OTC 25193
Corrosion Testing of Deepwater Tubing Materials under Extreme Pressure and Temperature Conditions

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Outline

- Introduction
- Experimental details
- Results and discussion
- Conclusions
- Acknowledgement
Introduction

➢ Ultra deep-water GOM plays

- Limited data & knowledge
  - Temperature (> 200 °C)
  - Pressure (> 10,000 psig)
  - TDS (> 200,000 mg/L)
- Equipment limitation
  - Autoclave
  - Flow-through

- ~ 90 announced projects
- > 200 °C and 20,000 psig
- CO₂ and H₂S
Experimental details

- Apparatus - autoclave

- All wetted parts are made of HC-276
- In-situ temperature, pressure and rotating speed controller
- Liquid sampling at T and P
- Multiple coupon holders
Experimental details

- Apparatus – flow through apparatus

- Pump (Feed Solution)
- Pressure Transducer
- Refill & Drain
- Test tubing
- Oven
- Cooling Coil
- Tygon tube

¼ in OD and 3/36 in ID HC-276 Tubing
Experimental details

Chemicals

- 3 M NaCl solution
- Saturated with CO2
- pH adjusted to 5.0
- Complex brine: 
  3 M NaCl + 0.15 M CaCl2.2H2O + 3 mM Na2SO4 + 3 mM NaHCO3, 
  CO2 saturated, pH adjusted to 5.0

Alloys used as coupons

- Carbon steel: C 1018, C 1010;
- Stainless Steel: 316 L, 410 and 420;
- Inconel alloys: I 718, I 825
- Nickel - Chromium alloy: G3
Test procedure

Testing solution saturated with CO$_2$ and pH adjusted at 25 °C

Autoclave: charge CO$_2$ at 25 °C

Heat up to targeted temperature

Cool down to 50 °C

Remove coupons, rinse with DI water and IPA, maintain in desiccator

Coupons were weighted before and after for weight loss calculation.

Electrochemical measurements were only conducted at temperature.

Coupon surface was analyzed by VSI, SEM and XRD.
Measurement techniques

- Corrosion analysis
  - Uniform corrosion - Weight Loss (WL), Linear Polarization Resistance (LPR).
  - Localized corrosion - Vertical Scanning Interferometry (VSI).
- Steel surface analysis
- Solution elemental chemistry analysis
  - Inductively Coupled Plasma (ICP).
Measurement techniques

- Vertical Scanning Interferometry
  - Non-contact optical method
  - Easy sample preparation.
  - Fast scan speed of 28 µm/s.
  - Point analysis in seconds;
  - Automatic whole surface analysis.
  - High resolution 2D profiles and 3D topography
    - Vertical resolution: 3 nm.
    - Optical resolution: 2.2 µm.

- Height measurements
  - Suitable for profiling pits, holes, grooves from corrosion.
  - Quantitative analysis of pit dept.

C 1018 (after cleaning), 250 °C, 1 M NaCl, 0.057 M CO₂ (aq), 24 hrs
Measurement techniques

How is localized corrosion identified by VSI?

1. After removing corrosion product scales, areas with potential pits were chosen for VSI analysis.
2. VSI measures valleys with a surface area defined by user and lists them by depth.
3. From weight loss (WL), the uniform corrosion rate was calculated and the equivalent depth of this uniform corrosion rate obtained.
4. Any depth > 5 times the depth from step 3 were considered pits (NACE ASTM G46-94, 1999).
Results and discussion

Temperature effect

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Corrosion Rate (μm in 18 hrs)</th>
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</thead>
<tbody>
<tr>
<td>100 C</td>
<td>4.9 mm/yr</td>
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<tr>
<td>250 C</td>
<td></td>
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</tbody>
</table>

Comparing to uniform corrosion rate 0.8 mm/yr, it is considered as pitting.
Results and discussion

- CO₂ effect

Test conditions: C 1018, 3 M NaCl solution, 250 °C

9.52 μm in 16 hrs = 5.2 mm/yr, comparing to uniform corrosion rate 0.1 mm/yr, it is considered as pitting
Results and discussion

Different alloys

- Nickel alloys I-718, I-825, G3, and SS 316 L all showed good corrosion resistance from both LPR and weight loss measurements.
- 13Cr 410 and 420 both had high uniform corrosion rate 10 mm/yr for the 18 hours experiment.

3 M NaCl solution, 250 °C, 0.057 M dissolved CO₂.
Results and discussion

- Extreme pressure – 24,000 psig, C 1010

- Reaction conditions: 250 °C, 24,000 psig, 0.03 ml/min (0.016 ft/s), complex Brine.
- Some uniform corrosion observed.
- No localized corrosion.
Results and discussion

➢ Extreme pressure – 24,000 psig, SS 316

Before corrosion test

After corrosion test

- Reaction conditions:
  250 °C, 24,000 psig, 0.03 ml/min (0.016 ft/s), complex brine.

- No obvious change of the steel surface observed.

- No localized corrosion.
Conclusions

- Reliable procedures were developed for corrosion studies at those xHTHP and high TDS conditions.
- Protective Fe₃O₄ scale was formed on C 1018 at 250 °C with CO₂ saturated 3 M NaCl solution.
- CRAs and nickel alloys studied did not suffer uniform nor localized corrosion at 250 °C with CO₂ saturated 3 M NaCl solution for 20 hours of exposure.
- VSI was demonstrated to be a powerful tool which can give localized corrosion information fast and easy.
- The equipment and method developed for xHTHP corrosion study will be extended to study corrosion inhibitors in the future.
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Thank you!
Questions?