SOLUTIONS FOR CORROSION MONITORING IN REFINERIES

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Abstract

Internal corrosion causes significant pain to refinery operators today, being a major reason for rising maintenance costs as well as bringing risks to the integrity and safety of the plant. Examples of corrosion are many and include internal corrosion in cooling water systems and side-streams, de-salting units, flare systems in carbon steel and in distillation units.

In this paper, an overview will be provided of the differing forms of corrosion, the purposes behind corrosion monitoring and the varying approaches and technologies for addressing corrosion. The paper will conclude with a case study from the Jamnagar refinery in India.

The paper will examine the differing forms of corrosion from general corrosion in carbon steel lines and vessels to localized corrosion in stainless steel units and naphthenic corrosion (localized, meza-type) in distillation units. Challenges also vary according to the age of the refinery and the design specifications during construction.

The different purposes and objectives behind corrosion monitoring will also be referenced. One is to verify and optimize the use of chemicals (corrosion inhibitors) for corrosion control, another may be to optimize the process for opportunity crudes, and a third may be to improve the general integrity management program and reduce turnaround downtime.

Thirdly, the different methods used for corrosion monitoring will be highlighted along with their benefits and limitations. Intrusive probes provide high accuracy and fast response, whereas Ultrasonic (UT) sensors generate accurate wall thickness measurements at a relatively low cost per position. The paper will show how intrusive probes and UT sensors can both be provided by Wireless Hart communication using the same infrastructure and allowing on-line communication at an affordable price, and how they are also applicable for high temperature applications.

In addition, the paper will cover how non-intrusive FSM (Field Signature Method) technology is often used in refineries for locations with high temperature naphthenic corrosion, due to its' ability to monitor both uniform and localized corrosion at the monitored area.

The paper will also include examples from almost two years of on-line, non-intrusive high temperature monitoring of the Jamnagar refinery in India, one of the world's largest refineries. The results will demonstrate how the refinery monitors and controls high temperature corrosion accurately and efficiently, optimizing production, and guaranteeing integrity management. Results show variations from single

measurements in the range of +/- 0.01 mm, or within the range of 0.1% of the wall thickness.

The paper will show how the corrosion monitoring methods described can be combined and integrated according to each refinery's' needs and application and will be of interest to all operators looking to improve economic performance and integrity in refinery operations.

Introduction

Corrosion and material degradation is one of the most significant pains in many industries, oil and gas refining included. Corrosion is a continuous challenge and a significant portion of a plant's maintenance costs are linked to material corrosion. There are many ways in which corrosion is addressed- painting, coating, cladding, cathodic protection and the use of chemicals (corrosion inhibitors) are some of them. The effect of a corrosion protection program must be verified, and the possible optimization of the protection processes can give significant contributions to the plant's financial bottom line.

In addition to being costly, some of the methods to control corrosion have side effects. A good example of this is use of corrosion inhibitors, which are chemicals that may have negative effects on the environment. The limited use of chemicals is therefore good both for the economy and the environment.

In addition to being a continuous cost and drain on resources, uncontrolled corrosion increases the chances of accidents and unplanned stops that may have a serious impact on the economy and environment as well as being a risk for personnel and the surroundings. A well-documented case is Chevron's Richmond Refinery fire in 2012, which was clearly corrosion related (see U.S. Chemical Safety Board's animation available on the web [1)] This is a typical example of how uncontrolled degradation over time can cause serious accidents - in this case without significant damage to personnel life and health.

Many factors have an impact on refinery corrosion challenges. Age, original construction specification and processes can be different from refinery to refinery. Changes in operational temperature and velocities can also influence plant performance.

Finally, the quality of the feed (crudes) may affect corrosion in the plant. Different crudes have different corrosion properties, linked to the ‘acid content’ of the crude (TAN number). Acid content is linked to the crude price and lower price crudes often have a higher acid content and therefore are more corrosive to the plant materials. Hence, refineries that buy crude in the spot market (opportunity crudes) often need a proactive corrosion protection strategy related to the blending of crudes, material selection, monitoring and inspection.

Corrosion challenges in refineries.

Refineries run complex processes and there are subsequently many different corrosion related issues in the plant, each needing its own monitoring and control strategy. Examples of corrosion issues in a refinery comprise corrosion under insulation, cathodic protection on underground sections of pipelines and tanks, as well as internal corrosion in process piping and vessels. This paper will focus on internal corrosion only.

Internal corrosion depends on the service of the pipe/vessel and the materials used.

Carbon steel piping within the refinery, for example, will suffer from uniform corrosion, depending on water content, the efficiency of desalting, the use of corrosion inhibitors, etc. This will be the case in in many of the refineries' early streams, side streams and cooling water pipes.

In addition, refineries have lots of heat exchangers. Hydrocarbon inlet lines may have carbon steel piping, and at the same time high temperatures - an obvious corrosion challenge. The heat exchanger tubes/plates are normally in corrosion resistant alloys, where corrosion attacks more often take place as localized pitting or crevice corrosion.

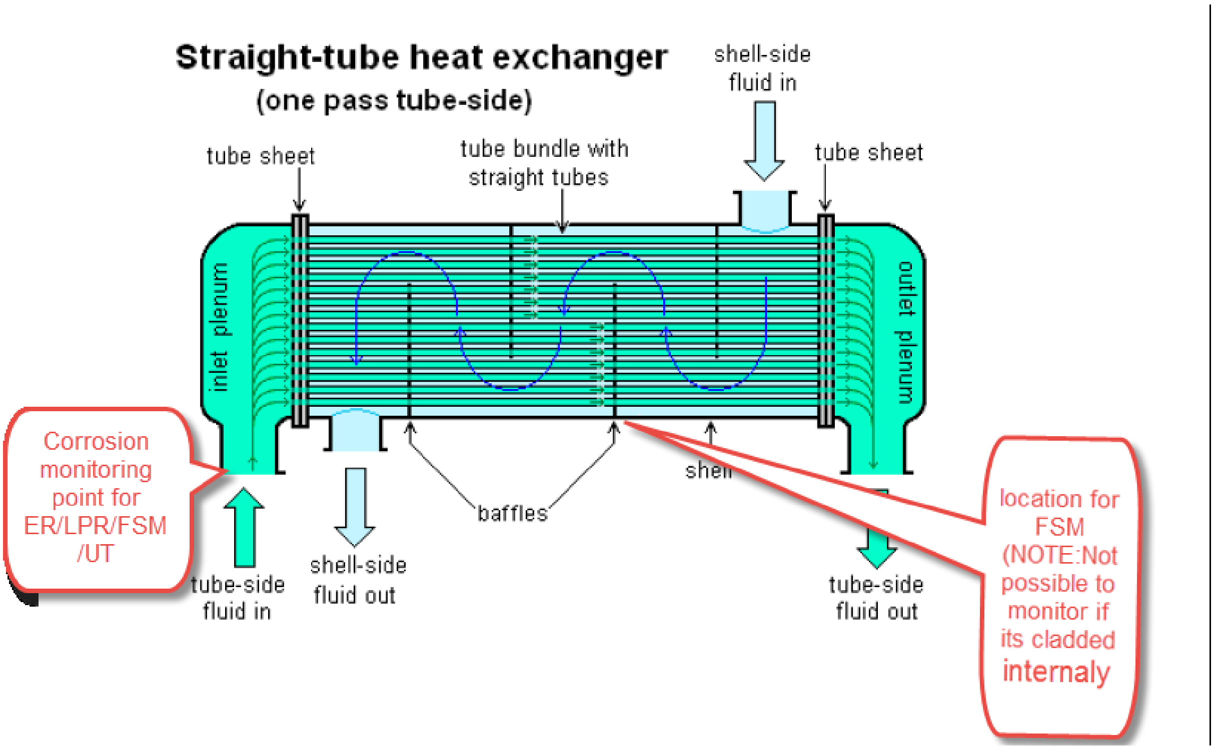

Figure 1 - Application example - corrosion monitoring on a heat exchanger.

A common problem in the high temperature distillation units is 'naphthenic corrosion', which normally initiates as localized corrosion attacks that may later form front lines where a sulfidic film is damaged. Over time, metal loss will appear as a combination of localized corrosion and more uniform distribution at the internal pipe wall. Several studies have been done on this topic [2)].

Corrosion Monitoring Technologies

There are a range of corrosion monitoring technologies that can be and are used in refineries, each with its own benefits and limitations. It is therefore important to choose measurement technologies according to the application and objectives of monitoring. Today, we are seeing a trend towards combining more technologies in integrated solutions for a complete monitoring strategy.

Intrusive probes are commonly used in refineries as well as in upstream oil and gas production. There are different styles of intrusive probes according to operating requirements. In refineries, retractable style probes are most commonly used.

The most common measurement principal for intrusive probes are Electrical Resistance (ER) and Linear Polarization Resistance (LPR) measurements.

Weight Loss Coupons are the simplest devices for intrusive corrosion monitoring. Pre-weighed steel samples are inserted into the pipe or vessel for a given period (say four months), then cleaned and weighed after retrieval. Based on the weight difference, corrosion rates, deposits and the tendency to localized attacks on the exposed coupon are calculated and reported.

ER probes (see figure 2) are based on measuring changes in the resistance of the probe's measurement element. As the metal element corrodes, the thickness is reduced and the resistance increases. Reference elements inside the probe are used to compensate for temperature fluctuations.

The advantage of ER probes is that they have a high resolution (down to 10s of nano-meters of metal loss), hence the response to (changes in) corrosion rates is fast. ER probes can be used in most environments (oil, gas and water) and are available with a high temperature rating.

The disadvantage of ER probes is that they are intrusive and that the measurements are local. Hence, the probe is mostly useful if the corrosion is uniform. It is difficult to pick up localized corrosion with an ER probe.

LPR probe measurements are based on calculating the current response to a small polarization of the probe's working electrode in a 2- or 3- electrode configuration. The corrosion rate is proportional to the current response measured, and utilizing empiric factors, corrosion rates can be determined from only one measurement. Other electrochemical methods like electrochemical noise are also applied in industrial corrosion monitoring.

LPR (and other electrochemical) probes require a conductive electrolyte (water) to perform, and are therefore normally restricted to just water systems.

Due to the high resolution and fast response, intrusive probes are important for active corrosion management, e.g. verification and optimization of corrosion inhibitor use. Typical locations for corrosion probes are in side-streams, low temperature process piping and heat exchanger inlets. Emerson provides transmitters for both ER and LPR probes (see figure 3).

The use of intrusive probes should be avoided in cases where internal composition is chemically aggressive, such as in alkanizing unit side-streams. For such locations, non-intrusive ultrasonic devices are a good alternative.

Intrusive corrosion monitoring is available with wireless Hart corrosion transmitters.

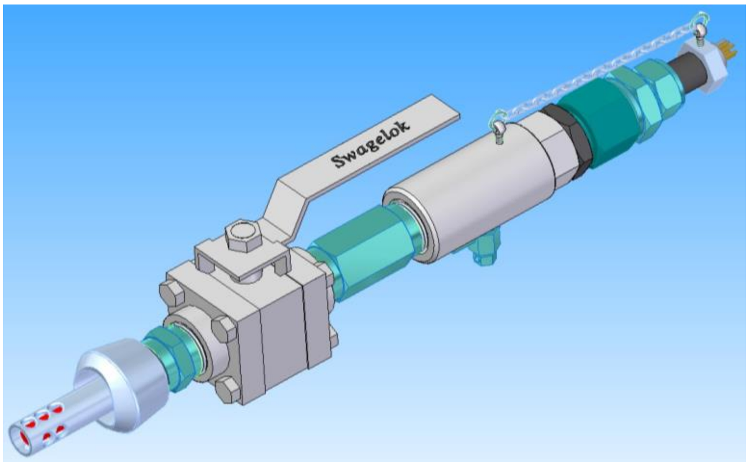

Figure 2 - Refinery style ER probe with full bore valve and packing gland

Figure 3 - Emerson's CorrLog wireless corrosion transmitter for ER and LPR probes.

Ultrasonic sensors (UT) are also used in refineries, and are now available for high temperature applications. Ultrasonics (see figure 4) measure the pipe wall thickness, and can also accurately detect changes in wall thickness on a pipe, from which corrosion rates are calculated. UT sensors' accuracy is typically in the range of 10 - 100 micrometers. In order to cover for non-uniform corrosion, an array of UT sensors are often used.

The cost of installing non-intrusive sensors is relatively low and installation convenient. This allows for large numbers of UT sensors to be installed, e.g. for permanent integrity monitoring (wall thickness mapping). UT sensors are also used in corrosion inhibitor control.

UT sensors are used in all types of refinery units. With the low installation cost per location, high temperature UT allows for the application of permanent wall thickness monitoring at a high number of selected locations around a plant - useful for an efficient asset integrity management program. UT sensors are available with wireless Hart communication.

Figure 4 - Permasense wireless UT sensor installed on pipe (courtesy of Permasense).

Field Signature Measurements (FSM) are based on measuring changes in wall thickness between sensing pins installed on a pipe or vessel. The method is based on feeding an electric current over the monitored area and measuring changes in voltage drop between pairs of sensing pins caused by changes in pipe wall thickness. FSM can therefore measure both uniform corrosion and identify localized corrosion at any location of the monitored area.

FSM has a resolution normally stated to 0.1% of the pipe wall thickness for uniform corrosion, and can be used at pipe/vessel temperatures of up to 500 oC. FSM is not available with wireless Hart solutions today.

Due to its' ability to monitor uniform and localized corrosion with a high resolution, FSM is used where few other alternatives have the same features. Due to a fairly high cost and complexity, FSM is most commonly focused on critical applications, like naphthenic corrosion monitoring at high temperature distillation units. A typical location of FSM in a refinery would be mainstream or downstream of the furnace after the apex of the bend.

Data acquisition and data management

In addition to measurement technology, data acquisition and data management is also important to the quality and value of the corrosion monitoring.

Traditionally, corrosion monitoring was carried out by using corrosion coupons where probes were normally interrogated off-line by a portable meter every two to four weeks. This concept has the advantage of simplicity and low installation costs. However, labour costs are significant, since all data has to be collected manually, and besides, the off-line data acquisition provide few data points limiting the ability to track corrosion rates versus process changes. Information is also significantly delayed in processing for the user.

Continuous corrosion monitoring increases the amount of data and therefore adds value with respect to correlating corrosion monitoring data with process changes and making the trending of data more accurate. Continuous off-line monitoring is utilized to some extent, using stand alone data loggers from which data are downloaded at defined intervals. Compared to on-line systems, the investment cost is still reasonable although there is still a delay before information reaches the user.

The industry trend is clearly towards on-line corrosion monitoring, allowing frequent data for optimized trending and process correlation, minimized labour for data collection, and real time information to the user. Limitations of on-line monitoring, however, are often down to the cost of field cabling, especially in the case of existing plants and platforms where the cost of field cabling may be prohibitive for having on-line corrosion monitoring upgrade approved.

The plot below (figure 5) is an illustration of how on-line data (in this case FSM) can be used to optimize corrosion inhibitor control in a case where the refinery is processing opportunity crudes. It illustrates how inhibitor dosing is related to changes in corrosion rates, and how a different TAN mix of crudes has an effect on the corrosion in the distillation units. The first period is used to create a good baseline for the monitoring, and later data is used to optimize the mix of opportunity crudes.

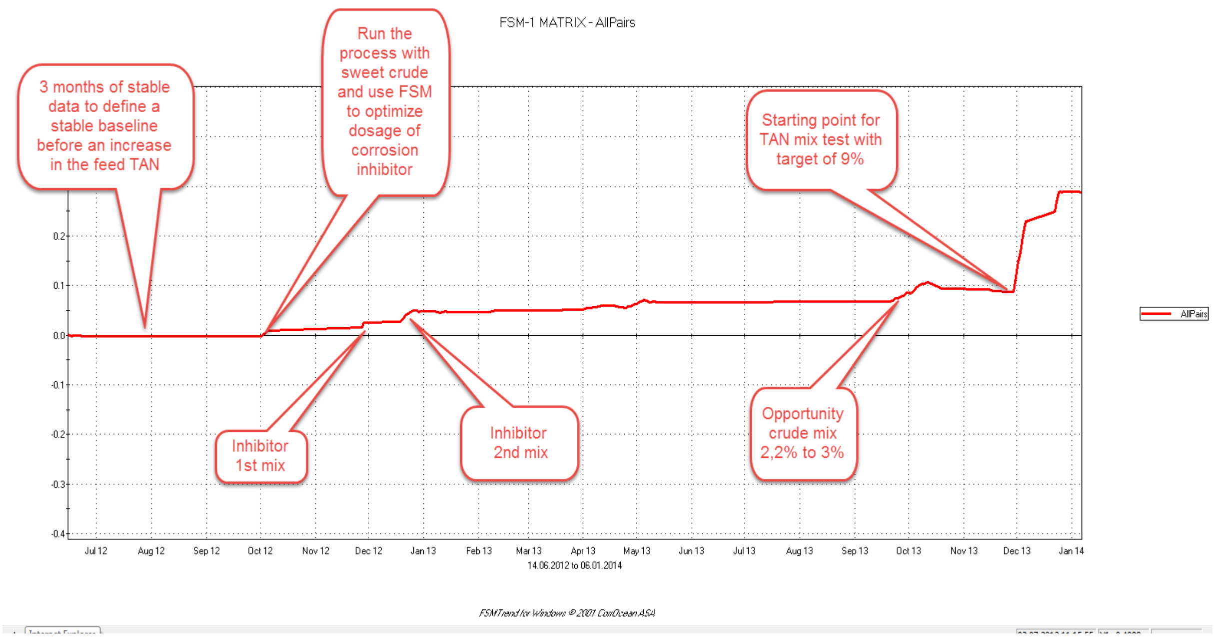

Figure 5: An Example plot for how on-line FSM data can be used to track and optimize the use of corrosion inhibitors when processing opportunity crudes.

Recently, wireless communication has become more acceptable in industrial applications, allowing on-line upgrades in plants at an affordable cost. Standards for wireless communication have been established, of which wireless Hart is one of the most common. This means that different monitoring functions can be integrated within the same wireless network. The more applications there are, the better it is, since communication goes in a mesh where the signal is routed in the most convenient way between the wireless Hart transmitters to the gateway.

As mentioned already, both intrusive probes and ultrasonic devices are available with wireless Hart communication. This allows the user to combine different monitoring technologies in one integrated wireless Hart system using the same gateways and infrastructure. This makes it easier to use the measurement technology that is most useful for each individual part of the process and also to combine various technologies for redundancy and improved reliability of the information obtained.

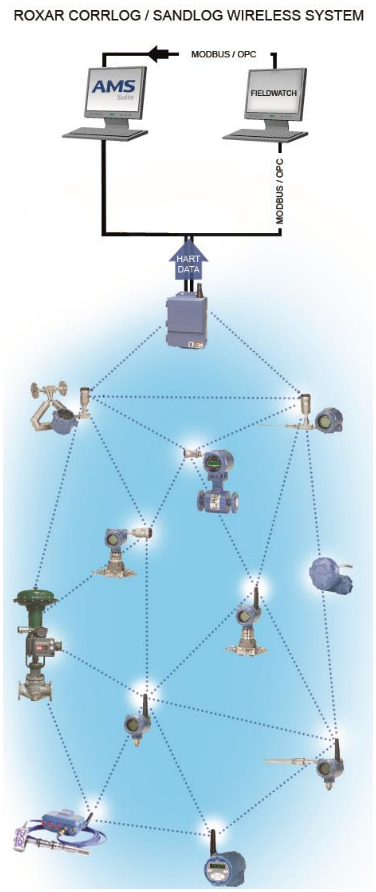

Figure 6 - Corrosion transmitters in a wireless Hart network with other applications, via the same gateway. Data is sent both to a general data management system and specific corrosion management software (Fieldwatch)

Different applications can also use the same data management software. As an example, intrusive probes and FSM technology can both be managed within Emerson’s Fieldwatch software, making the correlation and reporting of data more efficient.

The Jamnagar Refinery

This section is based on paper presented at the 12th Middle East corrosion conference and exhibition in Bahrain 2010 [3)] and a presentation made at the Eurocorr 2011 conference in Stockholm 2011 [4)]

The Jamnagar refinery is owned by Reliance Industries in Gujarat, India and has an aggregate refining capacity of 1.24 million barrels of oil per day. The refinery, commissioned in July 1999, is one of the largest refineries in the world, and one of the most extensive users of FSM corrosion monitoring.

The sensors were mostly installed in process streams in crude and vacuum unit furnace outlet lines, as well as other high temperature sections where the temperature is in the range of 200 °C to 400°C. Figure 7 shows pictures of the installation.

Figure 7: Sensing pins installed on pipe and termination in an online instrument on site

Since 2008, the monitoring at the actual site has continued, and typical data from the online system is presented below, illustrating the performance, reliability, resolution and accuracy of the system.

The plot in figure 8, for example, is from one of the FSM installed. Spike filters are applied and the plot shows general metal loss for all pairs from the beginning of October 2010 to January 2011. The total metal loss in the period is 0.32mm.

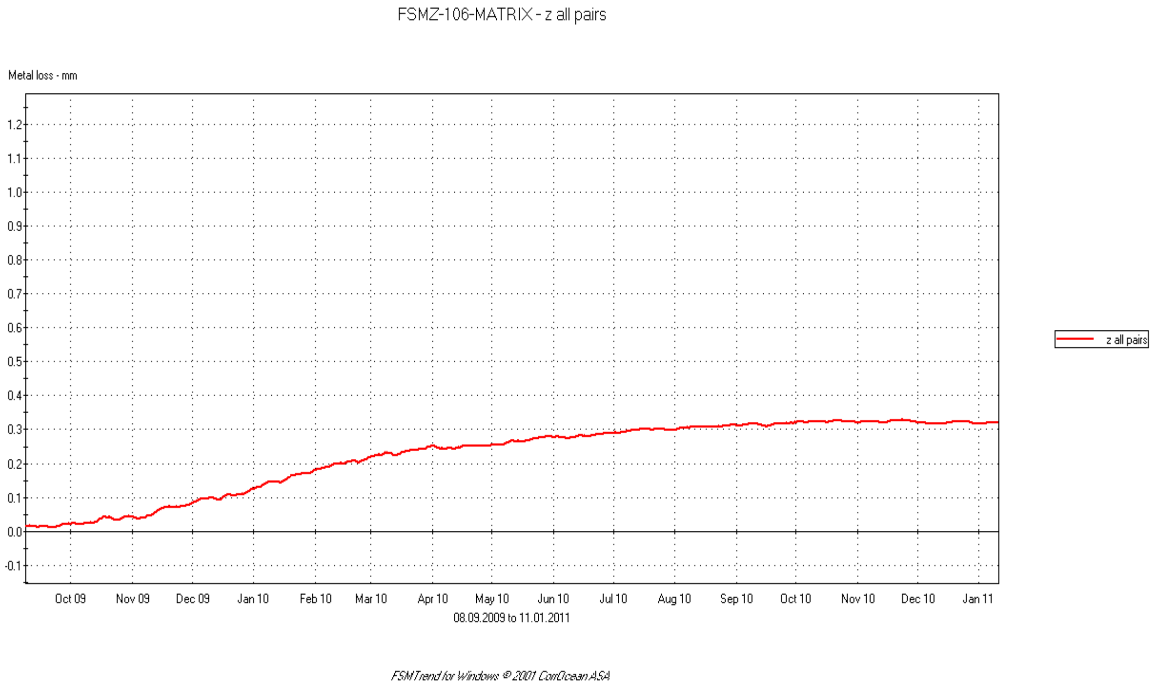

Figure 8: RC heater inlet to VDU line

Figure 9 is the same plot as figure 8 but is unfiltered with higher resolution in order to be able to see daily changes. As can be seen, random variations are in the order of 0.01 mm (10 micrometer), or approximately 0.1% of wall thickness.

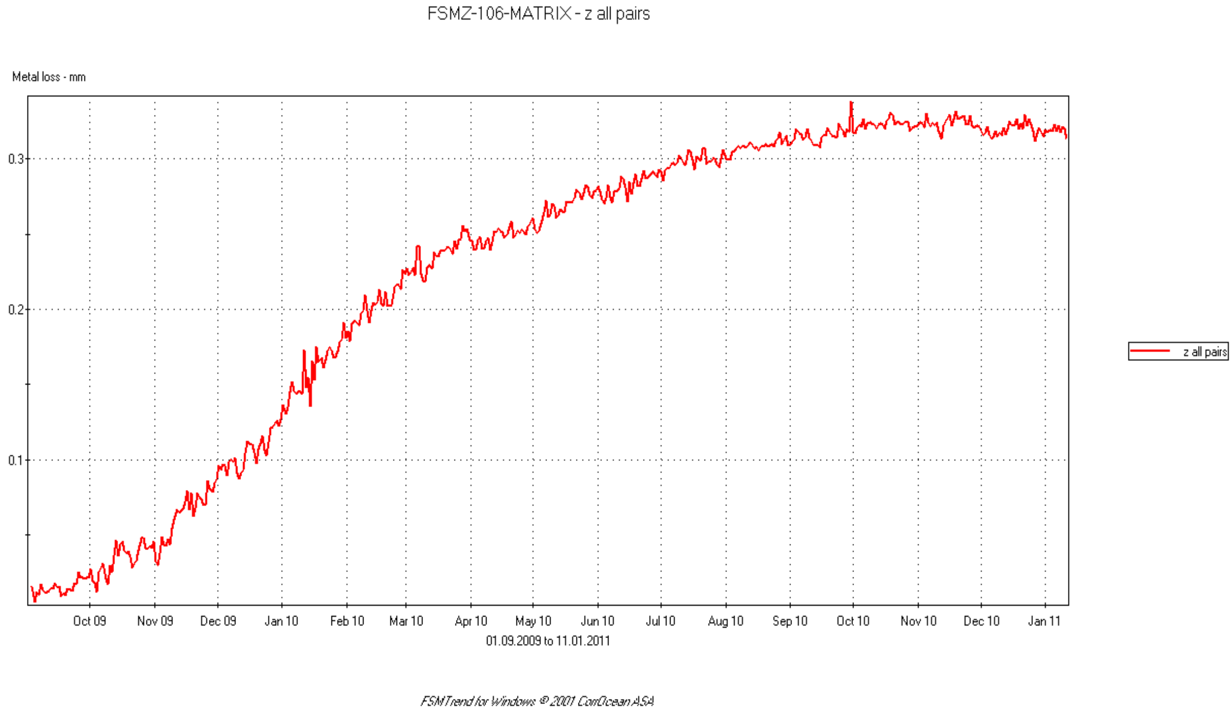

Figure 9: Same as figure 8 but unfiltered with higher resolution to be able to see daily changes

Figure 10 shows all data on a weekly basis and an expanded resolution plot for the fast detection of trends. Again, the resolution is better than 0.1% of wall thickness, and trends can be followed on a day-to-day basis.

Figure 11 illustrates a 3D plot of all the data at the start (September 2009) and figure 12 at the end (January 2011) of this period. It can be seen how metal loss is distributed within the matrix (observe that this plot is generated by the previous software version - the latest version will have other tools for visualization). The 3D plot of all data at the end of the period indicates a total metal loss of 0.32mm. It can also be seen that corrosion is fairly uniformly distributed, although some parts of the monitored area have higher metal loss than the rest.

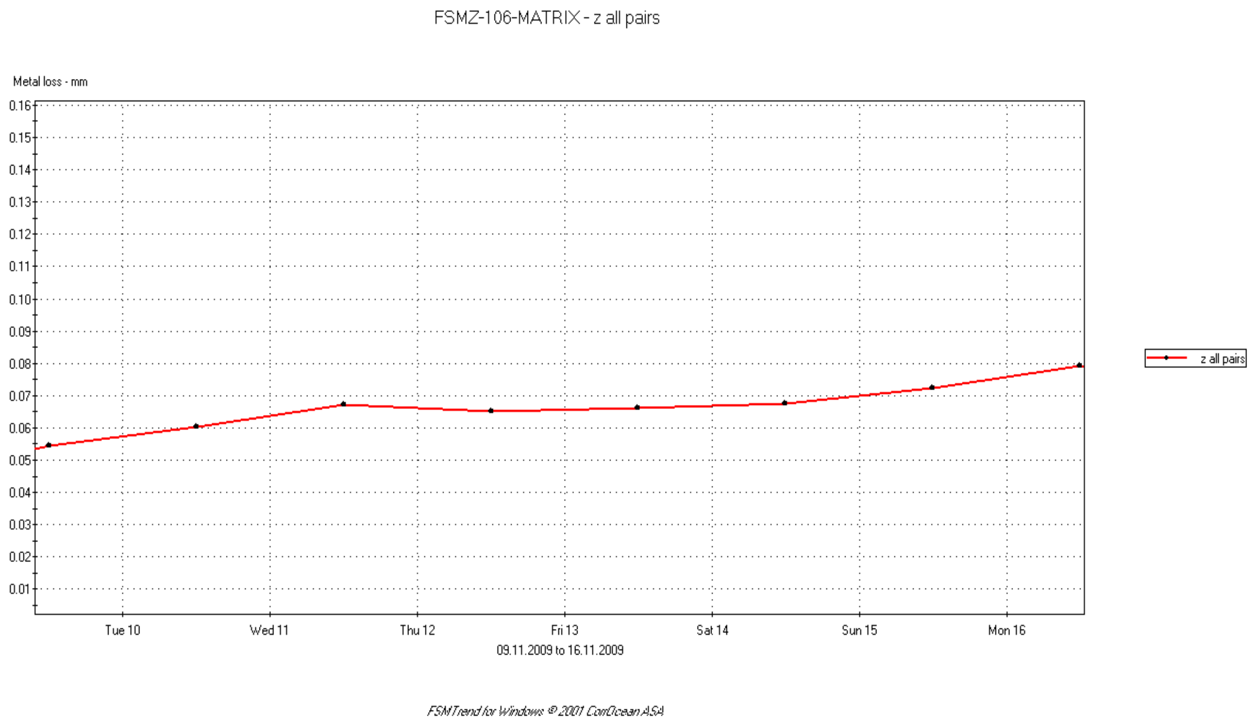

Figure 10: All data on weekly basis and an expanded resolution plot for the fast detection of trends

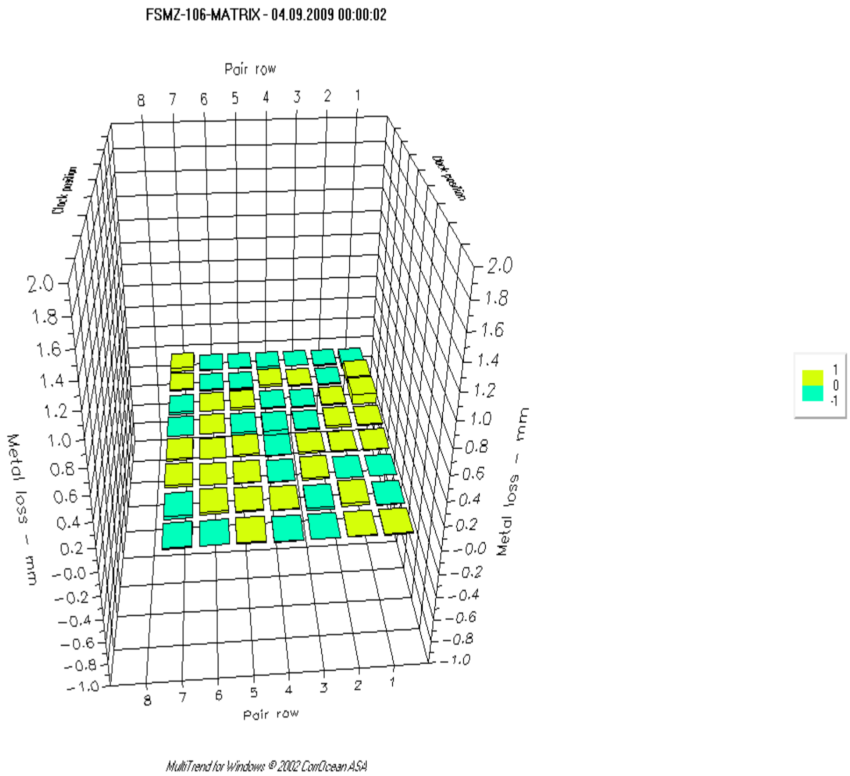

Figure 11: A 3D plot of all the data as of September 2009

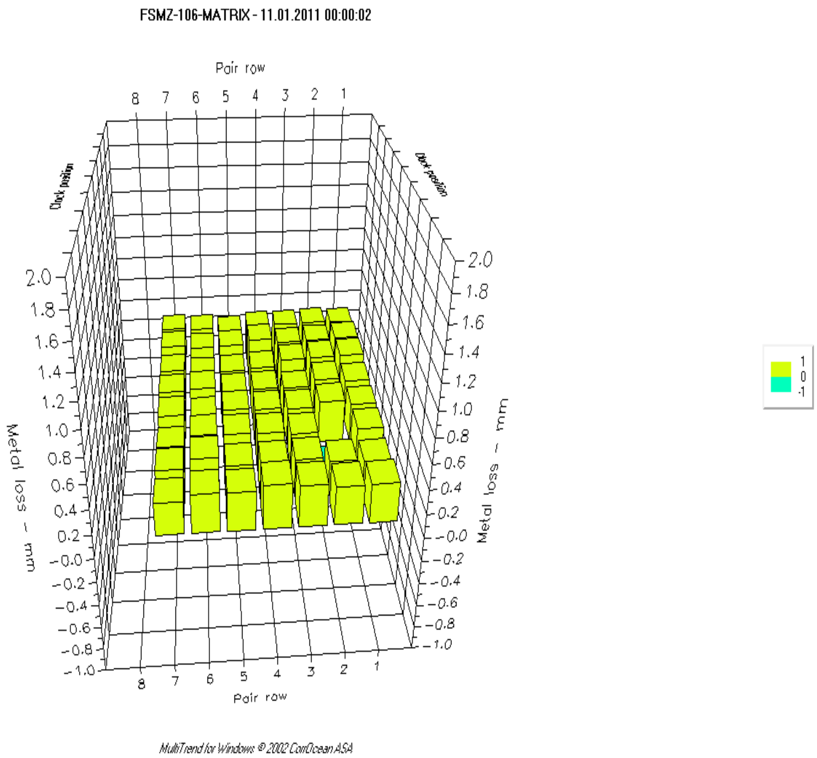

Figure 12: A 3D plot of all the data as of January 2011.

The results from the Jamnagar refinery illustrate how FSM can monitor and control high temperature corrosion accurately and efficiently, optimize production, and guarantee integrity management. The online systems' resolution is also within the range of 0.1% of the wall thickness. With crude oils having different corrosive properties, active corrosion monitoring and mitigation is having a key impact on the economics of the refining process and on the safety and maintenance of the plant.

Summary

Corrosion is a continuous challenge in refinery operations today – for maintenance and control but also as a potential risk for people and assets if not properly managed. Each refinery must adopt its own monitoring and control strategies to meet its specific needs.

A range of intrusive and non-intrusive methods exist - each with their own benefits and limitations. Yet, often a combination of methods will give the best overall monitoring program for a refinery.

Wireless Hart technology is increasingly accepted in the industry, and makes upgrades to on-line monitoring affordable. Many monitoring applications can be combined in the same wireless Hart network, including intrusive corrosion monitoring and non-intrusive UT sensors - all at the same time.

The Jamnagar case is a good illustration on how corrosion monitoring can be used to optimize the processing of opportunity crudes and how technological developments in corrosion monitoring are playing a fundamental role in maintenance, production control and risk management strategies.

References

1) U.S Chemical Safety Board, Chevron Richmond Refinery Fire Animation, April 2013 - available at the web (http://www.csb.gov/videos/chevron-richmond-refinery-fire-animation/)

2) A comprehensive study of Naphthenic Acid Corrosion, R.D. Kane and M.S. Cayard, Paper 02555, NACE 2002)

3) Wold, Jenssen, Stoen, Sirnes, and Shinde, Anand; On-Line, Non-Intrusive Corrosion Monitoring Based on Electric Field Signature Technology – An Update on Installation Experience and Field Data, Paper no 10082, 13th Middle East Corrosion Conference, Bahrain, 2010.

4) Wold, Støen: Intrusive and Non-intrusive Methods for Corrosion Monitoring in High Temperature Applications, Eurocorr 2011 Conference, Stockholm, 2011.