IC-004 SUPPLEMENTAL READING

H_2S (Sour) Corrosion in Pipelines: Mechanism, Risks, Diagnostics, and Mitigation

Part 2 of the Field Notes article Internal Corrosion: Sweet and Sour — the H_2S mechanism, the hydrogen-damage modes, where sour corrosion shows up, how to recognize it, and how to mitigate it. Companion reading for IC-004 — H_2S (Sour) Corrosion. (The sweet half of the article accompanies IC-003.)

BY ROBERTS CORROSION SERVICES FIELD NOTES FROM RCS ~6 MIN READ

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Hydrogen sulfide (H_2S) corrosion; commonly known as sour corrosion; represents one of the most challenging internal corrosion mechanisms encountered in oil and gas pipelines and processing equipment. For corrosion field technicians, pipeline integrity specialists, and engineers, understanding the complex electrochemical and metallurgical interactions driven by H_2S is critical for effective risk assessment, monitoring, and mitigation.

Sour corrosion not only causes metal loss but also introduces hydrogen-related damage modes such as hydrogen-induced cracking (HIC) and sulfide stress cracking (SSC), which can lead to catastrophic failures if undetected. This second part looks into the fundamental mechanisms of H_2S corrosion, typical environments where it occurs, diagnostic indicators, and advanced prevention and mitigation strategies. It also addresses common challenges faced in the field and practical solutions to overcome them.

Mechanism and Fundamentals of H_2S (Sour) Corrosion

At its core, sour corrosion arises from the presence of hydrogen sulfide gas dissolved in aqueous phases within pipelines or equipment. H_2S dissociates in water to form bisulfide (HS^-) and sulfide (S^{2-}) ions, creating a chemically aggressive environment that accelerates anodic metal dissolution and introduces hydrogen atoms into the steel lattice.

Key Electrochemical Reactions

> Anodic dissolution: $Fe \rightarrow Fe^{2+} + 2e^-$

> Cathodic reaction involving H_2S: $H_2S + 2e^- \rightarrow HS^- + H^-$ (atomic hydrogen)

> Hydrogen evolution and absorption: $2H^+ + 2e^- \rightarrow H_2$ (gas), or atomic hydrogen absorbed into steel

The absorbed atomic hydrogen can diffuse into the steel microstructure, leading to embrittlement phenomena such as:

- **Hydrogen Induced Cracking (HIC):** Formation of internal cracks due to hydrogen accumulation at inclusions or defects.
- **Sulfide Stress Cracking (SSC):** Stress-assisted cracking in the presence of H_2S, particularly in high-strength steels under tensile stress.

The formation of iron sulfide (FeS) scales on the metal surface can provide partial protection but is often porous or cracked, allowing continued corrosion underneath. The protective nature of FeS scales depends on pH, temperature, and flow conditions.

Where Sour Corrosion Occurs and Risk Factors

Sour corrosion is prevalent in environments where H_2S partial pressure exceeds approximately 0.003 bar (per ISO 15156 / AMPP MR0175 standards), including:

- Sour gas reservoirs and production wells
- Flowlines and gathering pipelines transporting sour fluids
- Processing equipment such as separators, scrubbers, and amine units
- Injection pipelines where souring occurs due to microbial activity or reservoir changes

Risk factors include:

- **High H_2S concentration:** Elevated partial pressures increase corrosivity and hydrogen charging.
- **Low pH (<5):** Acidic conditions increase H_2S solubility and promote aggressive corrosion.
- **High temperature:** Accelerates reaction kinetics and hydrogen diffusion.
- **Chloride presence:** Chlorides exacerbate corrosion and cracking susceptibility.
- **Flow regime:** Stagnant or low-velocity zones promote localized attack and hydrogen accumulation.
- **Material susceptibility:** High-strength steels with hardness above 22 HRC are more prone to SSC.

Dead legs, stagnant zones, and areas with deposits or biofilms are particularly vulnerable. Microbial souring can increase H_2S levels unexpectedly, raising risk.

Visual and Diagnostic Indicators

Sour corrosion often manifests differently than typical uniform or pitting corrosion:

Hydrogen Damage Signs

- Internal blistering or stepwise cracking visible on cross-sections.
- Intergranular or transgranular cracks detected by advanced NDT methods.

Surface Appearance

- Black iron sulfide (FeS) deposits or scales.
- Minimal visible metal loss despite severe subsurface damage.

Inspection Techniques

- **Phased Array Ultrasonic Testing (PAUT):** Detects internal cracks and HIC.
- **Wet Fluorescent Magnetic Particle Inspection (WFMPI):** Highlights surface-breaking cracks.
- **Inline Inspection (ILI) tools:** Calibrated for crack detection in sour service.
- **Chemical analysis:** Draeger tubes or online analyzers for H_2S concentration monitoring.
- **Corrosion coupons and probes:** Measure corrosion rates and hydrogen charging trends.

Prevention and Mitigation Strategies

Effective sour corrosion control requires a multi-pronged approach combining material selection, chemical treatment, and operational controls.

Step-by-Step Procedure for Sour Corrosion Management

1. **Risk Evaluation:** Measure H_2S partial pressure, pH, temperature, and chloride levels. Classify service environment per ISO 15156 domains (Domain 0, 1, 2).
2. **Material Selection:** Use sour-service qualified materials (e.g., API 5L X60 with hardness <22 HRC). Avoid susceptible high-strength steels or apply post-fabrication heat treatment to reduce hardness.
3. **Chemical Treatment:** Inject H_2S scavengers (e.g., triazine-based compounds) at 1–5 ppm per ppm H_2S to reduce free H_2S. Use corrosion inhibitors compatible with sour environments to form protective films.
4. **Operational Controls:** Maintain pH above 5 where possible to reduce H_2S solubility. Control flow to minimize stagnant zones and deposits. Implement pigging programs to remove solids and biofilms.
5. **Monitoring and Inspection:** Regularly inspect with crack-detection ILI tools and NDT methods. Monitor chemical treatment effectiveness via fluid sampling and corrosion coupons. Adjust mitigation based on inspection and monitoring data.

Common Challenges and How to Overcome Them

- **Incomplete H_2S Removal:** Scavengers may not fully eliminate H_2S in high-flow or complex systems. Combine chemical treatment with gas sweetening or physical removal (scrubbers).
- **Material Incompatibility:** Mixing materials with different galvanic potentials can worsen corrosion. Use isolation techniques and compatible alloys.
- **Hydrogen Damage Detection:** Early-stage HIC or SSC may be missed by standard inspections. Employ advanced NDT and maintain rigorous inspection intervals.
- **Microbial Souring:** Microbial activity can increase H_2S unexpectedly. Incorporate biocide treatments and microbial monitoring.
- **Operational Upsets:** Pressure, temperature, or flow changes can alter sour corrosion risk. Implement real-time monitoring and rapid response protocols.

Summary and Key Takeaways

- H_2S (sour) corrosion is a complex internal corrosion mechanism involving electrochemical metal dissolution and hydrogen-induced damage.
- It occurs primarily in sour gas and sour fluid environments with elevated H_2S partial pressures and acidic conditions.
- Visual signs may be subtle; advanced NDT and chemical monitoring are essential for detection.
- Prevention relies on sour-service materials, chemical scavengers, inhibitors, and operational controls.
- Challenges include ensuring complete H_2S removal, detecting hydrogen damage early, and managing microbial souring.
- Regular inspection, monitoring, and adaptive mitigation strategies are critical to maintaining pipeline integrity in sour service.

Referenced Standards and Guidelines

- **ISO 15156 / AMPP MR0175:** Materials for use in H_2S-containing environments in oil and gas production.
- **AMPP SP0472:** Inspection and mitigation of hydrogen damage in sour service.

- **AMPP TM0177:** Laboratory testing of corrosion inhibitors.
- **API 5L:** Specification for line pipe including sour service grades.
- **NACE SP0169:** Control of external corrosion on underground or submerged metallic piping systems (for complementary external considerations).

ABOUT

Roberts Corrosion Services, LLC

Established in 2011, Roberts Corrosion Services, LLC delivers comprehensive, turn-key cathodic protection and corrosion control solutions nationwide. Our end-to-end expertise encompasses design and inspection, installation and repair, surveys and remedial work. We provide drilling services for deep anode installations and a full laboratory for analysis of samples and corrosion coupons, as well as custom CP Rectifier manufacturing.

While our initial focus was on the Appalachian Basin area, we complete field work all over the US. We are a licensed contractor in many states and can complete a wide range of services. Our biggest strength is in our flexibility for our clients. Solutions and Results.