Corrosion Engineers in Action: From Design to Operations and Turnarounds

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Presentation outline

- The Corrosion Engineer's role in:
  - Laboratory
  - Design
  - Shutdowns and Operations

Corrosion Engineers In Material Testing Laboratory

Corrosion Engineers in Material Testing Laboratory

- **Role Overview:** Corrosion engineers in laboratories are often titled Corrosion Engineers or Metallurgists.
- **Key Responsibilities:**

- Corrosion Testing And Assessment
- Metallurgical Analysis
- Material Qualification
- Root-cause Analysis

- **Key Interfaces:**

- Chemists, Machinists,
- Mechanical Testing Technicians,
- Quality Assurance Personnel

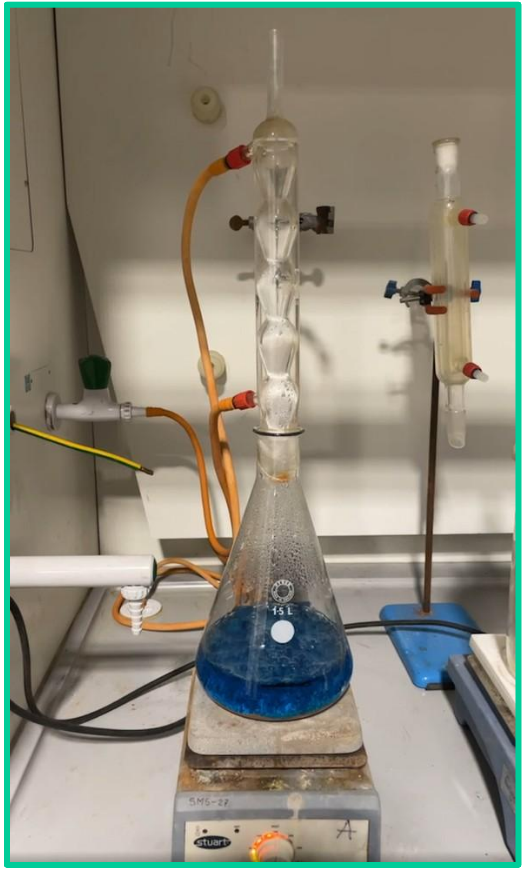
Day-to-Day Involvement of Corrosion Engineers in a Testing Laboratory

➢Corrosion Testing

- Performing corrosion testing to relevant standards, including:
  - ASTM G48, ASTM A262, NACE TM0284,NACE TM0177, Full Ring Testing – HSE OTI 95-635 / BS 8701

➢Metallurgical Analysis

- Microstructural characterisation and evaluation.
- Metallurgical qualification of new materials for Welding Procedure Qualification Records (PQRs).
- Post-corrosion test examination and assessment, such as: Identifying **stepwise cracking** after NACE TM0284 testing. Examining **pitting and surface/subsurface attack after ASTM G48 testing**.



Day-to-Day Involvement of Corrosion Engineers in a Testing Laboratory

➢ Root Cause Analysis (RCA)

- Assessment of corrosion and degradation mechanisms.
- Identification of failure modes.

➢ Field Support

- On-site replica metallography.
- Material condition assessment.
- Asset integrity support.

➢ Laboratory Audits

- Supporting laboratory audits in accordance with ISO/IEC 17025.
- Preparing required documentation and training records.
- Performing competency assessments.
- Demonstrating testing activities and technical competence to UKAS auditors.

FIGURE 2—SOHIC in Carbon Steel Under Applied Stress. Direction of tensile stress is normal to cracks linking the blisters.

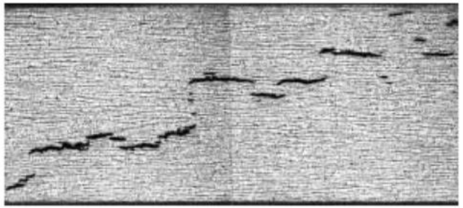


FIGURE 1—HIC in Carbon Steel Under No Applied Stress

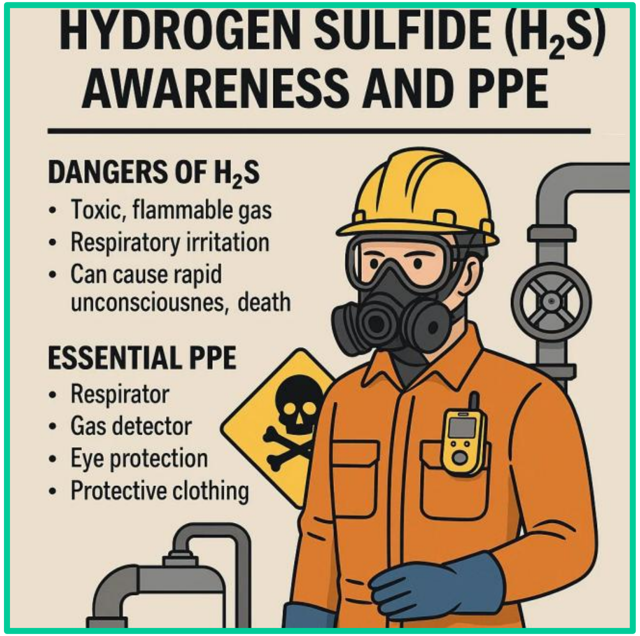
Day-to-Day Involvement of Corrosion Engineers in a Testing Laboratory

➢Training & Knowledge Development

- Training and mentoring laboratory technicians.
- Sharing technical knowledge and best practices within the team.
- Supporting continuous improvement and knowledge sharing.

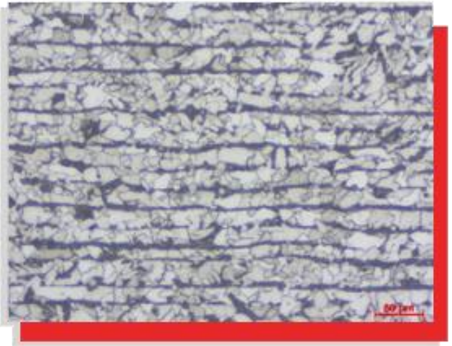
➢Health & Safety

- Following laboratory health and safety procedures.
- Handling corrosive chemicals and test equipment safely including H2S.

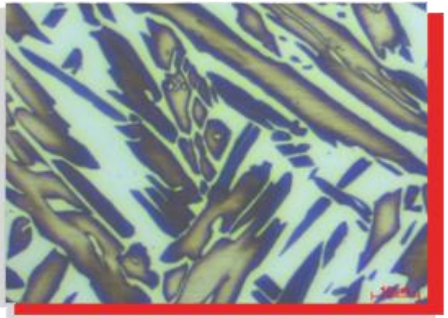


Key Learning for Corrosion Engineers working in a Testing Laboratory

- Understanding laboratory health and safety procedures, including the safe handling of corrosive chemicals, test equipment, and H_2S.
- Understanding corrosion mechanisms and material selection behaviour in various environments.
- Gain hands-on experience operating microscopes, SEM, EDX, OES, and other laboratory equipment.
- Understand the role of analytical tools in material characterisation.
- Understanding NACE MR0175 / ISO 15156 and ASTM standards.
- Gaining practical exposure to corrosion testing and failure analysis.
- Developing research, analytical, and problem-solving skills.
- Gaining plant exposure and understanding real-world applications.



Carbon Steel



Duplex Stainless Steel (Weld)

Case Study: In-Service Failure of Tee-to-Flange Weld Joint

❑ Background

- Project : B22 Full Field Development Project
- Failed Joint: Equal Tee to Weld Neck Flange Joint
- MOC: 6-in. Duplex Stainless Steel (UNS S32205)
- Service: Water Injection/Water Line
- Spool fabricated in shop and erected in site, and commissioned after successful hydrotesting
- Leakage reported approximately 45 days after commissioning
- Failed joint removed and submitted for metallurgical failure investigation

Figure 1: General view of the failed module

Case Study: In-Service Failure of Tee-to-Flange Weld Joint

❑ RCA Scope Defined

➢ Metallurgical Examination Performed

- **Visual Examination.**
- **Dye Penetrant Testing (PT).**
- **Fractography.**
- **Macro Examination.**
- **Hardness Survey**
- **Microstructure Examination**-No detrimental intermetallic phases detected. Ferrite content was within acceptable range
- **Chemical Analysis-** Tee, flange and weld metal compositions complied with UNS S32205 and ER2209 requirements.

Figure 2: Crack revealed by DP-outer diameter (110 mm approx.).

Figure 3: Crack revealed by DP-inner diameter (130 mm approx.).

Figure 4: Crack revealed by DP -across thickness.

Case Study: In-Service Failure of Tee-to-Flange Weld Joint

❑ Macro & Hardness Examination

➢ Findings

- Hardness Survey values were within DSS acceptance limits.
- Crack propagated through the tee-side HAZ into the weld metal.

➢ Key Observation

- Geometry transition at the tee-side root created a local stress concentration.

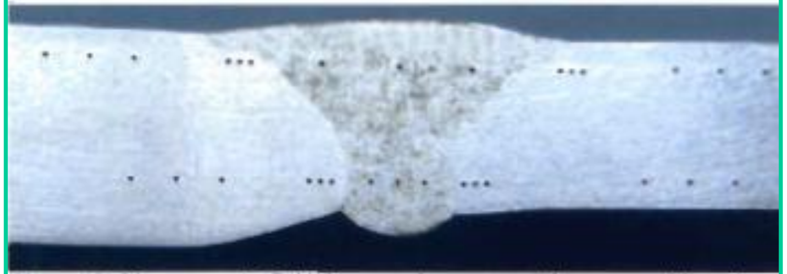


Figure 6: Macrograph @ X 5 - sample removed from sound location.

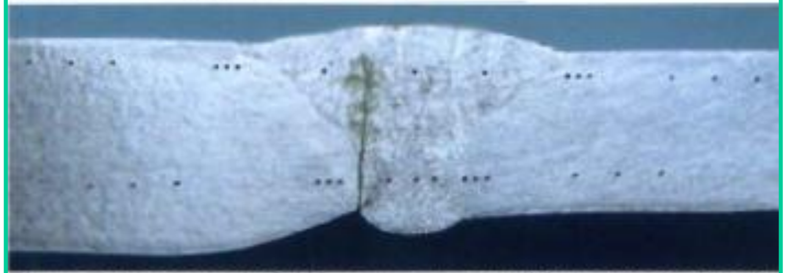


Figure 7: Macrograph @ X5 - sample removed from defective locatio

Case Study: In-Service Failure of Tee-to-Flange Weld Joint

❑ Micro Examination

➢ Findings

- PM: Ferrite in an austenitic matrix.
- WM: Cast structure consisting of ferrite and austenite.
- No grain-boundary precipitation or intermetallic phases were observed in the BM, HAZ, or WM.
- The cracking was observed to be transgranular.

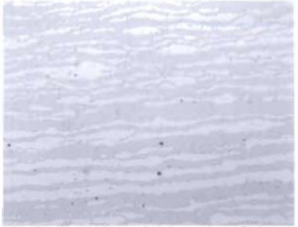


Figure 9: Etched; Original Magnification – 100X, showing microstructure of Tee base metal.

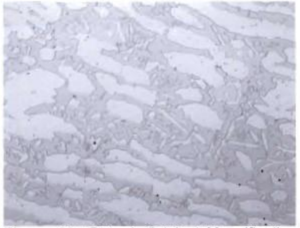


Figure 10: Etched; Original Magnification – 100X, showing microstructure of flange base metal.

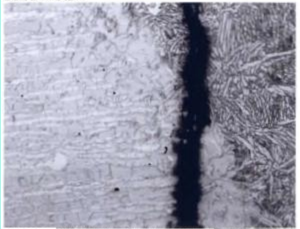


Figure 11: Etched; Original Magnification – 100X, showing microstructure of Tee HAZ.

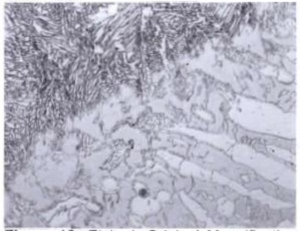


Figure 12: Etched; Original Magnification – 100X, showing microstructure of Flange HAZ.

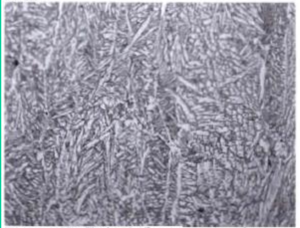


Figure 13: Etched; Original Magnification – 100X, showing microstructure of weld metal.

Figure 14: Etched; Original Magnification – 100X, showing microstructure at origin of crack.

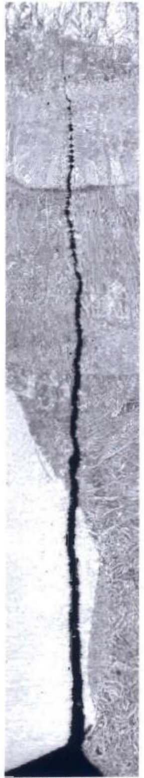


Figure 15: Etched; Original Mag.– 50X, crack profile

Case Study: In-Service Failure of Tee-to-Flange Weld Joint

❑ Fractography

➢ **Findings**

- Multiple crack initiation sites identified.
- Beach marks and fatigue striations observed.
- Progressive crack growth from weld root toward weld cap noticed
- Crack propagation region was flat and smooth.
- Final fracture - ductile with fibrous overload characteristics.

➢ **Failure Mode**

- Mechanical fatigue

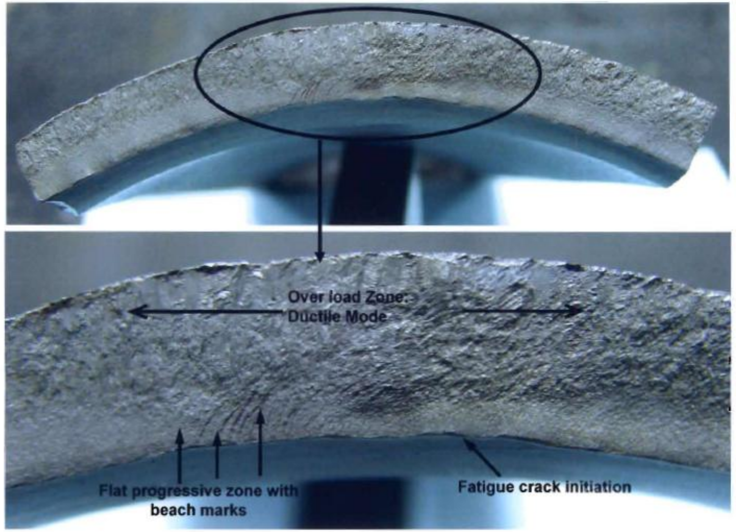


Figure 5: Macrograph illustrating the characteristics related to fatigue mode of failure.

Root Cause Assessment & Corrective Action

The investigation links the failure primarily to cyclic external loading, with geometry acting as a stress raiser

External cyclic loading
Unbalanced bending load and vibration

→

Stress concentration
Local stress concentration at tee-side root.

→

Fatigue initiation
Fatigue crack initiation at the weld-root toe / HAZ

→

Progressive growth
Crack advances through thickness and around circumference

→

Final failure
Ductile overload fracture.

Primary and Contributing Factors

- Unbalanced bending loads at the tee to flange joint.
- Cyclic loading from vibration source
- Stress concentration at weld root.

Recommended actions

- Review piping design for unbalanced bending loads
- Conduct a detailed site inspection of supports, connected equipment, and identify possible vibration sources
- Assess potential cyclic loading from vibrating equipment and develop mitigation plans.

Corrosion Engineers in FEED & Detailed Engineering

Contribution of Corrosion Engineers in FEED &Detailed Engineering

➢Role Overview

Corrosion Engineers in EPC (Engineering, Procurement and Construction) contractors and FEED (Front-End Engineering Design) consultancies are Titled as Materials and Corrosion Engineers. They work closely with different engineering teams **to develop robust design documents:**

- Corrosion Control using material selection, coatings, cathodic protection (CP), and corrosion inhibitors
- Asset Integrity Management , Design Reviews, Corrosion Risk Assessment Studies (CRAs)

Early-career engineers work under the guidance of a Lead Materials and Corrosion Engineer. As they gain experience, they take on more responsibilities and gradually work independently on assigned projects. Laboratory roles mainly focus on testing and analysis, while engineering roles apply corrosion knowledge to support safe, reliable, and cost-effective designs.

➢FEED & EPC Projects

- FEED stands for Front-End Engineering Design.
- EPC stands for Engineering, Procurement and Construction.
- During the FEED stage, high-level materials and corrosion requirements are defined by the Materials and Corrosion Engineer. These documents are further developed, reviewed, and finalized during the EPC stage, based on the recommendations from the Material and Corrosion Assessment (MCA), CRAS, COMPANY and International standards and the experience and technical knowledge of the Materials and Corrosion Engineers.

➢Corrosion Engineers in a FEED & Detailed Engineering projects Work Closely With engineers from

- Process , Pipeline , Piping, Mechanical

➢ Starting Documents

- PFD (Process Flow Diagram) and HMB (Heat & Material Balance) are the main starting documents for developing Material Selection. These inputs are provided by the Process Engineers.
- Our involvement in FEED and EPC projects is crucial, as inputs from the Material Selection Report (MSR) and corrosion mitigation documents are used by other engineering disciplines, including Pipeline, Piping, and Equipment Engineers.

STREAM NUMBER		1	2
STREAM DESCRIPTION		Chanda RWS Upstream Choke Valve	Chanda RW Downstream C Valve
Overall Phase			
Vapour Fraction		0.1063	0.1226
Temperature	C	72.6	71.4
Pressure	bar_g	65.0	33.0
Molar Flow	kmole/h	2297.1	2297.1
Mass Flow	kg/h	64852.9	64852.9
Mass Density	kg/m3	398.3	226.4
Molecular Weight		28.23	28.23
Vapour Phase			
Molar Flow	kgmole/h	244.2	281.6
Mass Flow	kg/h	5739.5	6841.6
Std Gas Flow	MMSCFD	4.90	5.65
Actual Gas Flow	m3/h	92.82	238.24
Molecular Weight		23.50	24.29
Mass Density	kg/m3	62.17	31.85
Cp/Cv		1.44	1.38
Mass Heat Capacity	kJ/kgC	2.268	2.046
Viscosity	cP	0.0151	0.0140
Thermal Conductivity	W/m-K	0.0401	0.0363
Compressibility		0.868	0.930
Mixed Liquid Phase			
Mass Flow	kg/h	59113.4	58011.3
Std Vol Flow	barrel/day	9852.8	9864.2
Actual Volume Flow	m3/h	70.53	68.18
Mass Density	kg/m3	838.28	850.84
Viscosity	cP	4.33	5.53
Liquid Phase			
Molar Flow	kgmole/h	190.6	155.6
Mass Flow	kg/h	25496.3	24482.5
Std Vol Flow	barrel/day	5052.88	4774.41
Actual Volume Flow	m3/h	35.98	33.70
Mass Density	kg/m3	708.67	725.97
Mass Heat Capacity	kJ/kgC	2.296	2.276
Viscosity	cP	0.7420	0.9028
Thermal Conductivity	W/m-K	0.0976	0.1065
Surface Tension	dyne/cm	13.03	15.78
Aqueous Phase			
Molar Flow	kgmole/h	1862.3	1859.9
Mass Flow	kg/h	33617.1	33548.8
Std Vol Flow	barrel/day	4999.70	4990.67
Actual Volume Flow	m3/h	34.54	34.48
Mass Density	kg/m3	973.30	972.86
Mass Heat Capacity	kJ/kgC	4.325	4.333
Viscosity	cP	0.4081	0.3827
Thermal Conductivity	W/m-K	0.6633	0.6665
Surface Tension	dyne/cm	63.62	63.85
Component Mole Fraction			
Nitrogen		0.000534	0.000534
CO2		0.018479	0.018479
Mercury		0.000000	0.000000
Methane		0.089939	0.089939
Ethane		0.011958	0.011958
Propane		0.008472	0.008472
i-Butane		0.002949	0.002949
n-Butane		0.003454	0.003454
i-Pentane		0.002787	0.002787
n-Pentane		0.001249	0.001249
n-Hexane		0.001759	0.001759

Day-to-Day Involvement of Corrosion Engineers in Engineering Projects

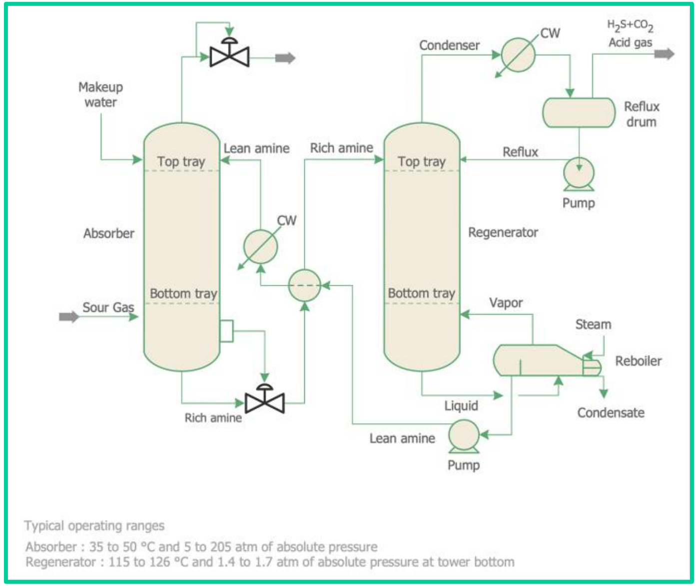
➢ Developing And Maintaining Key Engineering Deliverables, Including:

- Material Selection Report (MSR)
- Corrosion Risk Assessment Study (CRAS)
- Coating Specification
- Material and Corrosion Audit (MCA)
- Cathodic Protection (CP) Design

➢ Other Key Support Activities

➢ Commercial Bid Support

- Support the Commercial and Procurement teams during tendering by reviewing bid documents and confirming the correct material requirements. Late material changes can significantly increase project cost and cause delays.



Day-to-Day Involvement of Corrosion Engineers in Engineering Projects

➢ Procurement vendor Support

- Support the Procurement and Vendors in sourcing the correct materials in accordance with the project specifications.

➢ Fabrication/ Yard support

- Corrosion and Materials Engineers act as the custodians of M&C documents. We respond to technical queries and provide support to the Construction teams to ensure that the material selection and corrosion-control measures defined are correctly implemented.

Key Learning for Corrosion Engineers working in Engineering Projects

➢ Material Selection & Standards

- Develop strong knowledge of company specifications and international standards (NACE MR0175 / ISO 15156) related to material selection.

➢ Materials & Corrosion Documents

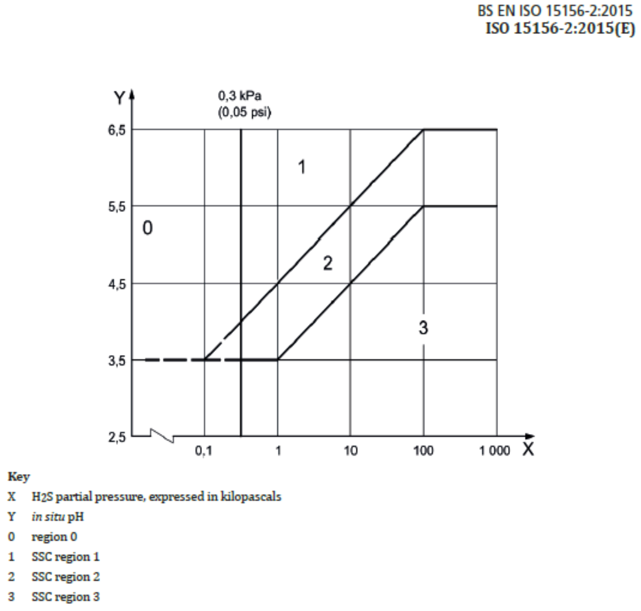
- Learn how to develop key materials and corrosion documents for major projects. Understand how these documents are applied and implemented during fabrication.

➢ Corrosion Modelling

- Learn how to use corrosion modelling software such as ECE, PREDICT for corrosion assessment.

➢ Project & Team Experience

- Understand how engineering requirements are translated into actual fabrication and construction.



Corrosion Engineers In Plant Shutdowns And Operations

Contribution of Corrosion Engineers in Plant Shutdown and Production Operations

➢ Role Overview

During plant shutdowns (turnarounds), Corrosion Engineers play a key role in maintaining the integrity, reliability, and safe operation of static equipment and piping systems.

➢ Key responsibilities include:

- Reviewing inspection findings and damage mechanisms.
- Assessing equipment condition and remaining life.
- Providing repair, replacement, and mitigation recommendations.
- Supporting fitness-for-service and return-to-service decisions.
- Identifying opportunities to inspect, repair, and improve asset integrity during shutdowns.

Shutdown and production operations share many common corrosion management activities. However, shutdowns provide greater access for inspection, maintenance, and corrective actions. For this reason, the role in both shutdowns and operations is presented together.

➢ During a shutdown, Corrosion Engineers work closely with:

- **API Inspectors and Equipment Engineers**
- Validate damage mechanisms during their inspections.
- Support return-to-service decisions.
- **NDT Technicians**
- Coordinate specialised inspections.
- Review and interpret NDT results.
- Identify areas requiring additional examination.
- Confirm extent of corrosion or damage.
- **Shutdown Lead Engineer**
- Prioritise inspection activities.
- Support risk-based decision-making.
- Ensure corrosion-related findings are addressed before startup.

➢ During a shutdown, Corrosion Engineers work closely with:

- **Operations and Process Engineers**
- Understand operating conditions contributing to degradation.
- Review process excursions and upset conditions.
- Recommend mitigation measures.
- **Maintenance and Repair Teams**
- Define repair requirements.
- Verify suitability of repair methods and materials.
- Corrosion coupon and probes retrieval before visual inspection, cleaning and analysis for metal loss and edge pitting.

Figure 21C- CC & ER probe; location D; as retrieved condition.

Figure 21D- CC & ER probe; location F; as retrieved condition.

Key Learning for Corrosion Engineers working in Plant Shutdowns

Key Outcome

- Develop practical engineering judgement for integrity management.

➢ Understanding Degradation Mechanisms

- Correlate operating conditions with observed damage mechanisms.
- Improve prediction of corrosion and material degradation threats.

➢ Inspection Data Interpretation

- Interpret NDT and inspection results.
- Understand inspection capabilities and limitations.

➢ Multidisciplinary Collaboration

- Work closely with inspectors, engineers, operations, and maintenance teams.

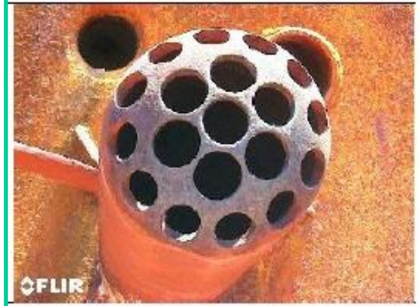


Figure 12B- 7-F-0103; location-burner end cap; material HR160- 37Ni, 29 Co, 28Cr- UNS N12160; withstand temperature up to 1204°C; resistant to sulfidation and chloride attack in both reducing and oxidizing atmospheres.

Figure 12C 7-F-0106; location-burner end cap; damage noted in high temperature corrosive combustion environment; existing material SS310; material upgraded to HR160- UNS N12160.

Key Learning for Corrosion Engineers working in Plant Shutdowns

➢ Fitness-for-Service Decision Making

- Assess equipment fitness for continued operation.
- Apply industry standards and risk-based assessments.

➢ Integrity Management

- Understand the relationship between inspection, maintenance, and risk.
- Support corrosion mitigation and asset life extension.

Presentation summary

- The Corrosion Engineer’s role in:
  - Laboratory
  - Design
  - Shutdowns and Operations

Thank you for your attention

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