream with 1-to-2 percent corrosive water.* Monitoring was performed at a BASF petrochemical plant constructed largely of carbon steel, 304L and 316L. Decades of debottlenecking and other process modifications had produced corrosion problems similar to the example mentioned earlier in this article where a corrosion failure resulted in the largest peacetime explosion in the U.K.

After a year of unsuccessful efforts to untangle process problems using conventional off-line corrosion monitoring, an automated, multi-probe SmartCET system was installed. For the first time, materials engineers, process engineers and plant operators were able to see immediate changes in corrosion behavior caused by specific variations in process parameters and work together to identify process modifications and remedial actions. The initial audit revealed that the environment was mostly a non-conductive organic phase, and the entry points for probes were mostly located on vertical pipe runs.

*Figure 3. Three probes in a spoolpiece.*
Three-element flange probes were recommended and installed at ANSI flange joints in a piping system in the areas where the most severe corrosion had been observed (Figure 3). Based on the results of the initial process evaluation that required several weeks, five predominant factors were identified that related directly to the chemical aggressiveness of the plant environment. They included:

- An upstream vessel was on an automatic pump-down schedule. Every time the vessel pumped down, the corrosiveness of the larger stream increased. The pump was replaced and the problem eliminated.
- Operations had initially reduced the concentration of a neutralizing chemical in the process and had anticipated an increase in corrosion rates. It was instead found that increasing the neutralizer actually increased corrosion rates. This new information helped to both reduce corrosion rates and provide process engineers new insight into the chemistry of the process.
- After viewing the corrosion data for the first time, a plant technician pointed out that an increase in corrosion rate of the 304L electrodes occurred immediately after they mixed a new batch of catalyst. By viewing corrosion rate along with the catalyst feed rate, a critical feed water level was established to limit corrosion while maintaining unit productivity goals (Figure 4).

Further investigations indicated the corrosion rate also varied significantly with process and operational events. Observers noted the corrosion rate of carbon steel correlated with the quantity of a key gaseous chemical used in the process.

In another process stream, short-term spikes of very high corrosion rates were observed intermittently but consistently, week after week. It was determined that the corrosion rate spikes coincided with the pumping of laboratory samples back into the process upstream. Operations changed its lab samples disposal procedure, which stopped the occurrence of short-term corrosion spikes.
Ultrasonic thickness measurements were recently taken on various parts of the piping in the vicinity of the corrosion monitoring points and indicated an average 2.965-mpy (thousandths of an inch per year) corrosion rate over a 16-month period. This data agreed very well with the 2.9 mpy corrosion rate determined by the SmartCET on-line, real-time corrosion measurements.

Partially dehydrated hydrocarbon stream. The use of on-line, real-time multi-technique monitoring methods has provided quantitative corrosion rate trends and indications of modality in systems containing oil and water in combination with corrosive gases. As shown in Figure 5, SmartCET provided complete representation of the corrosion taking place in both the CO₂-rich liquid condensate and in the actively condensing vapor phase in a dehydrated gas pipeline environment containing condensing water and glycol, methane and carbon dioxide. When compared to corresponding coupon data taken on the same exposure interval, uniform corrosion rates are about a factor of 10 higher in the liquid phase than in the vapor. The rates obtained by monitoring were very similar to those independently determined by mass loss measurements on the coupons. Furthermore, and perhaps more importantly, the mode of corrosion in the condensing vapor phase was found to be pitting corrosion (Figure 5). Analysis of the Pitting Factor measurement, taken during the automated measurement cycle, showed high values of Pitting Factor throughout the exposure period. In fact, after only a few hours, the Pitting Factor readings would have triggered a system alarm warning operators of this situation or activation of a closed loop remedial action such as chemical treatment. With the integration of this type of on-line, real-time corrosion data with process data through the DCS system, operators could have taken action before substantial damage had occurred.

Figure 5. Dehydrated gas vapor and liquid corrosion.

Integrating Corrosion Data into an Existing Control System

To successfully make the transition from off-line corrosion monitoring to use of corrosion as an on-line process variable, it is necessary to be able to show value to justify each step in this process.
Step 1 – Real-time corrosion data. The first step is to simply bring corrosion signals into the DCS along with other process data. This initiates the use of on-line, real-time corrosion measurement by plant operators to “see” corrosion and its short term variations in context with real-time process data.

Step 2 – Process correlation. Once real-time corrosion data is available, plant personnel can observe periods of high corrosion rate or when pitting damage is occurring. This provides a direct correlation between operational or process variables with corrosion events. Operations can start using the corrosion measurement device as a “tachometer” for the plant, analogous to how a race car driver uses a real tachometer to monitor the rpm of the engine, the “red line”, and achieve optimum performance from the vehicle while maintaining levels within acceptable limits.

Step 3 – Advanced applications. Deeper integration of the corrosion measurement device with the DCS and process knowledge system makes it possible to utilize automated root-cause analyses that learn as processes change. This might include automated, closed-loop control solutions where multivariate routines dynamically identify and make adjustments to the process or implement chemical treatments, as the need arises. At this level, it is simple to provide economic analysis on the impact of corrosion in much the same way that conventional process variables are used to optimize catalyst life in a process unit.

Corrosion Monitoring…The New Paradigm

Corrosion cuts across all major business verticals and affects nearly every part of plant process operations and the equipment used in these systems. Currently, the associated corrosion costs are not rigorously tracked since the “corrosion variable” is not being tracked through the DCS. Furthermore, conventional corrosion detection methods have not provided a method for proactive intervention. SmartCET now offers the means to interface real-time corrosion measurement with process information through the plant DCS, allowing new insight into the true economic impact of corrosion, new methods to achieve improved process control and efficiency, as well as better maintenance planning and asset management. It is this process-centric approach to asset management and optimized plant performance that helps make on-line, real-time corrosion monitoring unique.

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