Corrosion: a new process variable

Figure 1. Example of flange design corrosion probe.

The needs of companies that run and manage hydrocarbon processes are undergoing major changes with the realisations that:

- Up to 60% of the plant engineers will be retiring by 2010.
- Personnel actions cause US$ 20 billion annually in avoidable costs.
- 50% of maintenance is not needed and 10% may actually be harmful.

The net result is that fewer skilled personnel must respond faster, handle more complex processes and make better decisions to avoid bigger consequences.

The paradigm of process control is also changing; it is starting to go beyond the classic suite of process variables that affect operating conditions. The goal now is to bring information into the plant distributed control system (DCS) to directly indicate the impact of process conditions on plant assets. This allows corrective action to be taken at a much earlier stage, before substantial damage occurs, thus allowing reduced downtime and unplanned outages, increased productivity and substantial cost saving. An example of a new online, real time process variable is corrosion.

Impact of corrosion

Why corrosion? Studies have shown the annual cost of corrosion in the USA is approximately US$ 300 billion (4% of the GDP)[1]. Extrapolating from this data, current estimates show the global process industries spend US$ 50 billion/y on corrosion and its consequences. Furthermore, predictions indicate approximately 25% can be saved through proactive intervention implemented with new online, real time corrosion monitoring technology, as presented in this article.

Corrosion damage often leads to excessive expenditures because it is commonly misdiagnosed and accepted as routine maintenance and repair. Compounding the problem, corrosion measurements have conventionally been offline and directed to specialists disconnected from the online DCS data stream. Consequently, corrosion assessment is usually viewed historically after substantial corrosion damage has occurred and relegated to inspection and repair. The new standard is to utilise the DCS and process knowledge system to provide real time information, analysis tools and connectivity between operators, specialists and maintenance personnel.

Limitations of offline corrosion measurement

Conventional corrosion measurements require long time periods, usually viewed over months to years by corrosion coupons (metal samples exposed in the process stream) or non-destructive inspection techniques during unit turnaround. Long measurement cycles are necessary because corrosion damage must accumulate to a point where it can be accurately measured with these offline techniques. This averages corrosion over long intervals, producing an unrealistically low assessment of the corrosion rate.

Through real time monitoring applications, researchers have discovered that most corrosion damage occurs during relatively short periods of time, usually during process startup, changes, upsets or shutdown. Techniques with long measurement periods such as coupons and inspection simply do not view corrosion at a frequency that allows it to be related to process changes, or for corrective action to be taken before the damage has accumulated.

There have been many applications of corrosion instruments using linear polarisation resistance (LPR) or electrical resistance techniques. These techniques have been around for almost 40 years in laboratory and field use and can identify corrosion over shorter periods (hours to weeks). However, experience has shown that, due to their limited processing capability, they only produce qualitative indications of corrosion activity. This has greatly limited their use for quantitative applications involving asset management. These methods also are not responsive to localised corrosion (i.e. pitting) that accounts for up to 70 - 90% of corrosion failures, and they cannot be successfully used in many processes involving oil/water mixtures, H_2S containing streams or vapour phase environments.

The new process variable

Of greater benefit to plant engineers is online, real time corrosion data that can interface with the process control system. This allows corrosion to be viewed and used as a 'process variable'. It allows all data to be channelled through the same DCS interface and to correlate the corrosion activity with changes in other process variables. Therefore, the operator and plant engineering personnel can immediately see the

Russell D. Kane, Dawn C. Eden and David A. Eden, InterCorr International Inc.*, USA, present corrosion as an example of a new online, real time process variable for hydrocarbon process streams.

Figure 2. Installation of probe electrodes and electrode insulators in standard ANSI pipe flange.

effect of process changes, or implement control with the use of inhibitor chemicals, adjust pH with neutralisers or implement other remedial actions through process control. The process control system, therefore, has the ability in the longer term to achieve optimum production rates while protecting plant integrity, thus minimising downtime for unplanned failures, outages and damage repairs, resulting in increased equipment service life and unit productivity.

There are many advantages to online, real time corrosion monitoring. In the following sections, corrosion measurement technology is reviewed along with its application to a hydrocarbon processing plant. The data helped the plant operations team better understand the relationship between corrosion and process variables with substantial benefit.

Online, real time corrosion measurement technology

The technology described here is SmartCET®, which operates remotely at the point of measurement using an automated sequence of electrochemical techniques that assess both general and localised corrosion online in real time, an industry first.

Data from the remote monitoring unit is preprocessed to eliminate the handling of raw data. The unit outputs preprocessed data, in the form of a general corrosion rate and a ‘pitting factor’, every seven minutes. This level of data is generally appropriate for analysis by the plant operator and can be uploaded directly to the plant DCS. Both variables lend themselves to trending and alarming, in exactly the same way used for other process variables. For the corrosion and materials specialist, further statistical data is available that can provide more indepth information and diagnostics, including fault and trend analyses.

The techniques applied in SmartCET include the LPR technique in combination with two more quantitative techniques: electrochemical noise (ECN) and harmonic distortion analysis (HDA). This combination has been referred to as ‘Super’ LPR technology since it overcomes the many limitations of conventional LPR techniques. Namely, the device is capable of:

- Providing data quickly (every seven minutes).
- Increasing accuracy by measurement, an important corrosion proportionality factor that is factory defaulted in other instruments.
- Differentiating localised corrosion from general corrosion with the simple pitting factor.

This instrument is connected to a probe that contains sensing elements made from the same material as the equipment to be monitored. When selecting a corrosion probe, it is important to consider suitable installation locations and a probe design that allows for accurate corrosion measurements. Such details are usually determined by a preinstallation plant/process corrosion audit.

Online, real time corrosion monitoring

One example of a monitoring application using this new technology is a hydrocarbon processing plant operated by BASF Corp. in Freeport, Texas[2]. The plant runs a predominantly organic stream, and much of the plant is constructed of carbon steel, 304L and 316L. Decades of debottlenecking and other process modifications have produced corrosion problems, which have led to unscheduled and expensive shutdowns, environmental releases, equipment replacement, and upgrading materials in certain parts of the plant. Unfortunately, even some of the upgraded materials have shown excessive corrosion.

It would have been too expensive to rebuild the entire plant with more corrosion resistant alloys, and undoing the process ‘improvements’ was not an option. The complexity of the chemical process also precluded troubleshooting the corrosion problem using existing published corrosion data, laboratory tests or previous plant experience. Offline corrosion coupon testing was considered far too slow and cumbersome, and would require many years of manually installing, removing and testing coupons.

The plant site began using SmartCET to examine the real time corrosion behaviour. For the first time, their process engineers, plant operators and materials engineers could ‘see’ immediate changes in corrosion behaviour caused by specific variations in process parameters. Within a matter of weeks from system commissioning, process adjustments were identified that reduced corrosion rates while maintaining acceptable product yields and quality.

Probe configuration

The hydrocarbon process environment contained only approximately 1% of corrosive water, caustic, and possibly

Figure 3. Installation of carbon steel, 304L, and 316L probes in 8 in. pipeline.

Figure 4. SmartCET corrosion analysers mounted in explosion proof enclosures.

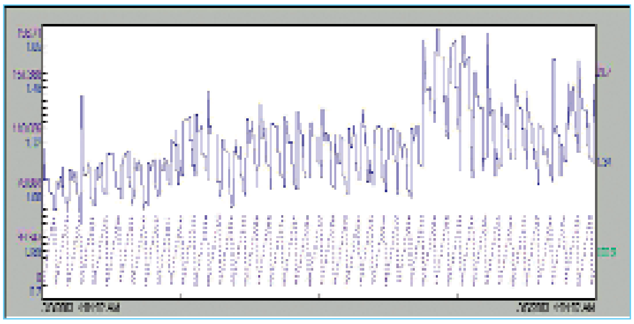

Figure 5a. Corrosion and pump down schedule.

entrained solids and gases. The corrosion monitoring probes were of a type shown in Figure 1 and were installed in an 8 in. diameter pipe section experiencing severe corrosion. The physical configuration of the corrosion probe, coupled with the SmartCET device, enabled high sensitivity monitoring in what was essentially a low conductivity environment where conventional electrochemical techniques would not have worked.

As shown in Figure 1, the corrosion monitoring system used innovative flange style probes that allowed corrosion monitoring around the pipe's complete circumference. These flange style probes matched the inside bore and surface of the piping and were placed between mating flanges. Figure 2 shows the simple assembly of a typical three element flange probe using a standard ANSI pipe flange. An advantage of this probe design is that it can be inserted into the actual process piping, thus making literally any flange location a monitoring point with little or no in-plant fabrication or modification. This design also facilitates placement of the sensor where needed, as opposed to where existing probe access locations may have been originally installed.

Figure 3 shows the installation of three probes with the three different materials (carbon steel, 304L, and 316L) in a single 8 in. pipe run. This location was downstream of the caustic water addition and the injection point for another process stream where all materials were used.

Figure 4 shows explosion proof enclosures housing the remote instruments: one for each of the probes in this system.

System utilisation and integration

After initial installation and operation as a stand alone system, SmartCET was integrated with BASF's process information management system (PIMS). This allowed operators and engineers to view corrosion data in real time alongside the standard process variables.

Representative data from the monitoring system are depicted in Figures 5a, b, c, d and e, which show the usefulness of the system in parametric experimentation and root cause analysis. It is evident from this data that the corrosion manifested in the plant was not an 'always on' condition, but varied greatly with a variety of process and operational variables. The following is a summary of the lessons learned through the monitoring process.

Vessel pump down

Figure 5a shows a correlation discovered between the corrosion rate of carbon steel and the pump down schedule for an upstream vessel. The vessel was on an automatic pump down schedule of once per hour. The reactor was automatically level controlled and, therefore, automatically increased its discharge flow rate when it received increased flow from the vessel. The reactor discharged a relatively small quantity of a mixed organic/aqueous stream into the primarily organic stream being monitored. Every time the vessel pumped down, the corrosiveness of the larger stream increased. Subsequently, the valve was replaced and the resultant corrosion rate decreased.

Neutraliser concentration

Operators had reduced the concentration of a neutralising chemical in the process. Recently, they thought this reduction could have been responsible for unusually high corrosion rates, and more neutraliser was slated to be added. Using the corrosion monitoring system, a process test was run to determine the effect of increasing the neutraliser concentration. As shown in Figure 5b, increasing the amounts of neutraliser greatly increased corrosion rates. This new information not only helped reduce corrosion by identification of a critical feed rate, but it also provided chemical engineers with new insight into the process chemistry.

Critical catalyst concentration

Parts per billion concentrations of catalyst are added to enhance the chemical reaction. Following a dramatic increase in corrosion rates, a plant technician pointed out that the increase occurred immediately after they mixed a new batch of catalyst. Due to the procedure used to mix the catalyst, small variations in catalyst concentration can occur.

Figure 5c shows the influence of catalyst concentration on the corrosion rate of 304L. It also shows that there is a critical concentration above which corrosion increases significantly.

Other operational variables

Figures 5d and 5e show more examples of how the corrosion rate varies significantly with process and operational variables. In Figure 5d, the corrosion rate of carbon steel is shown to have a direct correlation with the quantity of a key gaseous chemical used in the process. The daily variation in the amount of this chemical added to the process was not intentional.

Figure 5e shows data from another (primarily aqueous) process stream being monitored. Normally, its corrosion rate is quite low. However, observers noticed some short term spikes to high corrosion rates. These spikes in the corrosion rate reached levels that were over 10 times the baseline corrosion rate in the system. When examining operational information, researchers determined these spikes coincided with the pumping of waste samples back into the process. Shortly thereafter, operations changed their waste disposal procedure to stop the corrosion spikes and the resultant cumulative damage.

Evolution of online, real time corrosion monitoring

During the early phases of this corrosion testing programme, a list was made of the process variables that could have an effect on corrosion rates. Process tests were then run by adjusting one process variable at a time while monitoring the effect on corrosion rates and pitting factors. This soon revealed a highly complex relationship between process variables and corrosion behaviour. In order to address this complexity and maximise the efficiency of the testing programme, BASF engineers began using the multivariable testing protocol. With this system, a set of process variables was randomly modified at the same time. This type of corrosion evaluation would not have been possible without the real time corrosion data provided by SmartCET.

As more sites view corrosion as a real time process variable, more plants will be able to automate corrosion control by utilising the DCS data flow and higher level process knowledge systems that include process, business and asset management functions. This integration allows simultaneous visualisation of process variables and corrosion data.

The corrosion signal can easily and quickly differentiate corrosion in terms of cautionary or critical events so that the appropriate personnel can make process adjustments or take mitigative actions. In this situation, the corrosion instrument becomes the 'tachometer' for the plant, allowing productivity to be optimised while quantifying the damage to the unit so economic consequences can be evaluated and business decisions made with confidence. Utilising this new data channel, alerting software and event analysis tools are used to identify these events along with the root cause of the problem. Also, the integration of this information into the data management systems allows, for the first time, the damaging effects of corrosion to be viewed in economic terms so that their impact on plant profitability can be realised, thus achieving a new basis for reducing the high cost of corrosion.

References

1. KOCH, G. H. et al., Cost of Corrosion and Prevention Strategies in the United States, Report FHWA-RD-01-156, US Federal Highway Administration, 30th September 2001.
2. EDEN, D. C., CAYARD, M. S., KINTZ, J. D., SCHRECENGOST, R. A., BREEN, B. P. and KRAMER, E., Paper #3376, NACE Corrosion 2003, San Diego.

Notes

* *InterCorr International Inc. was recently acquired by Honeywell.* ■

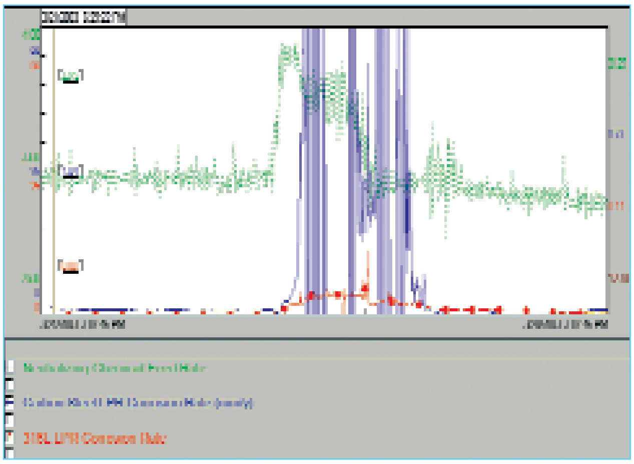

Figure 5b. Corrosion and neutraliser feed rate.

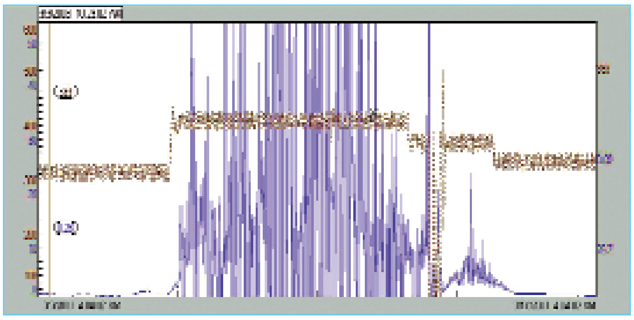

Figure 5c. Corrosion and cataylst feed rate.

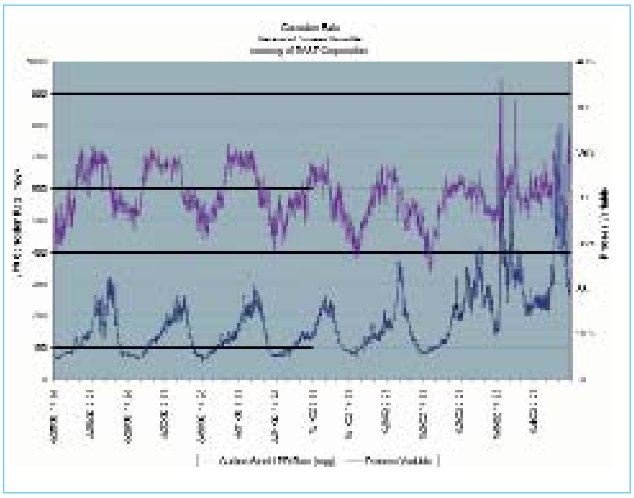

Figure 5d. Corrosion and key process variables.

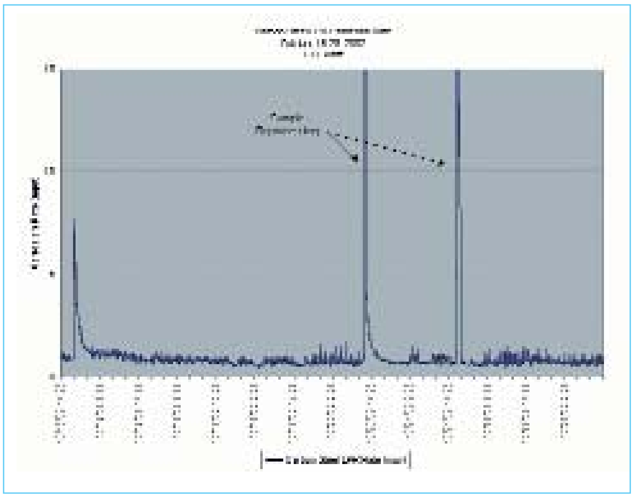

Figure 5e. Corrosion and sample reprocessing.