Comparison of Grade 91 and 347H Corrosion Resistance in the Low-Temperature Components of Direct Supercritical CO2 Power Cycles

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Outline

• Introduction
  – Heat Exchangers
  – Literature review

• Materials and Methods
  – Stainless Steel Grade 347H and Ferritic-Martensitic Grade P91
  – Experimental Procedure

• Results and Discussion
  – Weight measurement
  – Corrosion products characterization

• Conclusion
Direct sCO$_2$ cycle fluid (Allam et al.)

- Typical fluid composition: CO$_2$/H$_2$O/O$_2$ (95%/4%/1%)
- Pressure range: 3 to 35MPa
- Temperature range: Room Temperature to 750°C
- Phase change: Dissolved H$_2$O in sCO$_2$ → Aqueous fluid of CO$_2$

Literature Review

- Impacts of aqueous condensation

![Graph showing mass change of steels at 245°C with and without H₂O condensation.]

- Presence of water exacerbates corrosion degradation

![Graph showing corrosion rate of carbon steel in water rich and CO₂ rich phases at 50°C.]

Mass change of steels at 245°C with a H₂O condensation variable [Repukaiti et al.]

Carbon steel in water rich and CO₂ rich phases at 50°C [Choi et al.]

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Materials

- Stainless steel 347H
- Martensitic-ferritic steel P91

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Description</th>
<th>Cr</th>
<th>Ni</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>Mo</th>
<th>Fe</th>
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<tbody>
<tr>
<td>347H</td>
<td>Austenitic stainless steel</td>
<td>17.3</td>
<td>9.09</td>
<td>0.05</td>
<td>1.5</td>
<td>0.03</td>
<td>0.41</td>
<td>Balance</td>
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<tr>
<td>P91</td>
<td>Ferritic-martensitic steel</td>
<td>8.37</td>
<td>0.09</td>
<td>0.09</td>
<td>0.45</td>
<td>0.01</td>
<td>0.9</td>
<td>Balance</td>
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</table>

- Sample dimension: 20 × 25 × 6 mm with a 6 mm diameter hole
- 1200 grit SiC sandpaper surface finish
Immersion Test Configuration

- Alloy coupons
- sCO₂ Rich Phase
- H₂O Rich Phase

Graph showing pressure and temperature over time for different temperatures:
- 245°C
- 150°C
- 100°C
- 50°C

Time, total 500 hours

Pressure [MPa]

Temperature [°C]
**CO₂ and H₂O Phase Diagrams**

Pressure: 8 MPa, 95% CO₂ : 1%O₂ molar ratio  
Temperature: 50°C, 100°C, 150°C, and 245°C

**CO₂ and O₂ Solubility in H₂O**

**CO₂**

Solubility of CO₂ in pure H₂O as functions of temperature and pressure [Duan et al.]

**O₂**

Solubility of O₂ in pure water as functions of temperature and pressure [Geng et al.]


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P91 Secondary Electron Images

- 50°C
- 100°C
- 150°C
- 245°C

Spallation
Cracks
P91 Cross-Sectional Back Scattered Electron Images

In Progress

<table>
<thead>
<tr>
<th>50°C</th>
<th>100°C</th>
<th>150°C</th>
<th>245°C</th>
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<tbody>
<tr>
<td>Fe₂O₃</td>
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<td>Fe₂O₃</td>
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<tr>
<td>FeO(OH)</td>
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<td>Fe₃O₄</td>
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</table>

XRD Analysis of P91 Corrosion Products
Pourbaix Diagram of Fe-CO$_2$-H$_2$O

3Fe + 4H$_2$O $\Rightarrow$ Fe$_3$O$_4$ + 8H$^+$ + 8e$^-$

Fe$_3$O$_4$ + H$_2$O $\Rightarrow$ 3Fe$_2$O$_3$ + 2H$^+$ + 2e$^-$

Fe-CO$_2$-H$_2$O in 245 °C and 8 MPa

Fe-CO$_2$-H$_2$O in 50 °C and 8 MPa

Source: OLI Systems, Inc. OLE Studio, 2017
347H XPS Surface Depth Profile

Graphs showing the relative concentration (at%) of Cr, Fe, Ni, and O at different approximate depths (nm) for temperatures of 50°C, 100°C, 150°C, and 245°C.
Weight Change Data

![Graph showing weight change data for different temperatures and water phases.](image)
Conclusion

• 347H is more corrosion resistance than P91 in direct-sCO$_2$ power cycle environment where H$_2$O condensation takes place.

• Residual corrosion products on the P91 coupons were identified as Fe$_2$O$_3$ and Fe$_3$O$_4$, while 347H coupons showed minimal mass change and very thin passive layers.

• lower Cr steels such as Grade 91 may not be suitable for the low / intermediate temperature components in the direct sCO$_2$ power cycles.