HIGH LEVEL CORROSION RISK ASSESSMENT METHODOLOGY
FOR OIL & GAS SYSTEMS

Steve Hodges, Kerry Spicer, Rachel Barson & Gareth John,
Intertek-CAPCIS Manchester

Kirsten Oliver,
Intertek-Upstream, Sharjah

Emily Tipton,
Intertek-CAPCIS, Canada

ABSTRACT

Assessing corrosion risks and developing appropriate inspection and mitigation measures forms a vital part of Asset Integrity Management (AIM) for operating any ageing asset. However, for many systems detailed information is often scarce and/or unreliable, which prevents or limits the application of many Risk Based Inspection (RBI) databases / software systems, which are “data hungry”. In order to overcome this limitation, and to allow corrosion risk assessment of both existing and aging facilities, an alternative in-house expert system methodology has been developed.

The system is designed to accept a range of data inputs including “engineering judgment”, summary of inspection data, monitoring data, predicted corrosion rates, etc as may be available; thereby overcoming problems with sparse / non-existent data, whilst still providing a logical, transparent and fully auditable system for later review, update and modification as may be necessary.

The system can be used to drive the development of corrosion monitoring, fluid sampling and inspection plans for process plant. The use of the combined corrosion risk assessment methodology and automated Inspection Plan development, avoids the need for labor intensive inspection driven integrity management systems where data or resources are not available.

The overall system is described together with examples of application to both ageing and new facilities.
INTRODUCTION

Corrosion risk assessment, risk based inspection (RBI) and overall asset integrity management (AIM) systems are all heavily dependent on data, with the accuracy of assessments often being dependant (at least in some part) to the amount of and, just as importantly, the quality of input data available for consideration.

However, it is widely recognized that Oil and Gas assets worldwide, both new and old, can suffer from a shortage of data. For new assets this is often because of the need to set up and implement RBI systems during the design and construction phase, when drawings are often not finished, datasheets incomplete and more importantly operational data (operating temperatures, pressures and CO₂ contents etc) are not yet fully known. Conversely, aging assets may have well known and characterized operating pressures, temperatures and (at least some) inspection records, but can still be working on the original design assumptions when it comes to compositional analysis of fluids, even though they may have changed over time, also data may have been lost over time for older assets, for example due to; office moves, owner/operator changes or a lack of suitable electronic storage system. The latter problem is common in the oldest fields and assets which were originally built a considerable time before modern computing systems and databases were practical to implement and use.

It should be noted that data is not the only limit to successful implementation of AIM systems with top management support for the approach being just as important, but not the subject of this paper.

Lack of Data - Traditional Approach

The traditional fully quantitative approaches to RBI, carried out directly by large scale software based assessment systems, in accordance with industry standard procedures such as API(1) RP 580¹ and API RP 581² are data hungry. Consequently when faced with the data shortage situations described, howsoever arising, a stalling of the risk assessment process can occur until necessary data is obtained or the resulting assessments are either incomplete or inappropriate. This can lead to some areas not being inspected (or being over-inspected) until a corrosion risk assessment update is completed.

A classic example of problems associated with some fully quantitative systems is that of small bore piping, which is nominally non-flowing, being associated with a bigger diameter pipe in the same corrosion circuit (in this paper a corrosion circuit is defined as a group of piping segments experiencing similar process conditions and with similar materials properties. Items are grouped into corrosion circuits to reduce the overall assessment and inspection requirements). This scenario leads to unfeasibly high erosion/corrosion rates being predicted in the small bore pipe work, which in reality never sees the full process flow, and hence overestimation of the risk and excessively high frequency of inspection recommendation. This scenario also highlights that not all corrosion mechanisms can be modeled by the fully quantitative systems such as corrosion in dead legs.

It should be stated that, wherever possible, the established approach of performing a fully quantitative RBI with a ‘full’ database is always the ideal scenario. Unfortunately the usefulness of a fully quantitative assessment method when some crucial data is missing is debatable. In fact, with quantitative methods even a piece of relatively non-crucial data which presents little sensitivity to the assessment can stop the assessment being completed. For example, when assessing the carbon steel CO₂

---

(1) American Petroleum Institute (API), 1220 L St. NW, Washington, DC 20005
corrosion rate, the total dissolved solids (TDS) value, whilst a parameter in the normal corrosion rate model, often has minimal effect on predicted corrosion rate compared with temperature or pressure, if the data is not present some systems will not operate at all.

The other end of the scale is a fully qualitative assessment. This more readily allows an assessment to be made without all the data but is inherently less robust due to the lack of quantification.

**Alternative Approach**

In order to overcome these limitations an in-house expert system, Corrosion Risk Assessment Methodology (CORAM™ (2)) was developed. This is a semi-quantitative assessment method that provides a framework for overall assessment, including estimates of expected corrosion rates, regardless of the extent or completeness of input data.

It should be recognized that the system is not intended to be a “magic wand” that allows assessments regardless. It was designed to combine in-house corrosion expertise with current industry standards to provide an industry best practice approach to corrosion risk assessment and risk based inspection development. Hence the overall approach was developed in line with current industry best practice including API RP5801, API5812, Institute of Petroleum IP123 and IP134, ISO 92235, ISO 92246, Norsok M-5067 and ISO 15156-1 / NACE MR01758. It also follows current best practice UK industry guidelines; the original HSE report OTO449 developed by ourselves and its recent update, published by the Energy Institute10. These last two documents describe what is considered best practice with regards to management and mitigation of corrosion on oil and gas assets in the UK Sector.

The objective was to create a methodology that is aimed at providing a consistent and repeatable corrosion risk assessment across different implementing teams and across different assets. The methodology has been developed into an electronic database to enhance implementation, although can just as readily be employed as a paper based exercise if necessary.

**INCORPORATION WITHIN THE OVERALL AIM SYSTEM**

The assessment methodology adopted and its outputs, including risk assessment, corrosion control / mitigation and monitoring / inspection recommendations, form part of the wider Asset Integrity Management system that all large assets should operate under. Because it is developed in line with corrosion management guidelines means that it fulfils or contributes to several steps in the management process (Figure 1, taken from the EI Corrosion Management Guidelines10).

Corrosion risk assessment (planning phase) is the backbone to any corrosion management system as it provides the ammunition to enable appropriate selection of inspection, monitoring and mitigation strategies (implementation and analysis). The output of the inspection and monitoring processes is then fed back in to the risk assessment process to enable continual improvement (monitoring and measuring performance and review of system performance).

The outputs of the risk assessments and data collection/analysis enable refinement of original corrosion policy where necessary (review of system performance).

On a practical implementation and system interaction level the methodology developed fits in to the initial asset risk assessment process as either a paper based review or an electronic database driven review. Either way the outputs, of operational asset management practices, are usually fed into work planning database/software such as Maximo®(3) or SAP®(4). The integrity management

---

(2) Trademark Intertek-CAPCIS, Bainbridge House, 86-90 London Road, Manchester, M1 2PW, UK

(3) Registered trademark IBM; http://www-01.ibm.com/software/tivoli/products/maximo-asset-mgmt, IBM Corporation, 1 New Orchard Road, Armonk, New York 10504-1722, United States
recommendations, usually relating to inspection and monitoring, can also be managed manually if work planning software is not used on a particular asset. The initial risk assessment could well be on a new asset or an old existing asset, the process and systems alignment are similar.

**Inputs**

As previously stated, with any corrosion risk assessment the inputs to the assessment determine the accuracy and usefulness of the output. With the approach we have developed it is desirable to incorporate as much information as possible so that all known factors are taken in to consideration. In the electronic database approach electronic forms allow for entry of appropriate information. Although this currently incorporates all the common corrosion / deterioration threats, the system is adaptable to enable storage and consideration of asset specific items and to present these at the risk assessment stage against the appropriate mechanism(s) to ensure nothing is overlooked.

**Approach**

Once all relevant (and available) data has been collated and stored the database engine allows a review of that data to ensure everything is considered during the risk assessment phase. In running the risk assessment it is normal practice to do this as a “round table” workshop incorporating input from engineers and experts from different disciplines (materials, corrosion, inspection, production, maintenance, process, etc as appropriate) to ensure all angles are considered.

It should be appreciated that the approach is strongly reliant on expert engineering judgment, although still ensures a consistent process is followed. The first step is to review the operating conditions / environment and “de-select” any corrosion mechanisms / threats that are considered to be inappropriate for the system / circuit / vessel under consideration. Where there is uncertainty as to whether a specific mechanism is relevant or not it is left “live” for more detailed consideration later. The methodology then leads the assessment team step-by-step through each corrosion mechanism. When using the electronic database approach, then as each “live” mechanism / threat is considered, all the relevant system information available is presented along with guideline notes on appropriate limits, known issues and normal industry practice.

From this information, the assessment team assigns a Likelihood of Failure (LoF) ranking for each mechanism in turn and this is recorded together with justification comments. The procedure ensures that the LoF ranking takes consideration of all appropriate factors including:

- Material (i.e. carbon steel, stainless, steel corrosion resistant alloy, non-metallic etc),
- Process Conditions (temperature, pressure, flow, etc)
- Process Composition (CO₂, H₂S content, water-cut, gas-oil ratio, water chemistry, etc)
- Operating history (where available),
- Inspection history (where available),
- Mitigation measures adopted (i.e. internal coatings, chemical treatment, cathodic protection etc).

Where incomplete information is present the system adaptability comes into its’ own to enable sound engineering judgment to assign an appropriate ranking and store the crucial justification comments. A common example would be a high likelihood based on sour conditions but uncertainty as to whether the material of construction is sour service compliant to NACE MR0175 / ISO 15156. In such a situation a high likelihood ranking for sour cracking mechanisms must be given until material certificates, testing or operational experience can prove otherwise. Provided this reasoning is stated in the justification box it is clear what must be done, at a later stage, to enable a lowering of the asset risk.

---

(4) Registered trademark SAP; [http://www.sap.com](http://www.sap.com), SAP America, Inc., 3999 West Chester Pike, Newtown Square, PA, 19073, United States
This high likelihood ranking, until proved otherwise, will lead to a high risk ranking and hence relatively frequent inspection requirements. Figure 2 shows a screen shot of one of the mechanism assessment pages including the guidance notes to ensure consistency and the comments boxes to enable process audit.

Following individual mechanism likelihood assessment a determination of system likelihood is defined based on the worst case individual mechanisms (separately for both internal and external degradation). Consequence assessment is then addressed for that system and this is closely linked to operator guidelines for safety, environment and production costs. The product of likelihood and consequence give an overall risk ranking for each system in the asset.

Based on the overall system risk a separate internal and external “operation and control plan” are developed, or Written Scheme of Examination (WSE) if onshore plant (5). The inspection frequency determination in this procedure is normally related to risk level although this can be overridden provided the assessors record written justification. Whilst a default criteria has been developed, the system has been designed to allow alternative criteria (for example Operator Head Office or local regulatory criteria) to be substituted as necessary. As part of the operation and control plan / WSE recommendations are made regarding inspection, monitoring and sampling methods, locations and frequency.

Again it must be emphasized that completion of the output reports, i.e. the operation and control plan, WSE etc are not fully automated. The system described here requires an expert operator to incorporate the skill and knowledge of experienced engineers to complete it, gaining input from operations and other disciplines where required.

One of the major benefits of the approach is the audit trail that it provides. All the data considered as part of the assessment is stored in the database along with the risk assessment results and any assumptions or justification comments made. This means that subsequent risk assessment following further inspection/monitoring data collection can understand quickly the rationale behind the previous assessment and modify accordingly.

The structured step-by-step assessment, ranking and recommendation approach also ensure consistent application of the concepts used in the methodology to all systems across an asset. This has the benefit that multiple teams can perform assessments on the same asset where required and expect to conclude very similar results.

Adaptability

One of the major benefits of such an adaptable approach is that it can be applied at both a very detailed vessel-by-vessel or corrosion circuit level and also at a high “system” level, whereby an overview stance is taken and each system is assessed and ranked by the worst conditions in that system. The system approach requires greater operator skill to ensure that high likelihood spots are not overlooked and that inspection recommendations, for example, are appropriately targeted. However, the system approach allows a more generic overview particularly where a shortage of data is an issue.

To enable the system approach to be taken, often a range of operating conditions (e.g. temperature and pressure) are to be considered and the database approach allows for these ranges to be stored and presented with a single representative value used for corrosion rate calculation. As throughout, the approach adopted includes a facility to allow justification notes to be recorded relating to the value(s) assumed, so that the system is fully auditable.

(5) Written Schemes of Examination (WSE) are legislative requirements in the UK for onshore pressure systems and comprise of equipment ID, inspection frequency, inspection method, the name of the competent person certifying the WSE and the date of certification as a minimum.
The systematic mechanism by mechanism approach to likelihood assessment allows any additional mechanism not already embedded to be easily added.

The methodology has also been applied in developing a pipeline uncertainty modeling approach which also provides an auditable corrosion risk assessment of oil and gas pipelines taking account of the full operational history. This is particularly useful in pipelines which cannot readily be accessed for direct inspection and aims to provide valuable information in the inspection requirement and frequency decision process.

**EXAMPLES OF USE**

**Example 1: New and Old Plant – System Level Assessment**

An example of the implementation of the methodology is for a Middle East facility which comprises both an existing onshore process plant and offshore platforms; together with a new offshore platform, new pipeline and an extension to the production plant.

The new extension was designed to handle a new development in the same vicinity and required that an initial risk assessment be performed and that inspection/operational and control plans be established.

Dissimilarly, the aged process plant was to continue service for the old fluid before ultimately handling a mixture of new and old fluids. However, as the aged plant had no existing risk assessment or risk based inspection plan, analyses were required for both the current operating scenario and the updated scenario; whereby exposure to the new fluids of increased corrosivity would be accounted for.

The benefits of the adaptable yet consistent approach, described above, were numerable in this situation. For both the new plant but more particularly the existing plant certain information was not available. For the new plant this was because some of the design information had yet to be released and for the old plant this was associated with data loss from a fire. In both instances engineering judgment was required to provide an appropriate assessment based on the available, somewhat limited data.

Figure 3 to Figure 6 show the four pages of a WSE output produced using the described methodology. These are specific to the Molecular Sieve system for the new plant described above. These figures have been annotated to highlight some of the key points on the WSE output and the method in general.

Particular highlights to note are:

- the space to capture and review a temperature range including the option to record where these occur. A representative single value is used for automatic calculation of a representative system corrosion rate;
- the threat likelihood ranking with justification comments to allow reviewers to understand the assessment team thinking;
- the inspection frequency is calculated based on risk ranking but can be overridden with a justification comment to ensure the logic is understood by reviewers (in this case there is a part of the operational cycle where the CO₂ corrosion rates could be extremely high and hence more regular inspection is recommended until this is understood).

The nature of the project meant that different teams conducted the data collection and risk assessment for the different plant areas. However, because they used the same system a consistent assessment was obtained as the system presented the data for each mechanism as considered in turn. If there are any concerns regarding comparable systems being ranked differently the auditable nature of the process enables cross checking of the assessment team logic.
As a follow up to the development of the original risk assessment and development of WSE, we have assisted the Operator to turn the WSE’s and operation and control plans into Inspection Workpacks for the baseline inspection program which is now underway; that is detailed inspection documentation to guide inspectors, including; what to inspect, where to inspect, when to inspect, how to inspect (i.e. what techniques), etc.. Following this there can be a review of certain high risk ranked systems to potentially reassign the inspection frequency.

**Example 2: New Development – Broad Range of Asset Types**

A second example of application of this methodology was to a new development, again in the Middle East. The assets consisted of offshore platforms, multiphase pipelines to shore, processing onshore plus a gas export pipeline. A corrosion risk assessment and preliminary inspection plan (along with a suite of corrosion management documentation) was required for the assets at the build stage. Given that the project was at the build stage, not all the P&IDs and equipment drawings were available and some of the operational conditions were still somewhat speculative.

Using the described methodology the uncertainties in data could be handled allowing conservative engineering judgment to fill the gaps to enable completion of the risk assessment, again in a systematic way. The outputs from the risk assessment and inspection plan exercise were in this case manually incorporated into corporate styled report format rather than using an automated database report. The database was still used to ensure the repeatable assessment approach was followed and that the judgments made were auditable. Similarly to the first example, several engineers were involved in the corrosion risk assessment process and the use of the methodology ensured likelihood rankings were consistent across the assets. Also, any assumptions made and their impact were reported into the final manual output so that as new information comes to light as operations begin and initial inspections occur adjustments can readily be made to the risk assessments and hence risk ranking and inspection frequency.

Of specific interest in this case was the significant use of corrosion resistant alloys and stainless steels on the unmanned offshore platforms. The methodology allowed for consistent assessment against the appropriate internal mechanisms that could be a threat in the high CO₂ and H₂S conditions (sulfide stress cracking, hydrogen induced cracking etc) in addition to the potentially greater external threat of chloride stress corrosion cracking in the austenitic stainless steels. The majority of circuits were coated externally giving reasonable justification for lower likelihood ranking. However, for one circuit there was uncertainty as to application of an external coating; in this instance a higher likelihood ranking was applied until the circuit was proved to be coated, or was later remedially coated.

Additionally, the ability within the methodology to override the inspection interval (and provide justification) so as to align inspections into multiples of one another ensured that the minimum number of targeted inspection campaigns could be applied. This was of particular benefit for the unmanned platforms where ad-hoc inspections are far less feasible than manned or onshore assets.

To further highlight the adaptability of the described methodology; in this example, in addition to the pressure systems, it was used to assess the corrosion risk to the offshore structures and can readily be applied to other asset types such as downstream plant, petrochemical plant and power generation utilities with appropriate expert input.

**CONCLUSION**

In summary, a flexible methodology / expert system has been developed which enables robust semi-quantitative corrosion risk assessment and risk based inspection set-up with somewhat limited data [it should be reiterated that the more data the better to reduce uncertainties and allow more accurate risk
ranking]. The method is by no means an automated process and requires considerable expert input. However, the main benefits of the approach described are:

- Collation of all relevant / available data for easy review and assessment
- Consistent likelihood assessment and ranking across different assets and teams
- The ability to complete risk assessments with some data gaps (using engineering judgment)
- Auditable trail for decision justification from likelihood ranking through to inspection frequency override

Due to the expert system nature of the methodology it has proven to be successfully adaptable across a range of different asset types and industries.
REFERENCES

3. Institute of Petroleum IP 12; Model Code of Practice, Pressure Vessel Examination, part 12 (1993)
4. Institute of Petroleum IP 13; Model Code of Practice, Pressure Piping System Examination, part 13 (1993)
5. ISO 9223 :1992, Corrosion of Metals and Alloys - Corrosivity of Atmospheres - Classification
7. Norsok M-506, CO₂ corrosion rate calculation model (Rev. 2, June 2005)
Figure 1: The basic corrosion management process (6)

**Figure 2: Screen shot of CO₂ corrosion mechanism risk assessment step in the database system.**

Note: all information to make assessment including calculated corrosion rate plus guidance notes for consistency and comments boxes to enable system audit

[1 bar = 100,000 Pa, mmpy = mm/y]
Internal Written Scheme of Examination

System ID: SC5

Required Life to Abandonment: 25 (years)

Asset:

System Description: Molecular Sieve Dehydration

System Overview: From TEG Scrubber to Mol Sieve Filters and Mol Sieve Adsorbers for drying and on through Dust Filter. Including counter current regeneration from Regen heater to Regen scrubber.

Design Details

<table>
<thead>
<tr>
<th>Generic Material Type</th>
<th>Specific Material Specification</th>
<th>Design Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Steel</td>
<td>1.6mm CA</td>
<td></td>
</tr>
</tbody>
</table>

NACE MR0175 / ISO 15156 PWHT

Materials Selection Comments:
1FS4405/6 Molecular Sieve Inlet Filter (CS-1.58mm CA)
1VE4410/11 Molecular Sieve Adsorbers (CS-1.58mm CA)
1AC4100 Regen Gas Cooler
1VE4420 Regen Gas Scrubber
1FL4415/16 Dust Filter (CS-1.58mm CA)

Internal Coating

<table>
<thead>
<tr>
<th>Internal Coating Description</th>
<th>Internal Coating Application Date</th>
</tr>
</thead>
</table>

External Coating

<table>
<thead>
<tr>
<th>External Coating Description</th>
<th>External Coating Application Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumed</td>
<td></td>
</tr>
</tbody>
</table>

Insulated

<table>
<thead>
<tr>
<th>Insulation Description</th>
<th>Partially Insulated (PP/H)</th>
</tr>
</thead>
</table>

Figure 3: Page 1 of the WSE output
[CA = Corrosion Allowance]
Figure 4: Annotated Page 2 of the WSE output

Note: range of values for Temperature and Pressure and space to provide comment. Representative value used for corrosion rate calculations.

Note: threat and ranking backed up by justification comments for an auditable trail

Note: [1 bar = 100,000 Pa, mmpy = mm/y]
### Risk Assessment Results - Internal

<table>
<thead>
<tr>
<th>Internal Failure Mode</th>
<th>CO2 during regeneration cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Probability</td>
<td>10</td>
</tr>
<tr>
<td>Internal Consequence</td>
<td>10</td>
</tr>
<tr>
<td>Internal Consequence Driver</td>
<td>Gas release</td>
</tr>
</tbody>
</table>

![Consequence Matrix]

<table>
<thead>
<tr>
<th>Consequence (internal)</th>
<th>10</th>
<th>5</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal risk</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

- **7 - Very High Risk**

#### Internal Inspection Interval

<table>
<thead>
<tr>
<th>Maximum Internal Inspection Interval</th>
<th>7.5 (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation:</td>
<td></td>
</tr>
<tr>
<td>Recommended Internal Inspection Interval</td>
<td>1.5 (years)</td>
</tr>
<tr>
<td>Override Internal Inspection Interval</td>
<td>0.5 (years)</td>
</tr>
<tr>
<td>Explanation:</td>
<td>Potential high CO2 corrosion rates</td>
</tr>
</tbody>
</table>

Note: Ability to override calculated inspection interval and room for justification comment – again Auditable.

Figure 5: Annotated Page 3 of the WSE output
## Internal Inspection

Internal Inspection:

| Regen gas scrubber expected to be permanently wet - particularly inspect heads of vessels (as low CA) using scanning UT online, intrusive visual when offline. Scanning UT at a representative number of locations, particularly low points (vessels and piping): 12, 3, 6 and 9 o'clock pipework positions, also within 2 diameters downstream of pressure or flow control valves. Particular attention should be paid to deadlegs in case of deposit collection, especially at the bottom of the line, using radiography for small bore fittings. Intrusive visual inspection of accessible vessels during shutdown inspection. |

| Monitoring: |

| Dew point monitoring to 'protect' dry systems onward of SC5 |

| Sampling: |