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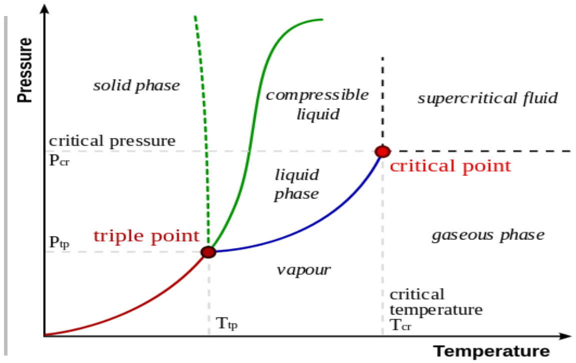

Short Duration Corrosion Performance of Carbon Steels in SCO_2 at 260°C

Alan Kruizenga, Matthew Walker, Elizabeth Withey

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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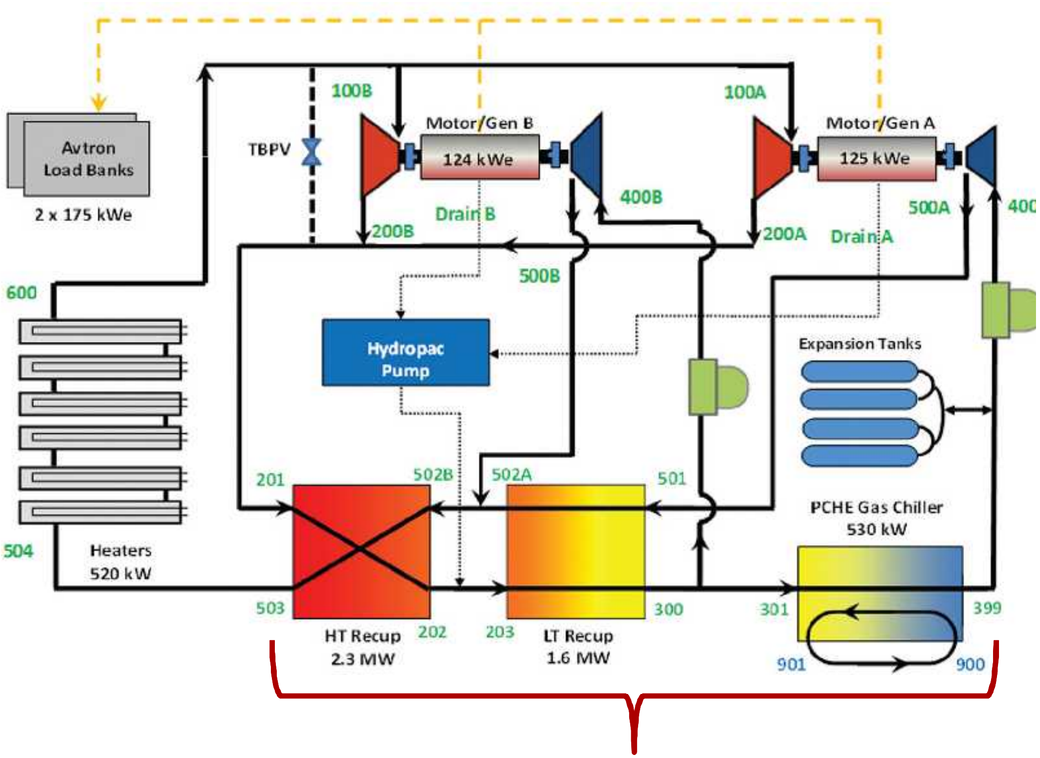
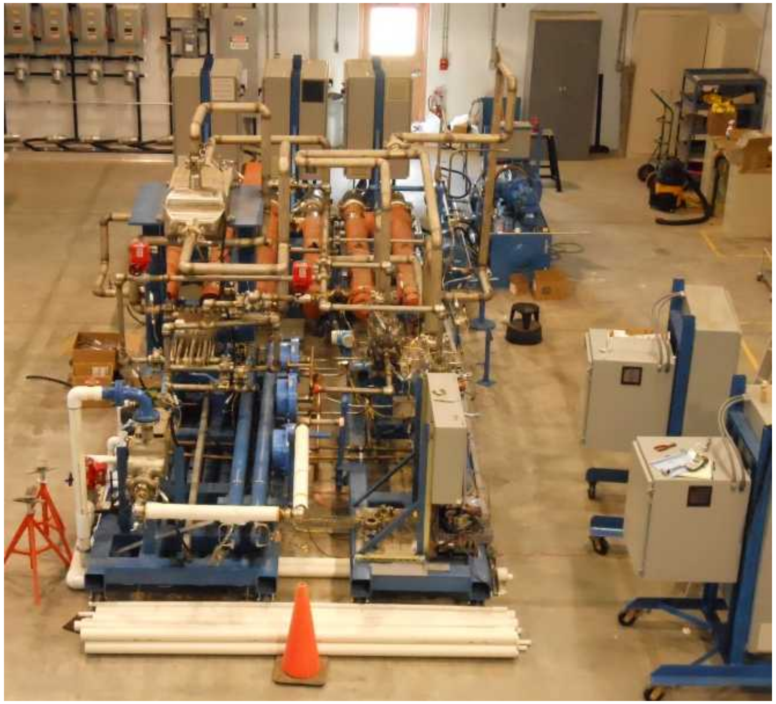
Leading the development of a game-changing technology

SCO_2 Recompression Brayton Cycle (RCBC)

- SCO_2 is a highly recuperative cycle: projected capital costs expect 50% of cycle cost due to heat exchangers
- Two recuperators, one chiller, and one primary heat exchanger



PCHE style units



Materials developments are key to the SCO_2 Brayton cycle

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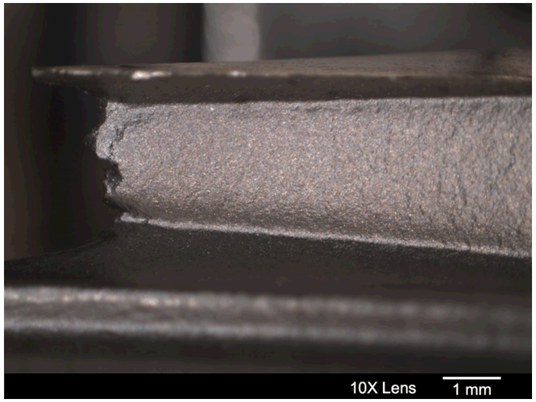
Fouling Mechanisms and Potential Impacts

Type	Examples	Potential SCO2 Brayton Impacts
Precipitation	Salt Scale (H2O) Oil Transport (CO2)	1. Decreased heat exchanger performance. 2. Cleaning / replacement of heat exchangers. 3. Local thermodynamic property variation.
Particulate	Fabrication Shavings	1. Erosion of surfaces and sharp corners. 2. Sedimentation of piping, headers. 3. Plugging of heat exchanger channels.
Chemical Reaction	Coking	1. Reduced heat exchanger performance 2. Localized hot-spots from high emissivity.
Corrosion	Oxide Formation	1. Reduction of material thickness. 2. Spallation of weak oxide layers. 3. Reduced heat exchanger performance.
Solidification	Vent Line Freeze-up	1. Blockage of vent lines and over-pressurization of other system components. 2. Mechanical failure due to cold temperatures. 3. Stuck mechanisms from material shrinkage.



Establishing SCO_2 materials testing capabilities at Sandia

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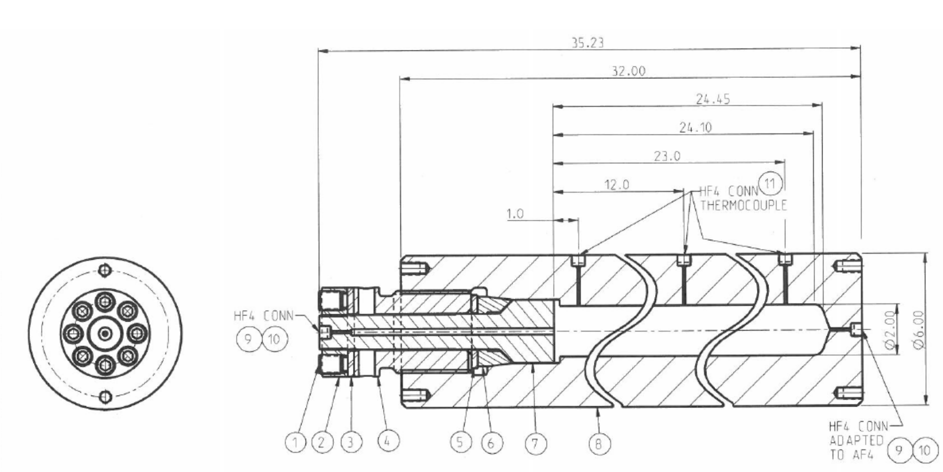
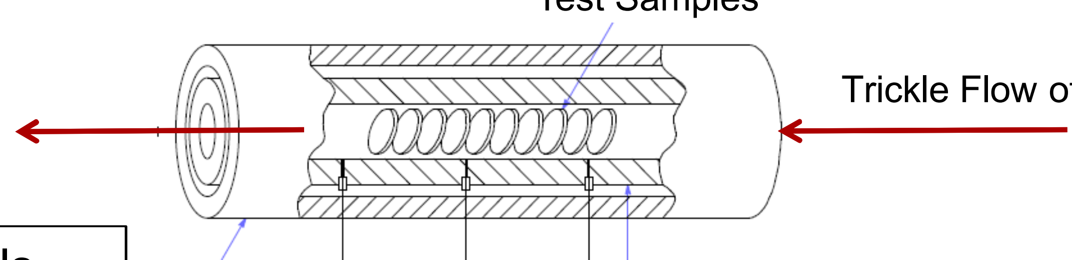
SCO_2 Materials Test Facility



- Test Volume size: 2”x 24” (cylinder)
- Up to 650°C, 3500psi
- CO_2 currently, also other fluids possible



Facility used to test materials performance over operational range of system requirements.

Determining suitability of mild steel for the Brayton cycle

Materials and Test Exposure

Per the Power Piping code (ASTM 31.1):

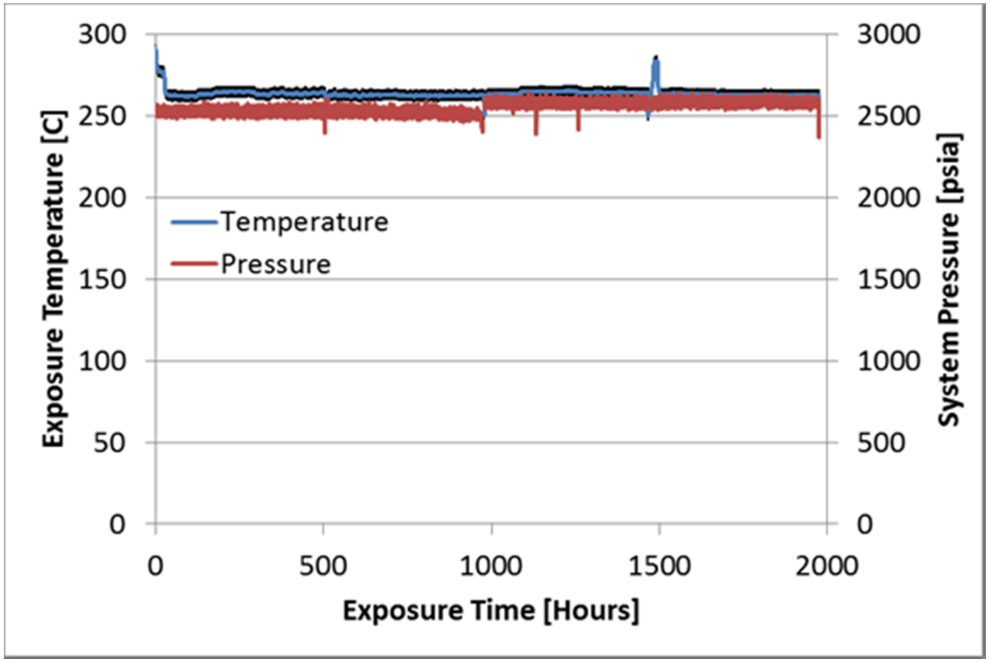
- X65Q
- A53, A106, and API-5L
- Seamless Low-Carbon Alloy
- Limited to 427°C (code indication carbide phase may be converted to graphite.

Fe	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Ti	Nb
Bal	0.15	0.97	0.012	0.003	0.18	0.09	0.05	0.07	0.11	0.31	0.034	0.0003	0.003	0.002

Samples were removed at:

- 506 hours
- 995 hours
- 1481 hours
- 1984 hours

Exposure was 263±3°C
2550±35 psia

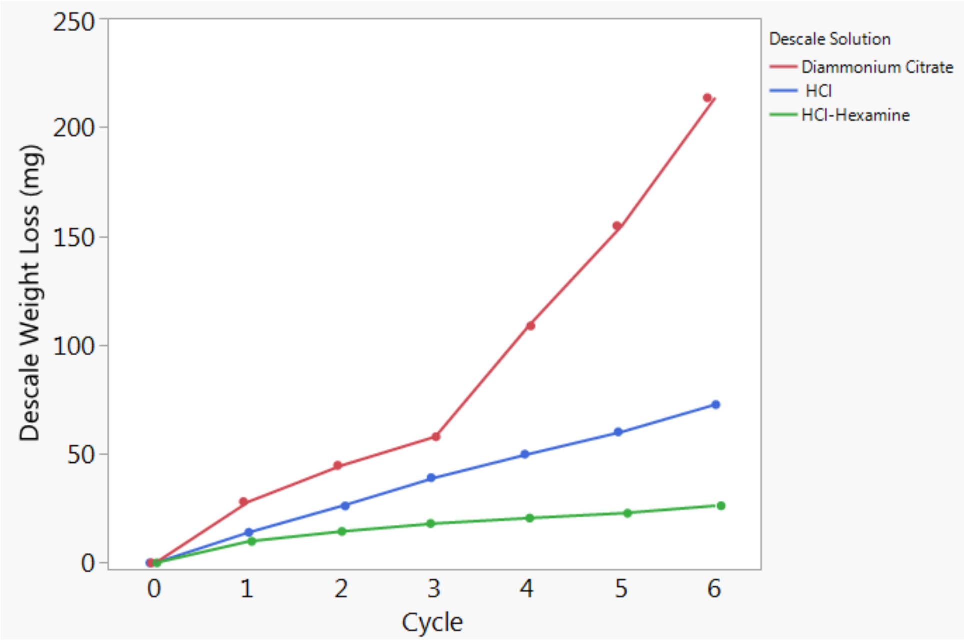


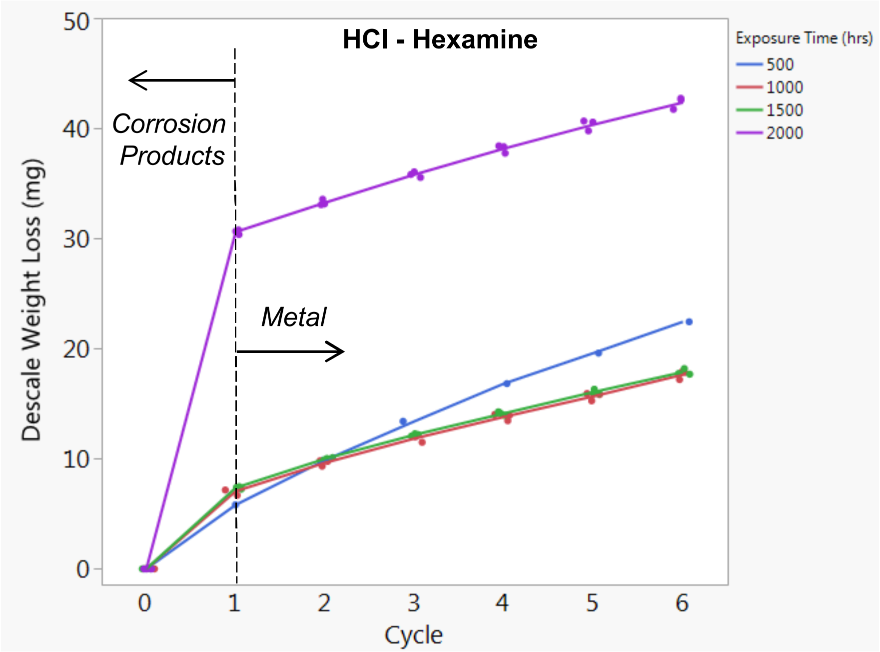
Two approaches for determining extent of corrosion

Corrosion Measurements

- Post-exposure sample weight gain measurements
- Measuring corrosion products through descale chemical treatment
  - Three descale solutions evaluated (ASTM G1-03)

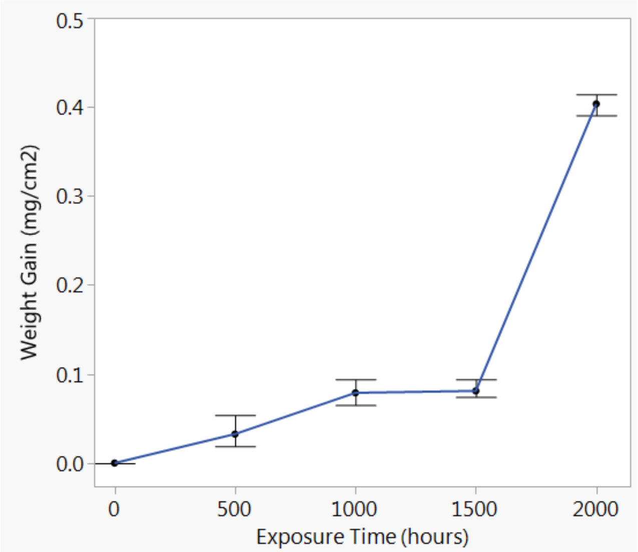
Solution	Solution Temp (°C)	Cycles	Cycle Duration (min)
6M HCl (21 wt %)	20-25	6	10
6M HCl (21 wt %) + Hexamethylene tetramine (0.3 wt %)	20-25	6	10
Diammonium Citrate (20 wt %)	75-90	6	10

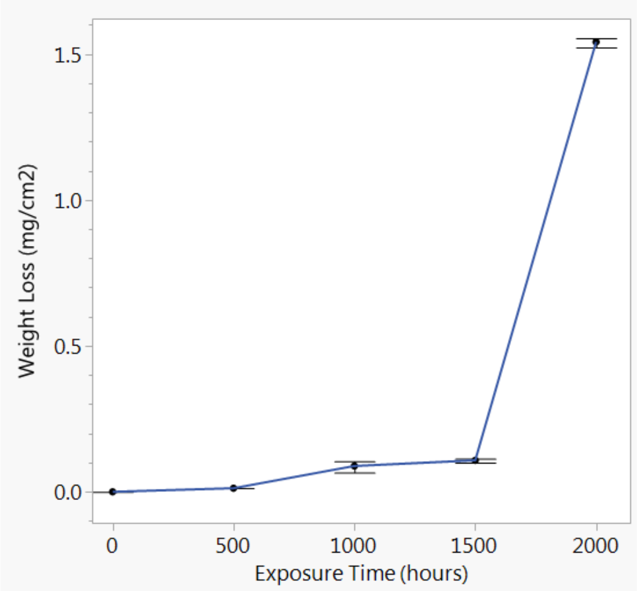


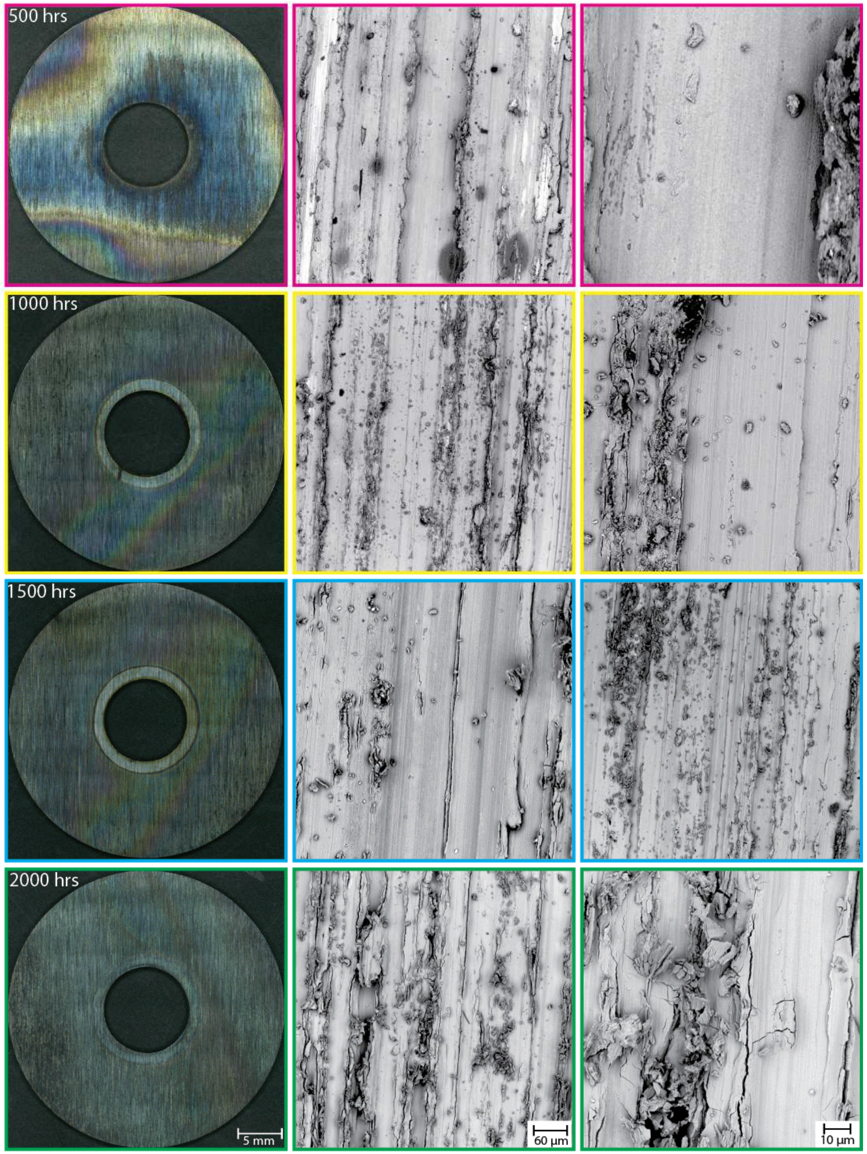


Consistent trend among the measurement approaches

Sample Corrosion Versus SCO_2 Exposure Time

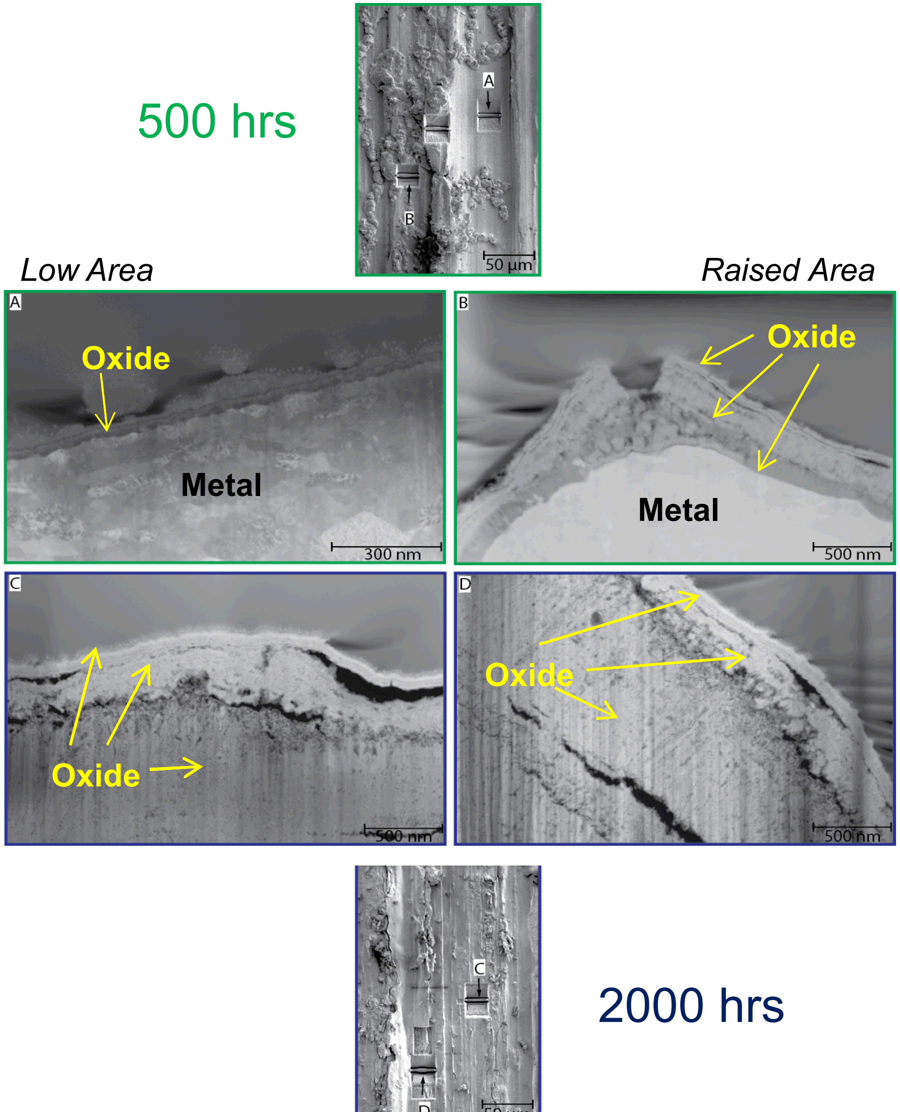


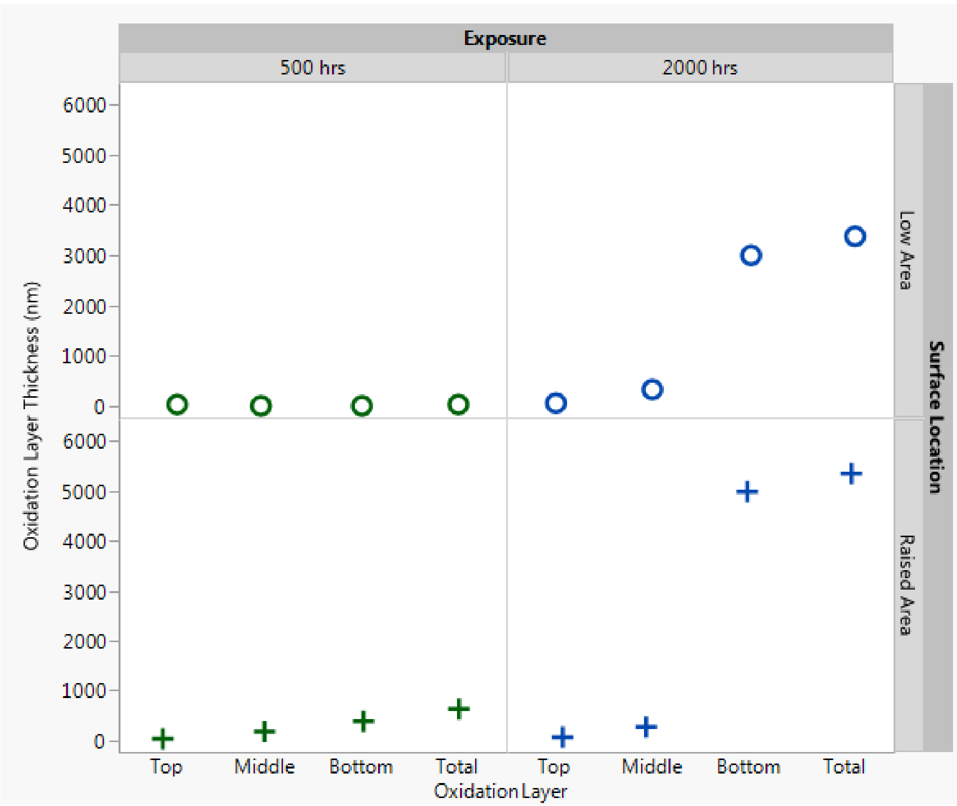




Internal Oxide Layer Growth --> Increased Corrosion Rate

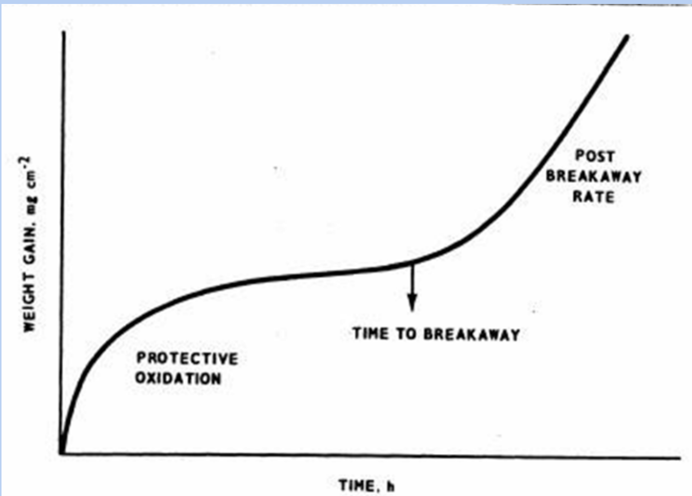
Oxidation Layer Thickness and Morphology versus SCO_2 Exposure Time





Results consistent with mild steel corrosion in CO_2

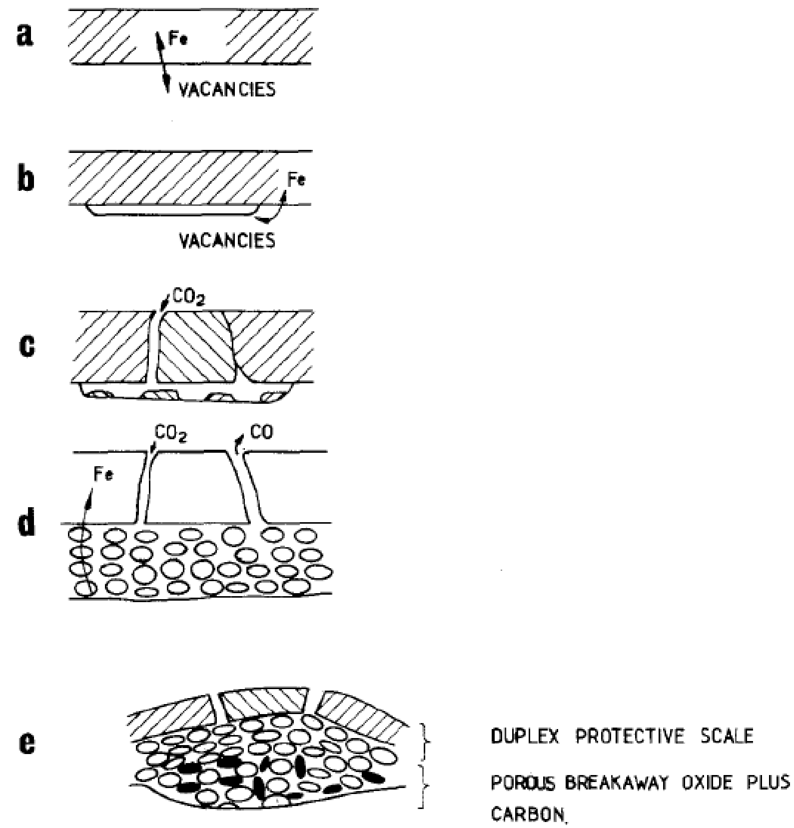
Behavior of Mild Steel during CO_2 Exposure



J. Ferguson, B.N.E.S. International Conference on Corrosion of Steels in CO_2, September 1974.

$$3Fe + 4CO_2 = Fe_3O_4 + 4CO$$

$$2CO = CO_2 + C$$

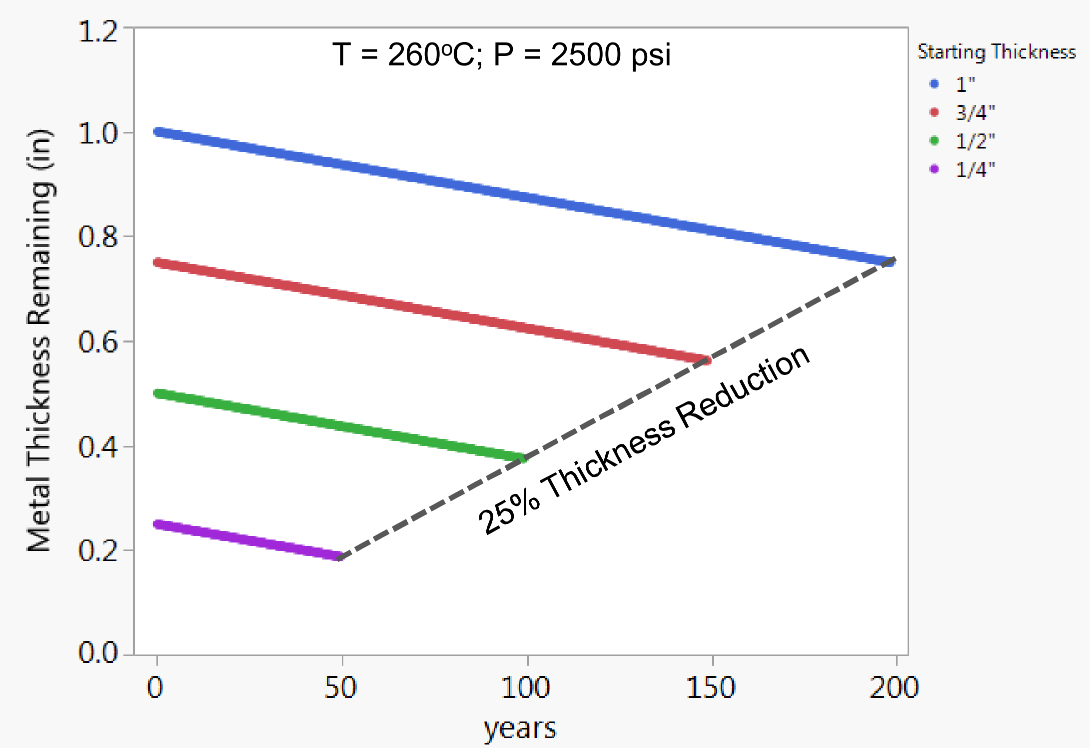


G. Gibbs, Oxidation of Metals, Vol. 7, No. 3, 1973

Low corrosion rate merits consideration in SCO_2 systems

Summary of Results

- Weight loss data used to determine:
  - Time to breakaway ~ 1500 hrs
  - Post-Breakaway Corrosion Rate: 0.032 mm/year (1.25 mils/year)
- Applicability of mild steel for components in SCO_2 Brayton cycles



Advancing materials development in SCO_2 environments

Path Forward

- Conclude this study with analysis of oxidation layer chemistry and carbon concentration
- Future Work will focus on SCO_2 Gas Chemistry
  - Rapid methods of screening corrosion effects to determine appropriate component materials
  - Most past work has focused at higher temperatures/pressures
  - SNL is working to develop in-house rapid materials screening as a function of temperature/pressure/fluid chemistry

Questions?