Integration of intrusive and non-intrusive methods for corrosion and sand/erosion monitoring

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There is an increased focus today on corrosion and sand/erosion monitoring in both upstream oil and gas production as well as in plant/refinery operations. The objectives for such monitoring include process optimization, increased production, the reduced use of chemicals, and the improved integrity and safety of facilities. A range of intrusive and non-intrusive methods are available today both for corrosion and sand/erosion monitoring. There are also a wide range of data communication options, and wireless technologies which are making on-line monitoring more attractive and less costly. This paper briefly provides an overview of the different monitoring methods alongside their advantages and limitations, and how they can be integrated within one system, using the same software and infrastructure.

The paper also presents data examples of non-intrusive corrosion monitoring for high temperature applications in refineries as well as sand/erosion data from an offshore North Sea field, using intrusive sensors and data management software.

Keywords:
corrosion, high/low temperature services, technologies

INTRODUCTION

THE GROWING THREATS OF CORROSION AND SAND

The growth in deepwater and wet gas fields, the prevalence of brownfields (where water cuts are increasing in volume), and the continued popularity of carbon steel pipelines for cost saving purposes – a material vulnerable to saline formation water – have all increased the likelihood of corrosion in offshore oil & gas operations today. Corrosion can lead to production losses, metal losses, which reduces the life of production and storage equipment, or safety and environmental set-backs, due to the corrosion of key infrastructure.

Similarly, corrosion remains a key challenge in downstream refineries.

Refineries purchase crude oil on the spot market, and various crudes can have different corrosive properties, due to the acid level of the crude (TAN).

Internal corrosion monitoring is used both to optimize the use of opportunity crudes in the refinery business, to help with maintenance, and to ensure the integrity of the plant.

Sand is also a key threat to production operations as well. With, 70% of the world's oil and gas reserves contained in sand reservoirs, sand clogged production equipment and obstacles to wellbore access through sand can unfortunately be increasingly common.

TRENDS IN CORROSION AND SAND/EROSION MONITORING

The last few years have seen three growing trends in corrosion and sand/erosion monitoring – the move towards on-line monitoring; the need for reliable and easy to use data management and reporting systems; and a trend towards integrated monitoring solutions.

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The growing trend towards on-line monitoring rather than offline solutions is due to a number of reasons:

- On-line monitoring generates real-time information, allowing remedial action to be taken at an early stage before damage takes place.
- On-line monitoring allows for more frequent data collection, improving the information level and accuracy of the monitoring data. Continuous, on-line data makes the correlation with other process parameters more convenient, providing additional information about why trends or changes takes place, and giving the user the necessary information to mitigate the problem correctly.
- On-line monitoring reduces the need for personnel involvement, which can be advantageous both for economic and operational reasons.

There is also a trend towards more complex measurement technologies, increasing the need for reliable and easy to use data management and reporting systems. Such complex information gives valuable additional data on the monitored system, but requires more powerful tools for analysis and presentation. FSM (Field Signature Measurement) and advanced electrochemical technologies are both examples of techniques that provide more complex information, compared with traditional systems. FSM will be referenced later.

Finally, there is a trend towards integrated monitoring solutions, combining more monitoring applications within one integrated solution. Benefits include that the same infrastructure (cabling, cabinets, software, etc) can be used for more monitoring functions; and the fact that it will allow integrated contracts for purchase, installation, commissioning, training and maintenance.

Figure 1 shows an example of an integrated monitoring solution,

FIG. 1 ***Integrated monitoring solution.***
Sistema di monitoraggio integrato.

where traditional corrosion monitoring (hydraulic system), acoustic sand monitoring, a FSM for direct erosion monitoring, and acoustic pig detectors, are all provided as one integrated system.

SAND MONITORING TECHNOLOGIES – AN OVERVIEW

There are a variety of sand monitoring technologies used in the industry today.
Intrusive erosion-based sand monitoring provides the direct measurement of sand erosion. It can be based, for example, on the electrical resistance (ER) principle, where metal loss on the element is measured as increased electrical resistance in a sensing element exposed to sand erosion. Sand production rates can then be quantified by combining measured metal loss rates with average sand particle size and flow data. This is based on knowledge regarding the relationships between flow rates, sand production, sand particle size, and metal loss. The same relationship allows for the calculation in other parts of a pipe system, based on erosion rates measured by the sand/erosion probe.
The advantages of intrusive, erosion-based sand probes are:

- The probe measures erosion directly, with erosion in other parts of the process calculated, when combined with flow data.
- There is no need for calibration. Sand rates can be quantified when combining measured sand erosion with flow data and average particle size.
- The probe is reliable in most flow conditions and information can be found, even if the instrumentation system has been down for a while.

The alternative to intrusive is erosion-based sand monitoring is

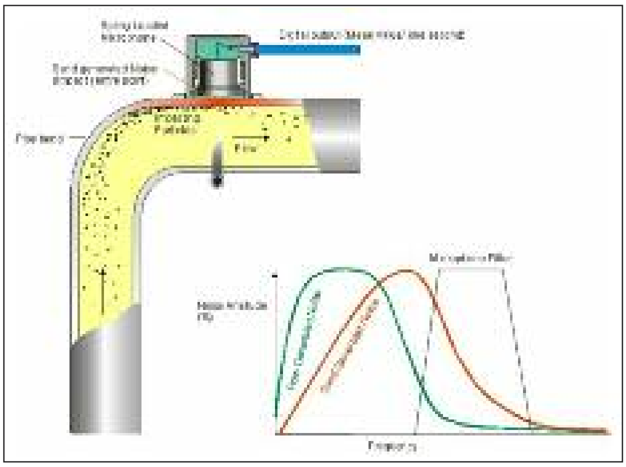

FIG. 2 ***Non-intrusive acoustic sensors, principle of measurement.***
Sensore acustico non intrusivo – principio di misura.

non-intrusive, acoustic sensors and intrusive probes, based on measuring sand erosion metal loss directly on the probe elements. Figure 2 shows the principle behind it.
Non-intrusive, sand monitoring systems measure acoustic impacts and noise, and the amount of sand particles in water, oil, gas or multiphase flow lines.
The operational principle is based on an acoustic emission sensor, which is clamped onto the production pipeline downstream to a 90° bend.
Sand particles, transported with the flow, hit the pipe wall at bends in the pipeline due to inertia, generating noise propagating in the pipe wall. The monitor detects this noise and converts it to a digital signal, which is transmitted via the sensor power cable to the safe area electronics. The safe area electronics comprises a 24 VDC Power Supply Unit (PSU), a Calculation & Interface Unit (CIU), and an intrinsic safety barrier between the detectors in the hazardous area. The CIU is a Modbus slave unit that calculates sand production rates based on the sensor signal and built-in algorithms.
The advantages of the non-intrusive, acoustic sand monitor are an immediate response to changes in sand production; and easy and inexpensive installation. These methods also provide continuous and real-time information to the user.

CORROSION MONITORING TECHNOLOGIES AN OVERVIEW

The traditional means of monitoring corrosion is through internal monitoring.
This can consist of test coupons, electrical resistance (ER) probes, and linear polarization resistance (LPR) probes. These coupons and probes are installed through a fitting system and placed within flow lines, process piping, or import and export pipelines – both topside and subsea.
For example, internal corrosion monitoring solutions Roxar/CorrOcean provides include weight loss coupons, where corrosion is determined from the weight loss over a period of time, and a range of electrical sensor based solutions, such as ER and LPR probes or galvanic measurements. Common for all these methods, except weight-loss coupons, is a high resolution and thus an ability to respond fast to changes in corrosion rates – a factor that is particularly useful for corrosion inhibitor programs.
Internal monitoring is also an effective means of monitoring corrosion further downstream – particularly in refineries. This has resulted in more efficient corrosion control where corrosives

vary from batch to batch and where corrosion control is critical with respect to integrity, maintenance and economic performance.
For all their benefits, however, there are limitations to internal, intrusive monitoring.
This includes the fact that corrosion on the probe does not necessarily reflect corrosion at the pipe wall, with limitations in detecting localized attacks, such as pits or weld corrosion.
Furthermore, corrosion is often most severe at the bottom section of the pipeline because this is the location where water is most likely to be present.
Monitoring such locations with traditional probes requires access to the bottom of the pipe, which would require big pits under the pipeline with space for access fittings and space for operating retrieval tools – quite a logistical challenge!
It is against this context that non-intrusive corrosion methods, directly installed on the pipe, have become increasingly attractive to operators. Non-intrusive sensors can be installed directly on the pipe, and the pipe can be buried in the soil along with the rest of the pipeline after installation.
Non-intrusive corrosion methods have become particularly popular in sour production (H2S) environments where direct measurements at the pipe wall can give more reliable measurements and where safety is a concern for probe retrieval operations.
For any application where space is important and where direct measurement on the pipeline provides monitoring and safety advantages, non-intrusive corrosion has become a popular alternative to traditional internal methods.
Yet, what form does non-intrusive corrosion monitoring take? The most common form is based on ultrasonic or electric field signature measurement technology. In this paper, we will look in particularly at the latter.

ELECTRIC FIELD SIGNATURE MONITORING (FSM)

One of the most popular non-intrusive monitoring techniques is electric field signature monitoring (known by Emerson as Roxar/CorrOcean CorrOcean FSM) – a technology which has been on the market since the early 1990's.
FSM is a non-intrusive method for monitoring corrosion, erosion or localized attacks and cracks inside pipelines, process piping or vessels. FSM can also be used in subsea pipelines and flowlines, underground pipelines, high temperature applications in refineries, applications in sour service environments, or in process piping and pipelines.
FSM is based on feeding an electric current through a selected section of the structure to be monitored. This is achieved through non-intrusive sensing pins which are distributed over the areas to be monitored. By inducing an electrical current into strategically located pipe sections, the induced electric current creates a pattern determined by the geometry of the structure and the conductivity of the metal.
Voltage measurements on each pin pair (up to 400 pin pairs can be applied in a matrix) can then be compared to the 'field signature' which provides the initial reference, and changes in the electrical field pattern can then be monitored. Conclusions can thereby be drawn relating to the general wall thickness and the initial signs of metal loss.
Figure 3 shows the installation of FSM, non-intrusive monitoring in Brazil where the sensing pins are welded to the external pipe surface, the instrumented pipe section is protected externally by a polyurethane compound, and the soil is then put back into position with interface boards and connectors (installed on a post) the only permanent components above ground. Figure 4 shows installed sensing pins with field cables and termination in an on-line instrument on site at a refinery.

FIG. 3 ***An off-line electric field signature system on an underground pipeline in Brazil. Cable from the instrumented pipe section is pulled to junction boxes for connection with the portable instrument for data collection. After installation, the pipe will be covered by soil, and only the connection post will remain visible.***

Sistema FSM off-line installato su linea interrata in Brasile. Il cavo di segnale è collegato alla junction box, la quale viene interrogata dallo strumento portatile per il download dei dati. Conclusa l'istallazione, la linea viene ricoperta in modo da rimanere visibile solo la connessione alla junction box.

FIG. 4 ***Field cables and termination in an on-line instrument at a refinery.***

Cablaggio di un sistema FSM on-line installato in raffineria.

There are a number of benefits to FSM technology.
Firstly, there is FSM's ability to distinguish localized attacks and general corrosion in real-time and to higher levels of accuracy and sensitivity, as well as its ability to detect corrosion rates much earlier than traditional corrosion methods. This allows corrective action to be taken before any damage occurs and is crucial to operators as they look to guarantee real-time flow assurance.
In sour service environments, for example, whereas traditional corrosion monitoring encounters difficulties due to iron sulphide (FeS) deposits disturbing the measurements generated from ER and LPR probes, the FSM method is not disturbed by such conductive deposits.
Installation is also much more cost effective and easier to apply than intrusive coupons and probes. One of the most critical sections of the pipeline, for example, is the bottom section (6 o'clock) of horizontal pipelines, where water collection is most likely to take place. The ease of installation compares favourably to traditional corrosion probes which require concrete pits to be dug under the pipelines.
This non-intrusive nature of the corrosion monitoring reduces installation and maintenance costs and increases operator safety – especially in the case of sour service fields.

RECENT DEVELOPMENTS IN ELECTRIC FIELD SIGNATURE MONITORING

As with any technology which has been available for 16 years, we at Emerson have further developed it. To reflect operator demand, for example, we have introduced online and real-time corrosion monitoring to FSM. Our on-line system and new, on-line data logger can be used with a wide range of wireless communications solutions (radio, telephone, GSM, satellite phone) as well as being powered through solar panels.
The advantages to the operator of online corrosion monitoring are significant.
These include a higher data collection frequency, thereby increasing the accuracy of the system and the ability to distinguish trends from random variations; and an online system which allows remote and wireless data communications direct to the operators' offices.
Today FSM can detect corrosion in a wide variety of different and often challenging applications. For example, in refineries and high temperature applications, the FSM can operate at pipe temperatures of up to 500 degree Celsius.
Since 2008, the first electric field signature on-line monitoring systems have been installed and commissioned, and the first data has been received. The background, installation and results from the first electric FSM installation at the Jamnagar refinery site in India was presented at the 13th Middle East Corrosion Conference and Exhibition in 2010 (1). Figure 5 shows an example plot showing all sensing pin pairs for the on-line monitoring system at the Jamnagar Refinery. Measurements are taken every 16 hours.
Based on the applications and experience from electric field signature measurement system installations, non-intrusive corrosion monitoring has become an important part of the refineries' system for optimizing production and its integrity management systems.

DEVELOPMENTS IN DATA MANAGEMENT & REPORTING SYSTEMS

FSM measurements generate a considerable amount of data - extensive information about corrosion rates and distribution. This has been exacerbated through the growth of online systems, such as ours, which generate more frequent measurements.

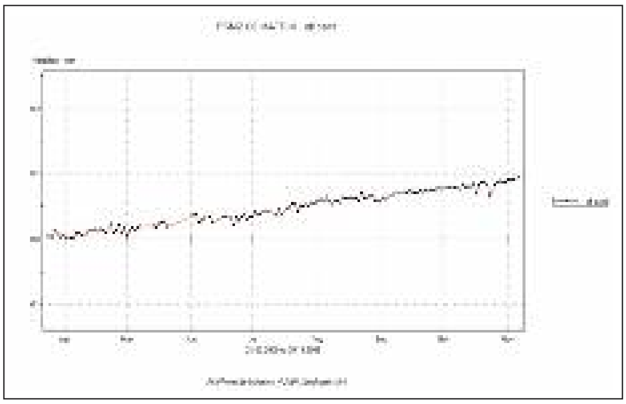

FIG. 5 ***Metal loss (all sensing pin pairs).***
Metal loss (su tutte le coppie di pin).

As well as the increase in data, there has also been a general trend among operators to more integrated monitoring systems which include not only intrusive and non-intrusive erosion monitoring, but also sand monitoring, pig detection and other downhole measurements. This, in turn, has resulted in an increase in users among the asset team who wish to access such a system.
As discussed in the introduction to this paper, the requirements for field monitoring software increases with the level of complexity and amount of information that must be analyzed. To this end, probably the single biggest area where we are taking FSM technologies, corrosion monitoring and sand monitoring forward is in the area of data management. Key components include:

- A field management software solution, combining the various software applications into one integrated data management system.
- Application software for each individual monitoring system (sand monitoring, FSM monitoring, or flow monitoring)

A NEW DATA MANAGEMENT SYSTEM

Our new data management system Fieldwatch is a specialized Windows-based field monitoring system which enables operators to 'watch their fields' remotely and which can handle intrusive and acoustic sand erosion sensors as well as corrosion monitoring sensors and pressure/temperature sensors within the same program system.
Data can be collected quickly from multiple locations and accessed through an intuitive user interface. The rapid retrieval and display capabilities of Fieldwatch also provide the user with the ability to quickly visualize data and identify trends and patterns or areas of interest for further analysis.
Specific data management features for corrosion monitoring, for example, include multi-user functionality with many users able to work simultaneously; fast data handling with real-time information available to all users; new data formatting; and an integrated, step by step software workflow which follows the product from system engineering through to data management and reporting.
The workflow includes the direct provision of technical documentation for the sensing pin matrix design; a service console for use by the service engineer during installation and commissioning for set-up, diagnosis, checking and verification; the receipt of data for data storage, analysis and reporting; and alarm facilities.
The latest version of the software will see a wide variety of reservoir instrumentation being incorporated into the new system, providing operators with a more complete picture of the reservoir and of production activities.

FIG. 6 ***Sand Management software installed in the product optimization room and platform control room at the operator. The screen shows the status of each sand probe by colour code.***

Sand Management Software installato nelle sale di ottimizzazione produzione e di controllo in piattaforma. Lo schermo visualizza lo stato di ogni sonda.

Instrumentation and modules that will be incorporated into the new version include the Roxar/CorrOcean acoustic and intrusive sand monitors and erosion probes, with the combined system resulting in the faster identification and validation of sand production and more effective remedial action to establish production control; the Roxar/CorrOcean downhole pressure and temperature gauges; and an updated well testing module which will generate results based on flow data direct from Roxar/CorrOcean's third generation multiphase meter.
The first installation of the new version is taking place on Statoil's Sleipner oil field in the North Sea where a combined sand and erosion monitoring system will see the integration of 3 Roxar/CorrOcean Sand Erosion probes and 94 acoustic Roxar/CorrOcean Sand monitors within the data monitoring system.
In this way, Statoil will have an instant overview of asset sand production and erosion, be able to validate data through smart alarm systems, and establish maximum sand and erosion free production rates for production optimisation.

DEVELOPING NEW APPLICATION SOFTWARE A SAND MANAGEMENT MODULE

Sand monitoring is now becoming a major element of the new data reporting system, allowing operators to be more proactive in taking the necessary remedial action to prevent sand interference, as well as providing them with the ability to access sand management data alongside other real-time field production data.
The new sand management module was developed jointly between Roxar/CorrOcean and a leading operator which had increasing requirements for such sand management software due to:

- The growth in maturing fields, requiring more water (more sand) and more gas (higher velocities, and potentially more erosion damage). Hence, the need for sand monitoring had increased.
- With an increasing number of sand monitors, the amount of data has increased significantly, and a faster/more efficient data management function was required.

The new software was developed and implemented by the operator at their North Sea field between 2008 and 2009. The field is located in the Norwegian Sea on the Norwegian continental shelf. The field has been developed with a floating concrete tension leg platform (TLP) and the northern part of the field is developed with two subsea templates with separate flow lines connected to the TLP.
The field was seeing an increase in sand production and there was a need to increase the field's sand monitoring capabilities to allow for the maximum amount of sand without affecting production and to meet the challenges of increased water content and more gas (more sand and higher velocities).
The new software has enabled the operator to respond faster to changes in sand production conditions, allowing them to secure control of significant sand production from the well, and establish maximum sand free production rates for production optimization. Figure 6 shows the screen status in the operator's platform control room and Figure 7 demonstrates a sand burst. The diagram also outlines the software tools available. Note that there are three parallel readings from the different elements on the sand probe. The comparison of the measurements at each individual element, as well as readings of the reference element, is used to verify that the probe data is valid.

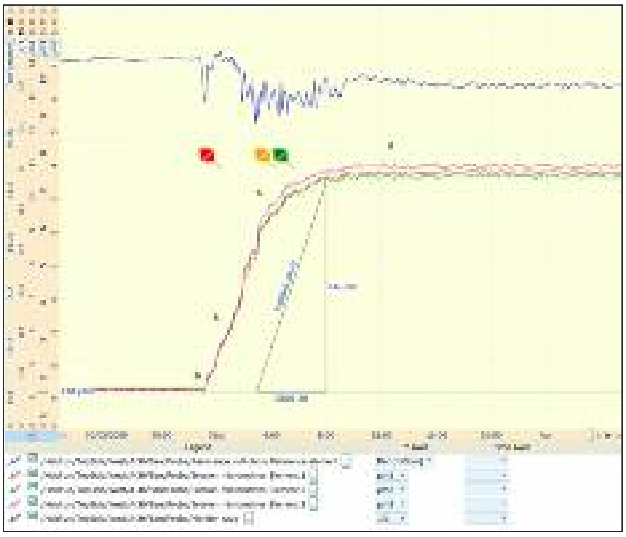

FIG. 7 ***Metal loss curves for the well during a sand burst.***

Curve di metal loss durante sand burst (pozzo petrolifero).

THE MOVE TOWARDS WIRELESS

Many of the solutions described in this paper to combat sand erosion and corrosion challenges are wireline-based, meaning that they are restricted as to the areas they can monitor in the reservoir. They are also encumbered by the need for electrical power and the cables required to position the sensors in remote locations, as well as having maintenance and data analysis implications. It's with this in mind that the next few months will see Emerson bring a number of firstly corrosion and later sand wireless transmitters to market – transmitters that can be used both upstream in the reservoir and downstream in refineries.
The transmitters, based on intrusive sensors that are installed into pipes or vessels through an access fittings system, will result in a significant reduction in installation costs compared to wired online systems, will allow for monitoring in previously inaccessible areas, and ensure that vital measurement data can be collected and acted upon in real-time.
Other advantages of wireless include the saving of space and costs. A recent study by Emerson of an actual offshore platform with about 4,000 I/O found that installing wireless along with other technologies in the process control system can save up to 7%, or more than $1 million.
In this case, the wireless transmitters will be just one element of a complete asset management system for offshore operations with direct integration to the field monitoring system, Roxar/CorrOcean Fieldwatch and Emerson's smart wireless network.

CONCLUSIONS

There is a trend in the market today towards more integrated on-line monitoring systems, providing more data of increasing complexity. The needs for more powerful data management systems are growing accordingly.
This paper has demonstrated that a new generation of data management software is facilitating the integration process and providing new features and functions for improved data management, data analysis and reporting. Field testing of the new software for sand management has verified the usefulness of the system, allowing more real time sand control and optimized production.
The advent of new wireless technologies will also facilitate the growth of sand and corrosion monitoring technologies into areas of the reservoir deemed previously inaccessible.
It is the authors' belief that the conclusions and learnings from this paper will have a major impact on corrosion and sand monitoring for many years to come.

REFERENCES

1. Wold, K; Jenssen, H; Stoen, R; Sirnes, G; Shinde, V; Anand, U; On-Line, Non-Intrusive Corrosion Monitoring Based on Electric Field Signature Technology – An Upgrade on Installation Experience and Typical Field Data; 13th Middle East Corrosion Conference and Exhibition, Bahrain, 2010.

Abstract

Integrazione di metodi intrusivi e non intrusivi per il monitoraggio corrosione/erosione

Parole chiave: corrosione, impieghi alta/bassa temp., tecnologie

L'attenzione verso sistemi di monitoraggio corrosione ed erosione sia nelle installazioni upstream, così come negli impianti di raffinazione, è in continua crescita. L'ottimizzazione dei processi di estrazione, l'incremento della produzione, la riduzione nell'utilizzo di inibitori ed in generale, l'aumento della sicurezza degli impianti, sono i motivi principali di tale interesse.
Attualmente sono disponibili molteplici tecnologie di monitoraggio corrosione ed erosione sia intrusive che non intrusive. Altrettanto varie sono le possibili opzioni per la trasmissione dati, tra le quali quelle on-line con tecnologia wireless. Nella memoria vengono descritti brevemente i principali metodi di monitoraggio, con particolare attenzione alle tecnologie impiegate nella gestione di un sistema integrato, ottenuto dall'utilizzo di software ed infrastrutture comuni.
Il lavoro presenta, inoltre, esempi di dati ottenuti con soluzioni software di gestione integrata, sia di sistemi non intrusivi per applicazioni in raffineria ad alte temperature, sia di sistemi di monitoraggio erosione di tipo intrusivo, installati presso le strutture offshore nel Mare del Nord.