INTRUSIVE MONITORING
(A Specialized Area of Corrosion Monitoring)
The RBI / CRA Process…..

- Requires Constant Feedback / Updating from all Available Sources.
- Inspection Frequencies Require Regular Review.
Corrosion Monitoring

KEY RISKS
(Water and Dissolved Gases)

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Generally the higher the concentration of dissolved gases in solution the higher the corrosion tendency.

**Oxygen most Aggressive.**
Effect of Water Cut on Oil Line Corrosion Rate

Corrosion Monitoring

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Corrosion Monitoring

Corrosion and Erosion Damage

FLOWLINE CO2 CORROSION and EROSION
Subsequent Erosion / Scale Undercutting in Direction of Flow

FLOW DIRECTION

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Corrosion Monitoring

- Applications and Benefits (as Part of an Overall CRA / RBI Process)
Reasons For Monitoring…..

- To help identify the location, rate, and underlying causes of corrosion and erosion.
Types of Monitoring.....

1. Intrusive
2. Non-Intrusive
Intrusive.....

- Test Coupons (of Same Material as Pipe.
- Corrosion Probes – Electrical Resistance, Galvanic, Weld etc.
- Erosion (Sand Monitoring) Probes.
Non-Intrusive…..(NDT)

- Electro-magnetic
- Radiographic
- Ultrasonic
What Monitoring Gives Us

• **Corrosion Coupons** – Pitting + Microbial + Corrosion Product Analysis.

• **Corrosion Probes** – Alarms For Process Trends / Corrosion Trends / Upsets / Loss of Inhibition.

• **UT Parent Metal Scan at Probe / Coupon Sites** – More Accurate Determination of WT Losses / Regular WT Trending, (Monthly Preferred at Main Complexes).

• **TOFD** – Additional Weld Monitoring (where Appropriate), e.g. Manifold Tees.

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1. A Coupon is not a direct measurement of wall loss but remains a useful guide to process trends and process ‘corrosivity.

2. An insulating washer separates the test coupon from the coupon holder and the pipe wall itself.

3. Coupons should be pulled at least annually for Examination / Weight Loss Measurement / Micro Swabbing.
1. Electrical Resistance probes (when used for Corrosion Monitoring), monitor material loss directly* and do not require a continuous conductive path. Therefore the ER technique can be used to monitor corrosion in areas where water wetting is not continuous or under deposits where conductive may be limited.

1. The replacement interval for electrical resistance probes is dependant on probe sensitivity and the corrosion rate. Readings from ER probes will be obtained manually or automatically via an offline or online logging system (PI).
1. ER probes of stainless steel, with similar mechanical properties as for the pipe that is the subject for monitoring. Hence the erosion sensors will not corrode and all material loss and can then be attributed to erosion.

1. Often there is little general evidence of solids posing a serious problem, other than very locally at Choke Valves / Sudden Geometry Changes.
POSITIONING
Corrosion Monitoring

Positioning

Watch Future Maintenance / Accessibility!

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Corrosion Monitoring

TOL
12 O’Clock
Corrosion Monitoring

TOL
12 O’Clock

O.K For Wet Gas
(Orientation Less Critical)

BOL
5 O’Clock

Watch Orientation

Better Than 6 O’clock
For Liquids
(Less Debris)

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MAIN PROBE TYPES
**Corrosion Monitoring**

**ER Probe**

**ER Electrical Resistance Probe** – is used to track rates of metal loss. The probe directly measures the increase in resistance of a metal as its cross-sectional area is reduced by corrosion. At suitable times, after probe bedded-in readings can be converted into corrosion rates.

Electrical resistance probes can be used in conductive systems, as well as non-conductive environments such as oil, gas, and atmosphere.

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Verifying Metal Loss

Culmulative Metal Loss v. Reference Electrodes

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Corrosion Monitoring

Combined Sand/Erosion and Corrosion Probe

- Erosion Elements
- Corrosion Element at Rear of Probe

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**Galvanic Probe** - operates by measuring the galvanic current in the circuit between a steel and a brass electrode and is particularly sensitive to the amount of oxygen in the water. Although the galvanic current, within certain restrictions, is proportional to the oxygen concentration in a system. **It is not intended to replace an oxygen sensor (Orbisphere).**
Weld probes - are fabricated to simulate Weld Composition but are not widely used.
Corrosion Monitoring

LPR Probe – LAB Use

LPR probes - are used in conductive environments such as water or any electrolyte. The operating principle is based on measuring the flow of current between multiple electrodes.

Pictures of an untreated LPR electrodes. Electrodes were exposed to surface water without corrosion inhibitor. The left picture shows the edge of the electrode with clear sign of crevice attack. The right picture shows the surface with pitting attack.

**No Inhibitor**
28 days

**Inhibited**
28 days

Pictures of an treated LPR electrodes. Electrodes were exposed to surface water dosed with 50 ppm oxygen passivator/corrosion inhibitor. The left picture shows the edge of the electrode, the right picture shows the surface; no signs of significant corrosion were found.
MORE EQUIPMENT DETAILS
Corrosion Monitoring

Types of Access Fitting

- Flareweld
- Flange Fitting

All Dims required to underside of CAP

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Mechanical System

2” Mechanical System Components

Thread Cap

Plug Assembly

Mechanical to Hydraulic Fitting Adapter

Flareweld Fitting

Pressure Retaining Cover

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Modern Conversion

Mechanical to Hydraulic Conversion

2” Mechanical access fitting

2” Mechanical fitting converted to hydraulic system with adaptor
Corrosion Monitoring

Service Valves

Single Isolating

Double Isolating

Safety Valves
Corrosion Monitoring

Retrieval Process

Retrieval Tool

Pressure Equalisation (Fitting Retrieval Process)

Retriever Removed (With Fitting)

Safety Valve

Valve Closed

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Corrosion Monitoring

Heavy Duty Cap with Gauge – Secondary Pressure Containment

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DATA TRANSMISSION
(REAL-TIME LOGGING)
Corrosion Monitoring

Logger

Logger (or Wireless Transmitter)

Corrosion Probe

Sand/Erosion Probe

Field Bus

PC/Software

Data
Gas Import – BOL Transmitter (White) / ER Probe and HD Cap (Blue)
Corrosion Monitoring

PROBE INFORMATION
ER probe metal loss results with the introduction of corrosion inhibitor at maximum production

- E: Inhibitor injected for 1 day only
- F: Inhibitor injection for 5 days
- G: Inhibitor injection stopped
- H: Inhibitor injection resumed

Corrosion rate increasing from 0.2 to 0.8 mm/yr

Corrosion rate reduced to approx 0.04 mm/yr
Corrosion Monitoring

Tracking Inhibitors

- Corrosion Inhibitor Commenced
- Platform Shutdown
- Un-inhibited Operations From Start-Up (Approx 5 Months)
- Probe Failure
- Metal Loss Prevented
- Previous Trend

Gas KO Drum

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Corrosion Awareness Day -
Corrosion Monitoring

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MONITORING EXAMPLES
• **ER Corrosion Probe Data** – early warning for loss of inhibition measured at tree.

• **Sand / Erosion Probe Data** - early warning of sand production and extent of erosion damage.
Effect of Corrosion Inhibitor Outage

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Corrosion Awareness Day -
Corrosion Monitoring
Corrosion Monitoring

Effect of Corrosion Inhibitor Outage

Production report - 07/04/12
Covering 05/04/12 - Corrosion Inhibitor Injection still offline.
Corrosion rate of 1.07 mm/yr = 0.0003 per day, or 3% loss of Annual Corrosion Allowance of 0.1 mm per day.

Initial spike noted on Inlet Corrosion probe AE-00025 hit 6.64 mm/yr (5.89 mm/yr equivalent rate).

Corrosion rate has since decreased and appears to have leveled off at around 1.22 mm/hr (1.47 mm/yr equivalent rate).

Total metal loss as reported by the intrusive probe is approximately 250mkm (0.00025mm) over the last 24 hours.

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Corrosion Monitoring

Effect of Well Openings

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After the last two well openings, there has been a large increase in the corrosion rate on XE3301 with corrosion rate peaks of approximately 4.5 millimeter per year being reached.

Excursions

32/04 opened, corrosion rate on Riser probe increases.
Corrosion Monitoring

Effect of Well Openings

Excursions

Corrosion rate peaked at approx. 900mL/hr for a brief spell around 03:30 this morning before dropping to approx. 100mL/hr around 10am.

The probe now appears to have failed as it can no longer stabilise the metal loss and corrosion rate is heading to zero.

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The larger spikes in the middle of the plot are when production was halted then restarted and the choke stepped open.

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COUPON INFORMATION
Corrosion Monitoring

Gas System Coupons –
Low Corrosion Rates

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Corrosion Monitoring
Corrosion Monitoring

Water Injection Coupons – High Corrosion Rates

Before Cleaning

Heavy Weight Loss and Microbial Attack
EXAMPLE GAS SYSTEM CORROSION RATES

NACE High

- Estimated Annual Corrosion Rate (mm/yr) - Typically 3 x Measured Rate
- NACE Low Corrosion Limit (<0.025 mm/yr)
- NACE Moderate Corrosion Limit (<0.126 mm/yr)
- NACE High Corrosion Limit (<0.254 mm/yr)

Highest Rates on Dehydration Unit

NACE Moderate

0.042
0.045
0.069
0.069
0.024

NACE Low

0.000
0.050
0.100
0.150
0.200
0.250
0.300

Cond. KO Drum
Separator
Pre MOL Export
2nd Stage Aftercooler
Dehyd In Gas KO Drum
Dehyd In Gas KO Drum

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Coupon Trending

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### Corrosion Awareness Day - Corrosion Monitoring

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<table>
<thead>
<tr>
<th>NACE RP-0775-2005 (Categorization of Carbon Steel For Oil Production Systems Corrosion Rates)</th>
<th>Average</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Severe</th>
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</thead>
<tbody>
<tr>
<td>Mils (mil/yr)</td>
<td>0.000</td>
<td>1.000</td>
<td>4.000</td>
<td>10.000</td>
<td>10.000</td>
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</tbody>
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</tr>
</thead>
<tbody>
<tr>
<td>Mils (mil/yr)</td>
<td>0.000</td>
<td>5.000</td>
<td>7.900</td>
<td>15.000</td>
<td>15.000</td>
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</tr>
</thead>
<tbody>
<tr>
<td>Millimetres (mm/yr)</td>
<td>0.025</td>
<td>0.250</td>
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<tr>
<td>Millimetres (mm/yr)</td>
<td>0.013</td>
<td>0.130</td>
<td>0.200</td>
<td>0.280</td>
<td>0.380</td>
</tr>
</tbody>
</table>

**Typical Standard is 0.100 mm/yr, (for 30 yr life).**

**i.e. NACE Medium Rate**

**International Codes**

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**Corrosion Monitoring**

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MAINTENANCE
Corrosion Monitoring

PI / Experion Control

Logging
0101
- Choke 0.00 %
- VHP 87.44
- WHT 12.39
- Wing Valve Closed
- Master Valve Closed
- ESDV Closed
- Acoustic 1504 nV

0202
- Choke 0.00 %
- VHP 87.44
- WHT 12.39
- Wing Valve Closed
- Master Valve Closed
- ESDV Closed
- Acoustic 1504 nV

Subsea Riser
- S/S Riser Acoustic 1504 nV
- S/S Riser Corrosion 1422.54 mm 3.80 mm
- S/S Riser Erosion 303.76 mm 3.57 mm

Proppant Filters
- Proppant Filter 1 Acoustic 1504 nV
- Proppant Filter 2 Acoustic 1504 nV

Production Header
- Prod Header Acoustic 1504 nV
- Prod Header Corrosion 909.67 mm 1.11 mm
- Prod Header Erosion 6.51 mm 0.56 mm

Control System
- Field Flowrate 0.00 MBD/day

All Acoustic

All Intrusive

Export
- Riser Acoustic 4866 nV

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Corrosion Monitoring

Management Codes

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**Coupon Status Indication Codes**

<table>
<thead>
<tr>
<th>Status</th>
<th>Description</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Coupon changed out</td>
<td>No Action Required</td>
</tr>
<tr>
<td>Yellow</td>
<td>Coupon change out visit due</td>
<td>Action Implemented or Underway</td>
</tr>
<tr>
<td>Red</td>
<td>Coupon not changed out</td>
<td>Action Required</td>
</tr>
<tr>
<td>B/D</td>
<td>Below Detection</td>
<td>No Action Required</td>
</tr>
</tbody>
</table>

**Probe Status Indication Codes**

<table>
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<th>Status</th>
<th>Description</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>OK</td>
<td>No Action Required</td>
</tr>
<tr>
<td>Yellow</td>
<td>Probe malfunction - Known Reason</td>
<td>Action Implemented or Underway</td>
</tr>
<tr>
<td>Red</td>
<td>Probe malfunction - Reason Unknown</td>
<td>Action Required</td>
</tr>
<tr>
<td>Blue</td>
<td>Alarm malfunction - Known Reason</td>
<td>Action Implemented or Underway</td>
</tr>
</tbody>
</table>

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QUESTIONS ?