



Managing Corrosion and Sulfur Deposition in Sour Gas Gathering System

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**NACE Calgary Section
Elemental Sulphur Corrosion Seminar**

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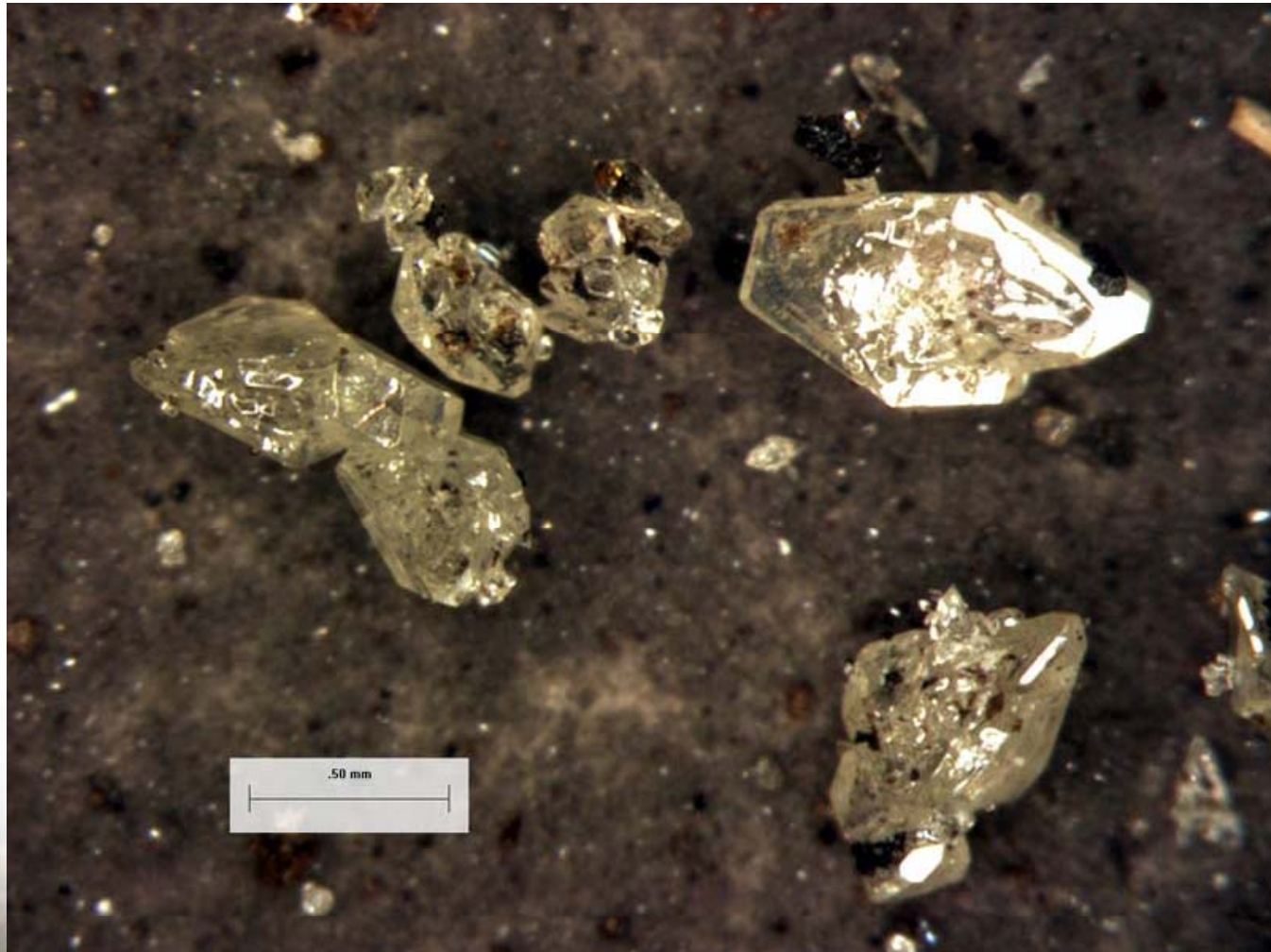
Outline

1. Sour Gas + Sulfur Threats
2. Well Characteristics
3. Corrosion Design Basis – Well, Pipeline
4. Lab Testing
5. Startup
6. Run and Maintain
7. Summary

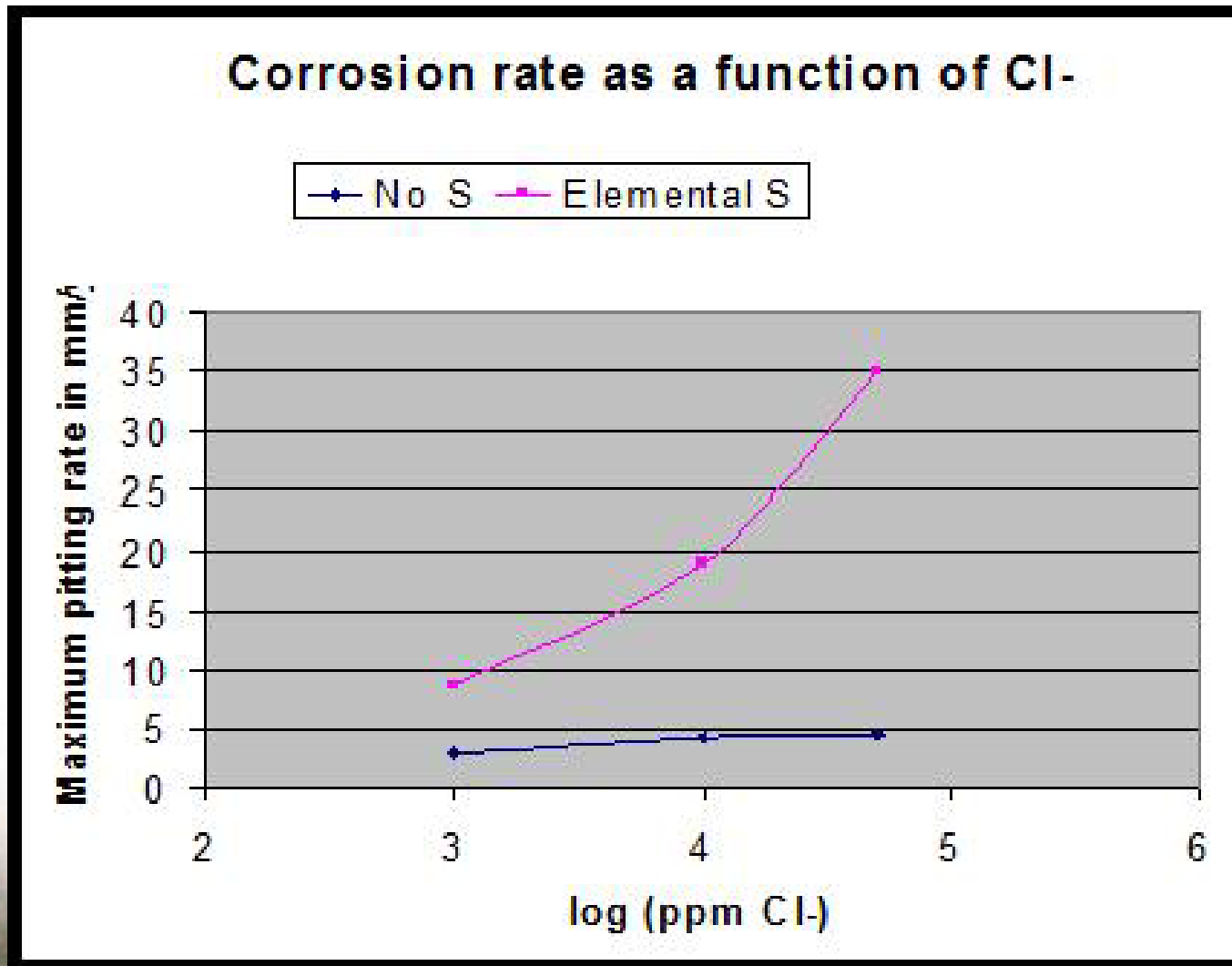
Main Threats in Sour Gas

- Corrosion
 - H₂S and CO₂
 - Brine – Cl⁻ \geq 10,000mg/L; 6-8mm/yr
 - **Elemental S – with brine; 34mm/yr**
 - Methanol - $>1:1$ with water can deteriorate protective iron sulfide layer
 - Low pH – iron sulfide layer becomes non-protective
- S₈ Deposition

Elemental Sulfur



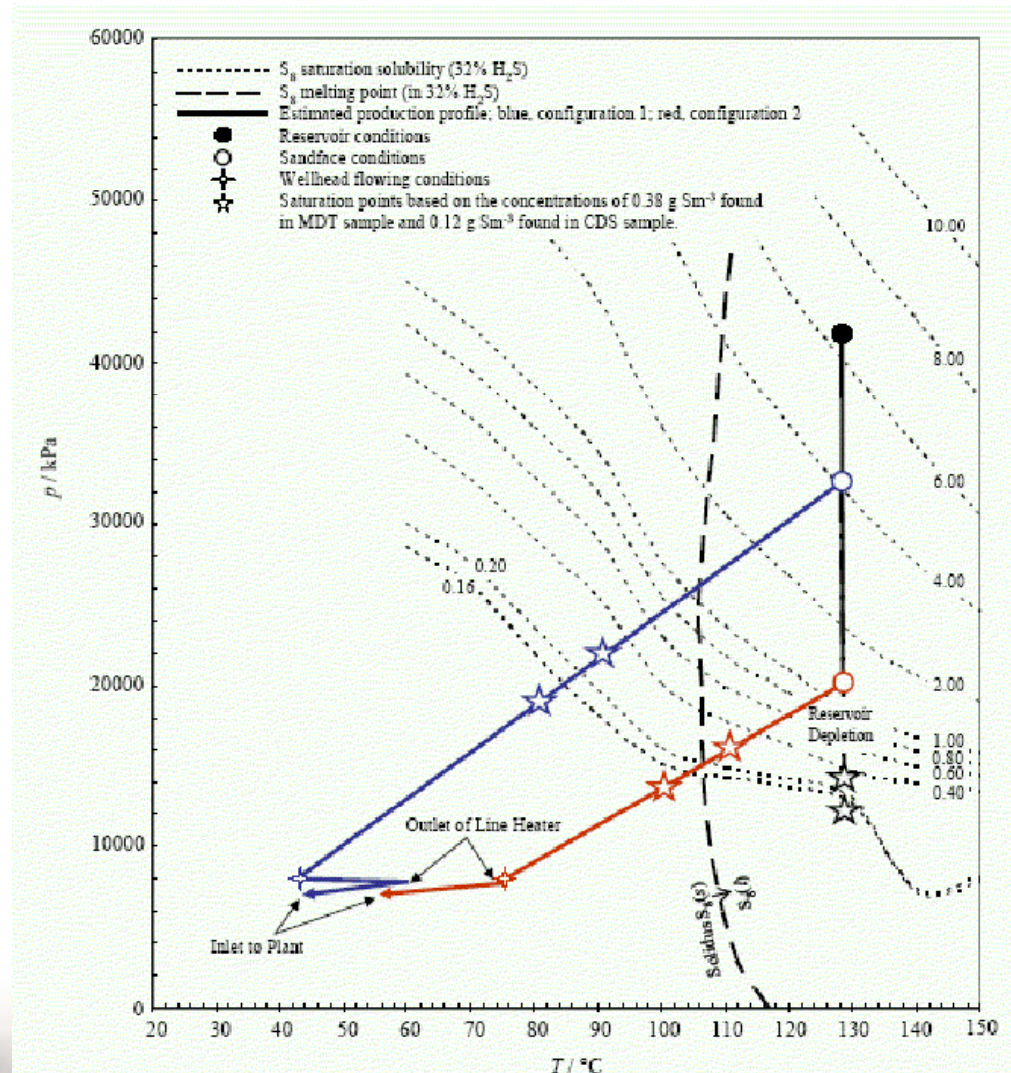
Effect of Elemental Sulfur



Well Characteristics Important for Well & Pipeline Integrity Plan

- % H₂S and %CO₂
- Brine composition – now and future
- Condensate Presence
- Depth, T and P
- Sulfur content
 - Ranges from <100ppm TSS to 16kg/d??? Or 300++kg/E3m³ Gas
 - ASRL Model – S_g Solubility

S₈ Deposition





Corrosion Design Basis for Sour Gas with Elemental S Present

- Consider the threats and mitigation strategies
- CS vs CRA Production Tubing/Packer
- Internally Bare CS vs Lined CS vs CRA Pipeline
- How corrosive?, flaring restrictions?
- Sulfur Solvent Use
 - Continuous injection at SSSV & wellhead
 - Continuous through Cap string to bottom
 - Batch applications downhole

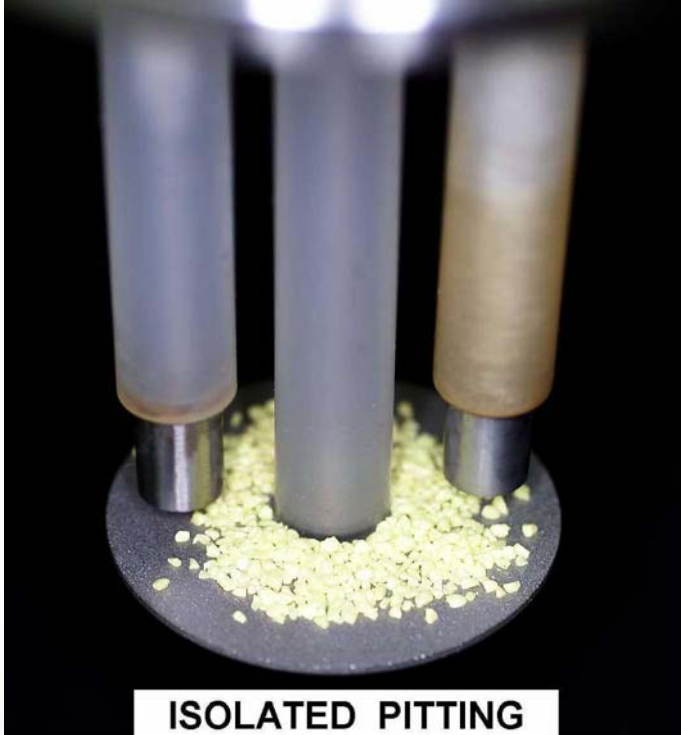
Corrosion Inhibitor Testing

- Autoclave Testing for corrosion performance
 - In-situ partial pressures of H₂S and CO₂
 - Insitu T, Brine composition(s), solid S₈
 - Slow stirring, pre-corroded coupons, general and pitting measurements
- Compatibility testing
 - Test for sludge, emulsions, performance deterioration
 - Sulfur solvent, amine solutions, glycols

Isolated Pitting in Sour Gas Gathering System

60°C, 50 psi H₂S, 50 psi CO₂

After 160 hours



No sulfur 100,000 ppm Cl ⁻ Corrosion rate 0.4 mm/yr	
5g sulfur 1000 ppm Cl ⁻ Corrosion rate 1.8 mm/yr	
5g sulfur 10,000 ppm Cl ⁻ Corrosion rate 25.5 mm/yr	
5g sulfur 100,000 ppm Cl ⁻ Corrosion rate 26.9 mm/yr	

Well Decisions

- CRA vs CS Tubing vs Combination (CS + CRA)
- CRA vs CS packer, seating nipples
- S₈ Management
 - Cap String to above packer
 - Diesel to SSSV (and to wellhead piping)
 - Choice depending on location of S deposition:
 - Continuous CI to bottom with DMDS batches, or
 - Continuous S Solvent with inhibitor to bottom
 - (Continuous S dispersant: lower S levels – Future?)



Pipeline Decision

- CS pipeline
 - Require CI facilities, pig & batch
 - Pig & batch requires flaring
 - ILI requirements
 - Repairs
- Lined CS pipeline
 - CI facilities for piping, downstream bare steel
 - ILI requirements
 - Limited pigging/batching/flaring
- CRA Pipeline
 - Risers, valves
 - Acid compatibility



Sulfur Solvent Optimization

- Recent initiative to decrease the frequency of batch solvent treatments.
 - Lower Sulfur solubility = Less Sulfur carried to wellbore
 - In the process of moving from 2-4 weeks ->3-6 weeks
- Plan to reduce daily Diesel injection rates
 - Diesel injected downhole and at surface facilities
- Focus has been on OPEX optimization (field has been plant constrained)

Well Start up

- Pre-batch
 - Pre-batch surface piping and pipeline
- Temporary separator after well stimulation
 - Confirm elemental S presence/absence
 - Lower Cl-, increase pH, remove solids
- Incremental Cl concentration and batching
- Observations/adjustments pending flow rates and presence of solid sulfur

Example Start up Requirements

Type	First Batch (2 to 3 days before flowing)	Continuous Injection Inhibition over-dosage: factor, for 2 weeks	Second Batch (3 to 7 days after flowing)
All flow regiemes except the cases below	Required	2 x	Not Required
IA (High Flow-High Cl ⁻)	Required	2 x	Required
IIS (Low Flow-High Cl ⁻ & Sulphur)	Required	4 x	Required

Temporary Test Separator



Run and Maintain

Important to Develop a Plan to Maintain Facility Integrity

- Integrity Reference Plans
 - Mitigation Plan
 - Monitoring Plan
 - Inspection Plan

Integrity Reference Plan - Well


- SSCC resistant metallurgy
 - CRA packers and seating nipples
 - CS tubing and wellhead
- Continuous Sulfur solvent through cap string to bottom or to SSSV
- With batch sulfur solvents, use continuous corrosion inhibitor through cap string to bottom
- Confirm chemical rates, compatibilities
- Monitoring to detect CHANGE in production conditions
- Inspections to confirm performance



Integrity Reference Plan – Bare Steel Pipeline


– Mitigation

- Maintenance pigging
- Batch inhibition
- Continuous inhibition
- Changes required depending on water chemistry, sulfur presence and water flow rate – monitoring is very important due to the significant corrosion rate if not using the proper mitigation program for the conditions



Integrity Reference Plan – Bare Steel Pipeline (Cont.)

- Monitoring – Managing change in conditions is key
- Bottom mounted tee for sampling at well site and pipeline junctions
 - Corrosion inhibitor residuals
 - Chloride concentration
 - Fe/Mn
 - TSS (mg/L) – Sulfur and load?
- Field Signature Method – monitoring devices placed on known corrosion sites from ILI



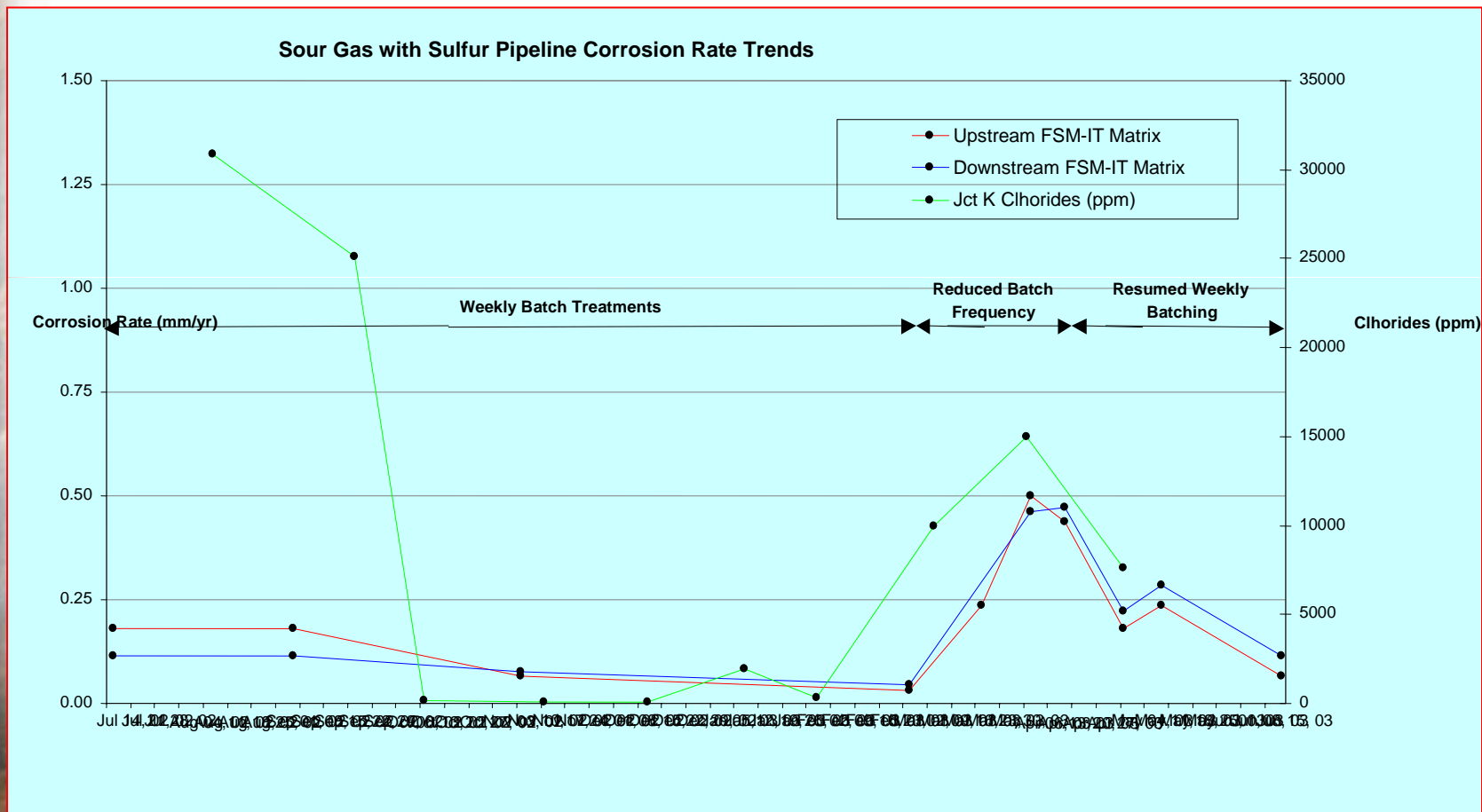
Integrity Reference Plan – Bare Steel Pipeline (Cont.)

- Inspection
 - ILI on regular basis – Sulfur presence increases frequency
 - Bell Hole Inspection – set up on known ILI features

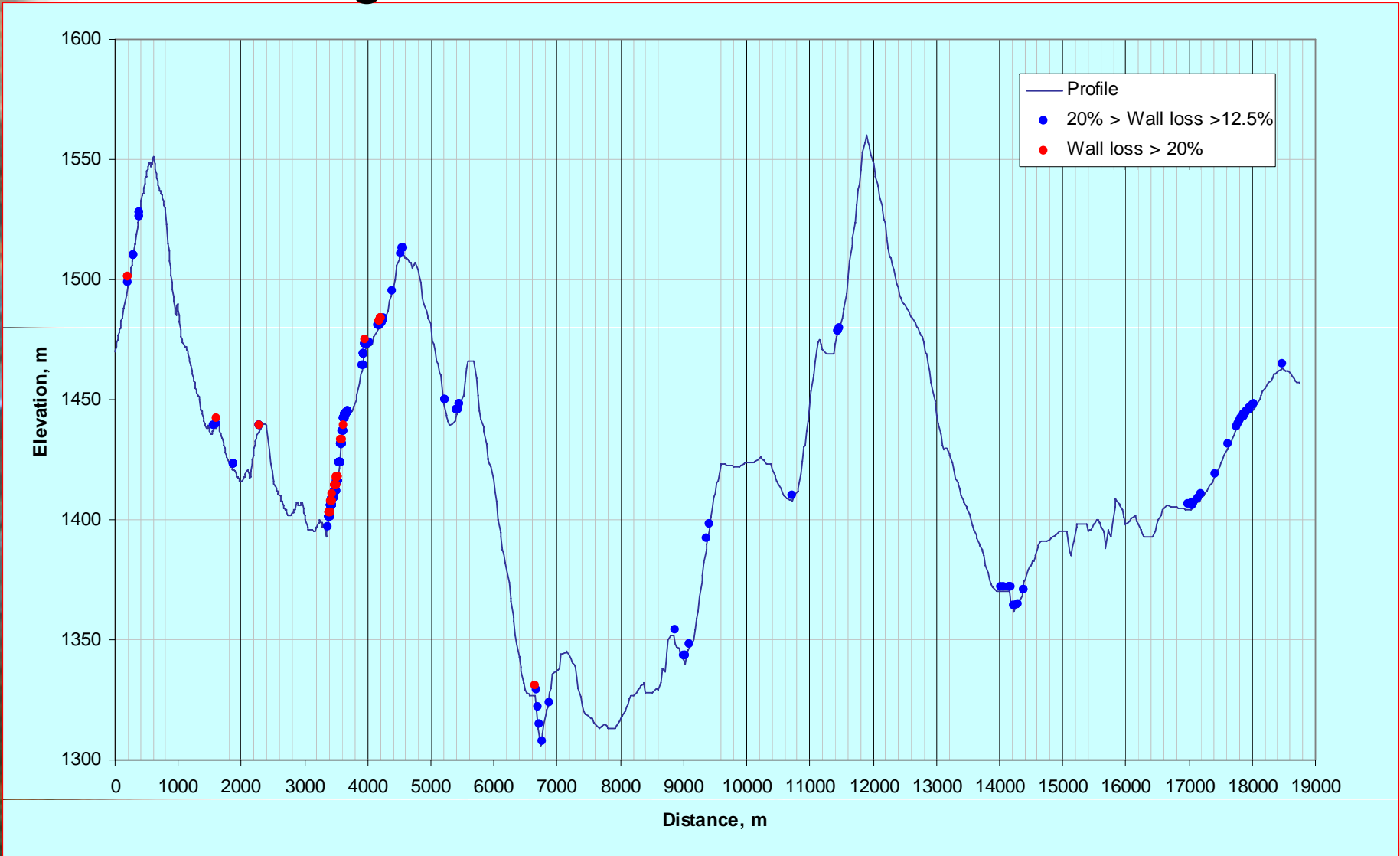
Example Mitigation vs Conditions

Type	Continuous Injection Inhibition	Pigging frequency ¹⁾	Batching frequency ⁷⁾	Wire Brushing with batch ²⁾	Sulphur solvent
I (High Flow-Low Cl ⁻)	Required ³⁾	Not required	Not required	Not required	Not required
IA (High Flow-High Cl ⁻)	Required	NR	Not required	Not required	Not required
II (Low Flow-Low Cl ⁻)	Required	NR	Not required	Not required	Not required
III (Low Flow-High Cl ⁻)	Required	NR	4 weeks ⁵⁾	Not required	Not required
IS (High Flow-Low Cl ⁻ & Sulphur) ⁴⁾	Required	4 weeks	Not required	26 weeks	Optional ⁶⁾
IAS (High Flow-High Cl ⁻ & Sulphur) ⁴⁾	Required	4 weeks ⁵⁾	4 weeks ⁵⁾	26 weeks	Optional ⁶⁾
IIS (Low Flow-Low Cl ⁻ & Sulphur) ⁴⁾	Required	4 weeks ⁵⁾	4 weeks ⁵⁾	26 weeks	Optional ⁶⁾
IIIS (Low Flow-High Cl ⁻ & Sulphur) ⁴⁾	Required	1 week ⁵⁾	1 week ⁵⁾	13 weeks	Required

Corrosion Monitoring



ILI - 'S₈+Brine' Corrosion





Summary - Sulfur Requires Extra Attention

- Solid sulfur removal – pigging, solvents or dispersants
- Higher concentrations of continuous corrosion inhibitor
- Incremental batch inhibitor treatments
- Increased sampling/monitoring
- Increased inspection/ILI frequency



Thank you for your Attention

“Be careful if you have Cl- and sulfur”

Questions?