Corrosion Overview: Internal Corrosion, External Corrosion and Cathodic Protection

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Presented by:
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Industry Trends

55 reported incidents for onshore gas gathering since 1996

Corrosion responsible for approximately half of reported incident for gathering systems

Source: US DOT Pipeline and Hazardous Materials Safety Administration
Industry Trends

In light of recent incidents and in keeping with overall move toward an integrated Process Safety culture, several new recommendations may affect gas storage operations

- PHMSA NPRM: Safety of Gas Transmission and Gathering Pipelines
- PHMSA Advisory Bulletin
  - ADB-2016-02 Safe Operation of Underground Storage Facilities for Natural Gas
- API 1170 “Design and Operation of Solution-mined Salt Caverns Used for Natural Gas Storage”
- API 1171 “Functional Integrity of Natural Gas Storage in Depleted Hydrocarbon Reservoirs and Aquifer Reservoirs”
- State regulations
Corrosion Mechanism

Anode
- Where current leaves the metal surface into the electrolyte

Cathode
- Where current enters the metal surface

Electrolyte
- Solution capable of conducting electricity
- Water or soil

Metallic Path
Internal Corrosion

Internal corrosion is most significant failure mode for gathering systems transporting corrosive fluids

All Reported Incident Cause Breakdown: 20 Year Average (1996-2015)
System Type: GAS GATHERING  State: ALL  Offshore: ONSHORE

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<tr>
<th>Reported Cause of Incident</th>
<th>Incident Cause SubType</th>
<th>Number</th>
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<tr>
<td>Grand Total</td>
<td></td>
<td>55</td>
<td>100.0%</td>
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</table>

Source: US DOT Pipeline and Hazardous Materials Safety Administration
Internal Corrosion

**Uniform Corrosion**
- Distributed more or less uniformly over surface
- Can occur in isolated areas where water tends to accumulate

**Localized Corrosion**
- Small, discrete sites of metal loss – pits or cavities
- May or may not be associated with corrosion product

**Localized Corrosion - Under-Deposit Corrosion**
- Deep penetration with lesser general corrosion in surround areas
- Under or around deposits or collection of material
Internal Corrosion

**Galvanic Corrosion**
- Electrical coupling of two dissimilar metals

**Velocity/Flow-Related Corrosion**
- Erosion Corrosion, cavitation, impingement
- In storage, periods of heavy abrasion from particulates coming up from well

**Environmentally Assisted Corrosion (EAC)**
- Cracking of a metal through electrochemical processes enhanced by particular pipeline environments
  - Hydrogen-Induced Corrosion (HIC)
  - Hydrogen Embrittlement (HE)
  - Stress Corrosion Cracking (SCC)
- Often difficult to detect during the pre-failure phase
Microbiological Induced Corrosion (MIC)

- Biological processes of microorganisms can alter metal surface by physical & chemical means
- Typically two modes of existence:
  - Planktonic (free floating)
  - Sessile (attached to pipe wall)
- Prominent bacteria important in corrosion include:
  - Sulfate-Reducing Bacteria (SRB)
  - Acid-Producing Bacteria (APB)
  - Other microorganisms
    - Sulfate-reducing Archaea (SRA) or
    - Sulfate-reducing prokaryotes (SRP)
- Standard bacteria culture testing may not correlate to MIC caused by other microorganisms
Internal Corrosion Monitoring

Asset Survey
- I/W Wells
- Water Removal Equipment
- Gathering Line

Monitoring
- Coupons
- NDT
- Water Sampling
- H2S Sampling
- Solid Analysis
- Bore Scope

Risk Assessment and Risk Ranking
Internal Corrosion Monitoring

**Monitoring Locations**

- Vessels
- Piping, Stub Ends and Wellhead Sweeps
- Drips
- I/W Wells
- Receivers (pigging)
Internal Corrosion Monitoring

Complementary testing

- Coupons/Probes
- Bacteria Analysis
- Liquid/Solids Sampling
- Gas Sampling
- Non-destructive Testing
  - Field Separators
  - Wellhead Separators
  - Drips
  - Bottles
  - Piping
- Inspection and Analysis
  - Visual Inspection (cut-out)
  - In-Line Inspection

<table>
<thead>
<tr>
<th>Corrosion Type</th>
<th>Coupon</th>
<th>ER</th>
<th>LPR</th>
<th>Spool</th>
<th>NDT</th>
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<tr>
<td>Corrosion, General</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<td>ECN</td>
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<td>Corrosion, Localized</td>
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<td>X</td>
<td>X</td>
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<td>ECN</td>
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<tr>
<td>Environmentally Assisted</td>
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<td></td>
<td></td>
<td></td>
<td>H2</td>
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<td>Flow Assisted</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<td>Acoustic</td>
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</table>
**Internal Corrosion Monitoring**

**Corrosion coupons** are small, weighed and measured specimen of metal that are inserted into a system and exposed to that environment for a specified period of time.

**ER probes** determine metal loss over time by measuring the increase in the electronic resistance of an electrode as its cross-sectional area is reduced by corrosion.

**LPR probes** instantaneously measure a corrosion rate by measuring the degree of resistance to a small applied potential.
**Galvanic probes** are used in water injection systems to measure the galvanic current in the circuit between a steel and a brass electrode, which can be sensitive to the amount of oxygen in the water.

**Hydrogen Probes** monitor hydrogen permeation in steels, which can lead to embrittlement, blistering, and decarburization resulting in the failure of the material.

**Electrochemical Noise (ECN)** are similar to LPR, can be flush or “finger-like”, and distinguish between general vs. localized.

**Acoustic Solids Monitoring** monitors for solids, but does not directly monitor damage to pipe from erosion.
Internal Corrosion Monitoring

**Microbiological Testing**

- Serial Dilution Method
- Bio-Probes
  - Used to suspend sample elements in the area to be monitored for bacteria.
- Other techniques
  - Isotope Analysis
  - Adenosine Triphosphate (ATP) Photometry
  - Hydrogenase Measurements
  - Adenosine Phosphosulfate (APS) Reductase – specific to SRB
  - Quantitative polymerase chain reaction (qPCR)
Internal Corrosion Monitoring

Water / Fluid Analysis
• Liquid collection sites
• On-site / laboratory testing (pH, iron, manganese, chlorides)

Solids / Debris:
• Cleaning pig runs, Cut-outs, Coupons
• On-site and Laboratory Analysis (Elemental, EDS, XRD, XRF)

Gas/Liquid Hydrocarbon
• Carbon Dioxide, Hydrogen Sulfide, Oxygen, Sulfur Compounds, Water content

Chemical makeup provides significant information relative to corrosivity
Internal Corrosion Monitoring

Non-Destructive Evaluation

- Manual Ultrasonic Testing
  - Different scanning techniques (A-scan/ B-scan)
  - Grids

- Automated Ultrasonic Testing
  - Multi-Channel imaging
  - X-Ray

Establish monitoring interval specific to site location.
- A Rating (High corrosion rate ≥ 5.0 MPY or nearing wall thickness tolerance)
- B Rating (Moderate corrosion rate 1 - 5.0 MPY)
- C Rating (Low corrosion rate < 1.0 MPY)
Assessment

**In-Line Inspection (ILI)**

- Design requirements / limitations
  - ILI Applications (Tethered, Launcher / Receiver)
- Requires using cleaning tool prior to use of smart tool.
  - Scraper discs/cups, brush-type, blade cleaning elements.
- ILI Smart Tools
  - Magnetic Flux (MFL), transverse, crack detection, combo
- Tool Results
  - Accuracy
  - Predicted Failure Pressures
  - Validation

Assessment

Opportunity inspections

ILI validations

• Expected results based on other monitoring data
• Validation digs

Visual Inspection

• Scale/Liquids
• Corrosion/Pitting
Assessment

**Surface Evaluation**

- Surface cleaning / prep
  - Initial observations may not be accurate in terms of wall loss
- Gas-liquid/scale interface
  - Under-deposit corrosion
  - MIC
- Pitting
  - appear small but be very large below the surface
Monitor / Repair / Replace

Monitor

• Reassessment intervals / Continual Monitoring
  • Corrosive environments, non-linear growth rates
  • Mitigation

Fitness-for-Service (FFS)

Repair / Replace

• Short-term solution vs. Long-term planning
  • Replacement tends to be “when” not “if”
  • Holistic approaches, prioritize lines/wells
  • May repair more severe indications while scheduling future field modifications
  • Consequence of failure
  • Ability to shut in affected lines, reroute gas flow
  • Cyclic operations
  • Projected growth rates and time to failure
External Corrosion is another root cause that affects gathering systems.

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- **State**: All  
- **Offshore**: Onshore

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**Grand Total**: 55 100.0%

Source: US DOT Pipeline and Hazardous Materials Safety Administration
External Corrosion

**Pipeline Coatings**
- The first and foremost defense in corrosion control
- Fusion-bonded epoxy, extruded polyolefin systems, multi-layer epoxy, mill applied tape, coal tar

**Cathodic Protection (CP)**
- CP supplements coating for 100% protection
- Reduce the corrosion rate by making it the cathode of an electrochemical cell
- The addition of current to a more electronegative state
- Per 49 CRF 192 Subpart I, cathodic protection system must be placed in operation within 1 year of pipeline operation

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**NACE SP0169**
- Negative (Cathodic) potential of at least 850 mV
- Negative polarized potential of 850 mV
- A polarization of a minimum of 100 mV
**Galvanic Anode**

- Current provided by dissimilar sacrificial metal
- The anode is active (negative) with the respect to the other and corrodes
- Current is discharged from active metal and flows to the protected asset
- Anode backfill provides low resistivity environment and prevents passivation
CP Design Types

**Impressed Current**

- Current provided from external power source
- Rectifier used in conjunction with anodic ground-bed to disperse current
- Current dispersed through ground-bed follows return path through pipe back to rectifier
CP Design Types

Impressed Current

- Rectifier
  - Negative cable connection to pipe
  - Converts AC power to DC power
- Ground-bed
  - Positive cable connection to rectifier
  - Consists of a bed of anodes to aid in current dispersal
  - Backfill surrounds anodes to provide uniform current distribution
## CP Design Types

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<th>Galvanic Anode</th>
<th>Impressed Current</th>
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<tbody>
<tr>
<td>Small current requirement</td>
<td>Higher current requirement</td>
</tr>
<tr>
<td>Lower soil resistivity's</td>
<td>Higher soil resistivity</td>
</tr>
<tr>
<td>Localized protection</td>
<td>Large protection field</td>
</tr>
<tr>
<td>Power source not required</td>
<td>External power source</td>
</tr>
<tr>
<td>Lower cost</td>
<td>Higher cost</td>
</tr>
<tr>
<td>Minimized stray current interference</td>
<td>Increased stray current interference</td>
</tr>
<tr>
<td>Evenly distributed along asset with high frequency</td>
<td>Minimized pipeline connections</td>
</tr>
</tbody>
</table>
**CP Design Types**

**Ground-bed Configurations**

- Distributed
- Linear
- Conventional Shallow
  - Horizontal anode placement
  - Vertical anode placement

- Deep Well
CP Design Types

Preferred CP Design in Storage Fields

- Impressed current design
  - Soil resistivity measurements at depth important
- Remote deep well ground-bed
  - Critical for protection current to reach pipe at excessive depth
- Designed to protect piping, well, casings and all associated appurtenances
- Isolated wells may require separate CP system
CP Design Process

Design Factors

• Environment corrosivity
• Soil structure and resistivity
• Bare or coated asset
• Coating quality and electric strength
• Metal or alloy of asset
• Asset size (diameter, length, wall thickness, etc.)
• Presence of other metallic structures and stray current
• Historic CP measurements or existing systems
CP Design Process

**Soil Resistivity**

**Metallic Surface Area**
- Coating efficiency
- Calculate bare metallic surface area

**Current Requirement**

**Anode Data**
- Anode Potential
- Anode Efficiency
- Design Life
- Anode Utilization Factor

**Circuit Resistance**
- Linear Pipeline Resistance
- Wire Resistance
- Current Attenuation
- Anode/Ground-bed Resistance
- Remote Earth
CP Design Process

Adjust variables to improve design

• Determine Ground-bed Type
  • Conventional Horizontal or Vertical
  • Deep Well
• Determine Anode Characteristics
  • Anode type and size
  • Number of Anodes
  • Length and size of anode bed
• Rectifier sizing

Calculations

• Current Attenuation
• Ground-bed Resistance
• Other Resistances
• Remote Distance

Circuit Characteristics

• V, I & R
CP Monitoring

**Electrical Isolation**
- Isolated flanges, di-electric unions, weld-end-insulators

**Test Stations**
- Two-wire
- Foreign crossings and bonding
- AC/DC Coupons
- IR drop
- Casings

**Reference Cells**

**Remote Monitoring**
CP Monitoring & Maintenance

Periodic Surveys

• Potential Measurements
  • Monthly, Bi-monthly, Annual Readings Close-Interval Surveys (CIS)
• Line Current Survey
  • Pipeline Current Mapper (PCM)
• Coating Surveys
  • Alternating Current Voltage Gradient (ACVG)
  • Direct Current Voltage Gradient (DCVG)
• Rectifier and Ground-bed voltage and current output

Equipment Maintenance

• CP System Components
• Coatings
• Test Points

Direct Examinations