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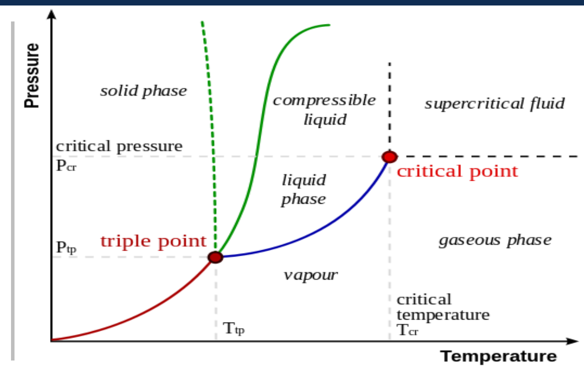

Supercritical CO_2 Heat Exchanger Fouling

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

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Outline

1. Introduction
   a) Relative efficiency numbers for SCO2
   b) Fouling mechanisms

2. Observed fouling in SCO2

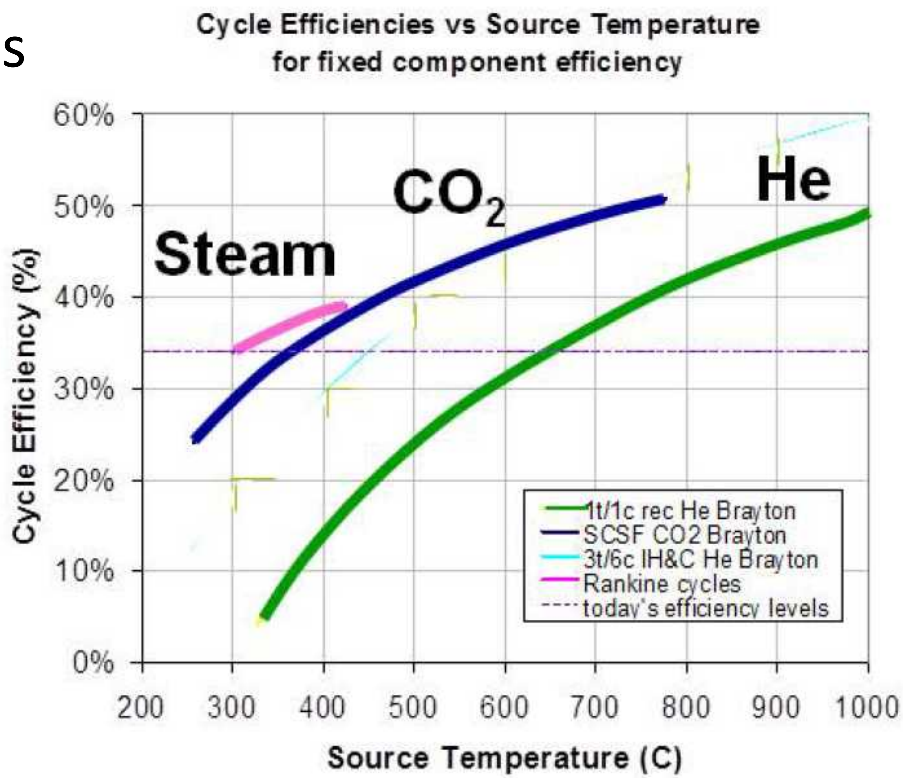
3. Analysis and Discussion

4. Conclusion

5. Path Forward

The Case for SCO_2

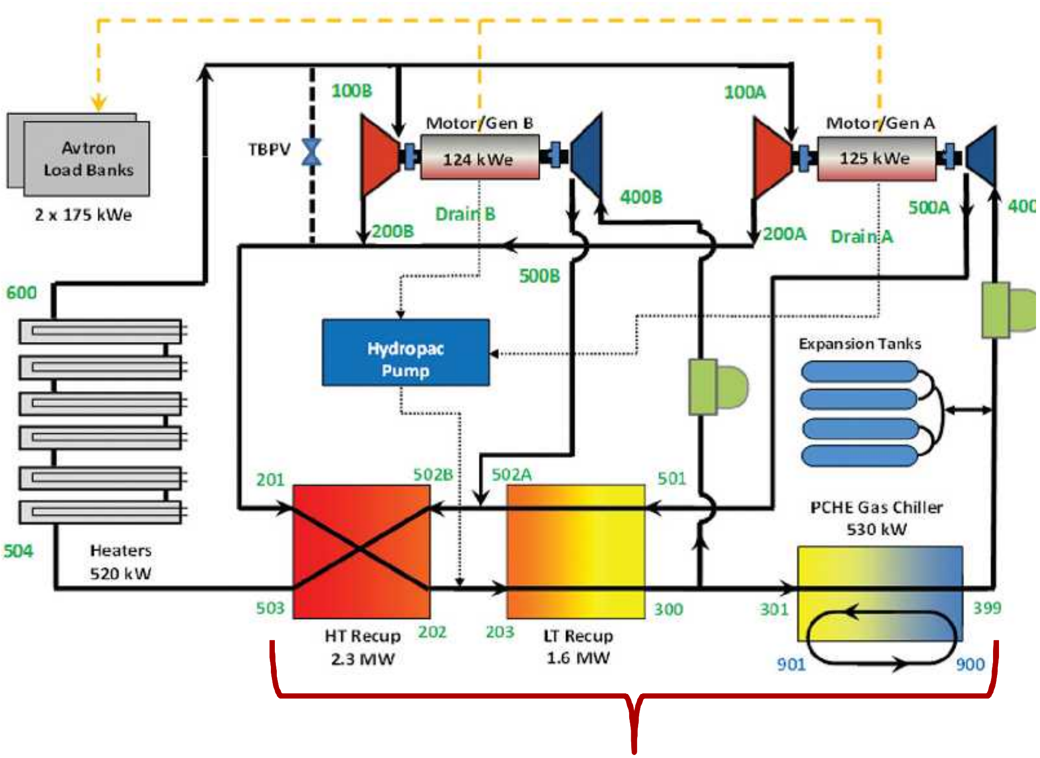
- SCO_2 has potential to surpass optimized steam cycles in cycle efficiency.
- Difference in efficiency is projected to be nearly 10%
- 9.5¢/kW-hr (average cost in 2012) →7.3 ¢/kW-hr



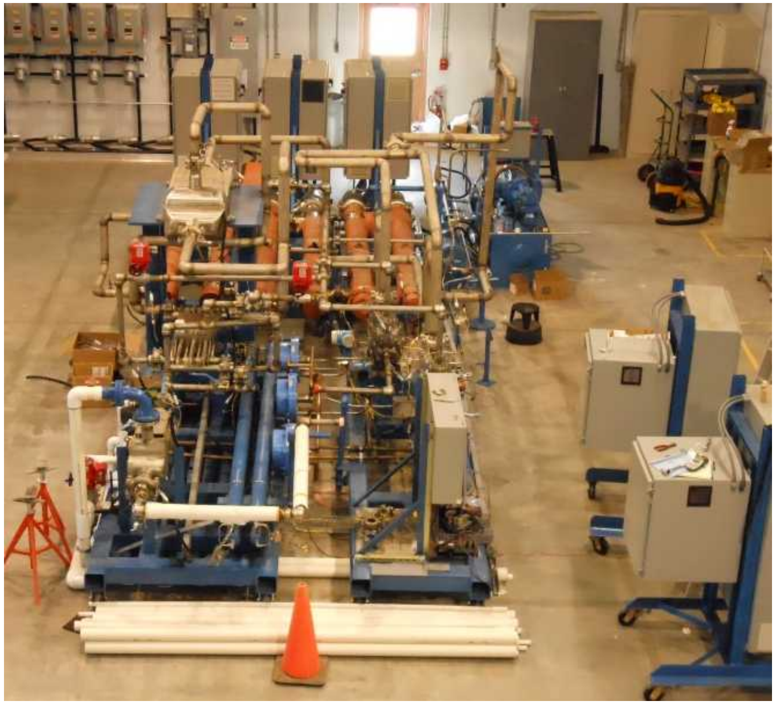
EIA website: accessed April 2014: http://www.eia.gov/oiaf/aeo/

SCO_2 Recompression Brayton Cycle (RCBC)

- SCO_2 is a highly recuperative cycle: projected capital costs expect 50-80% of cycle cost due to heat exchangers
- Two recuperators, one chiller, and one primary heat exchanger



PCHE style units



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.

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More of this data has recently become available for a variety of conditions (temperatures, pressures) and alloys (Ferritic-Martensitic, Austenitic, and Nickel alloys) :

University of Wisconsin (Tan, Roman, Cao, Firouzdor), CEA (Rouillard), and others

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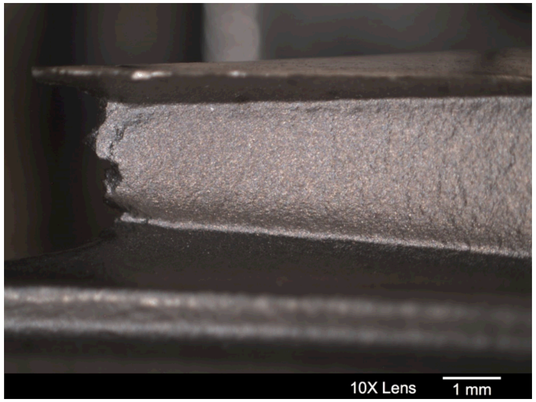

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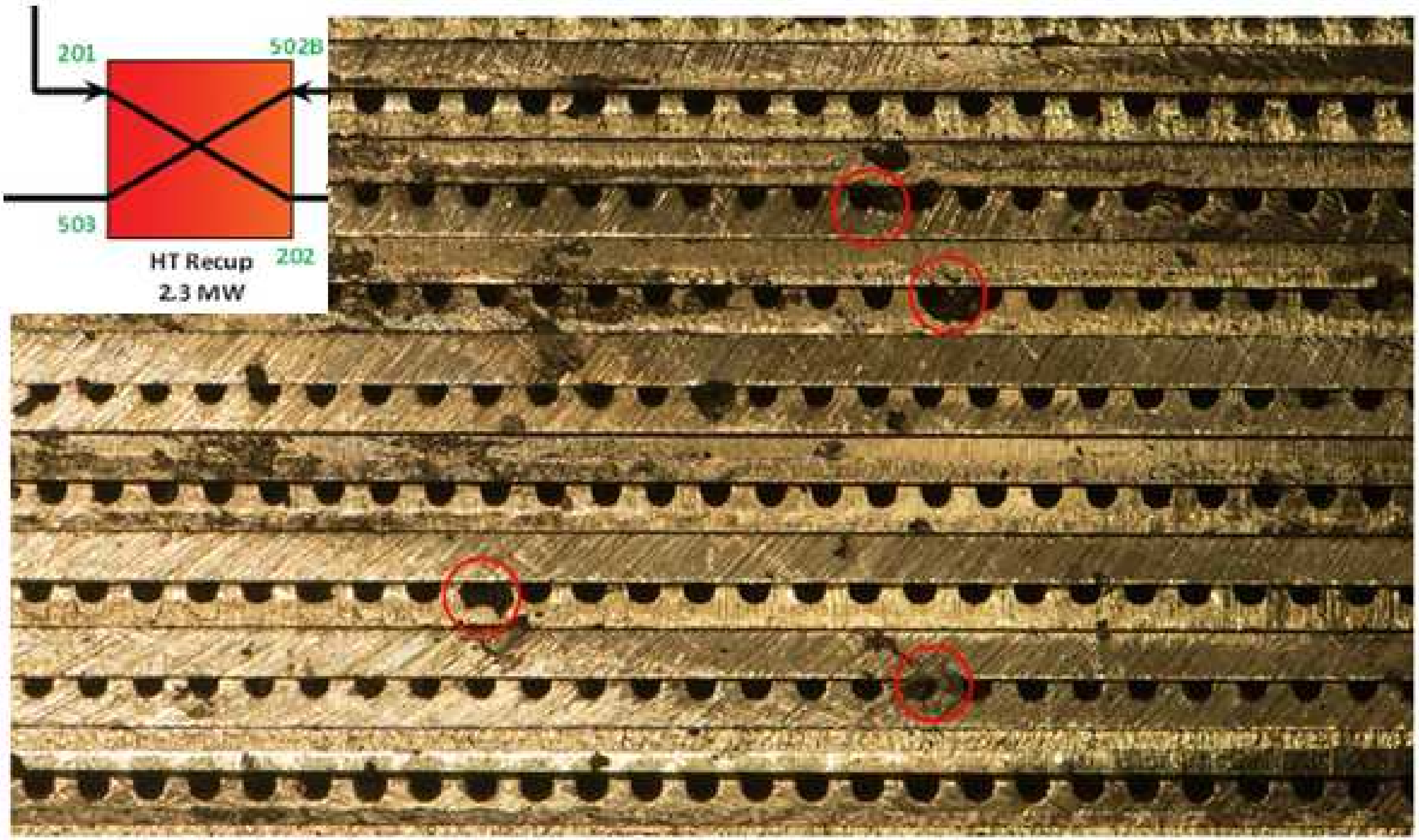
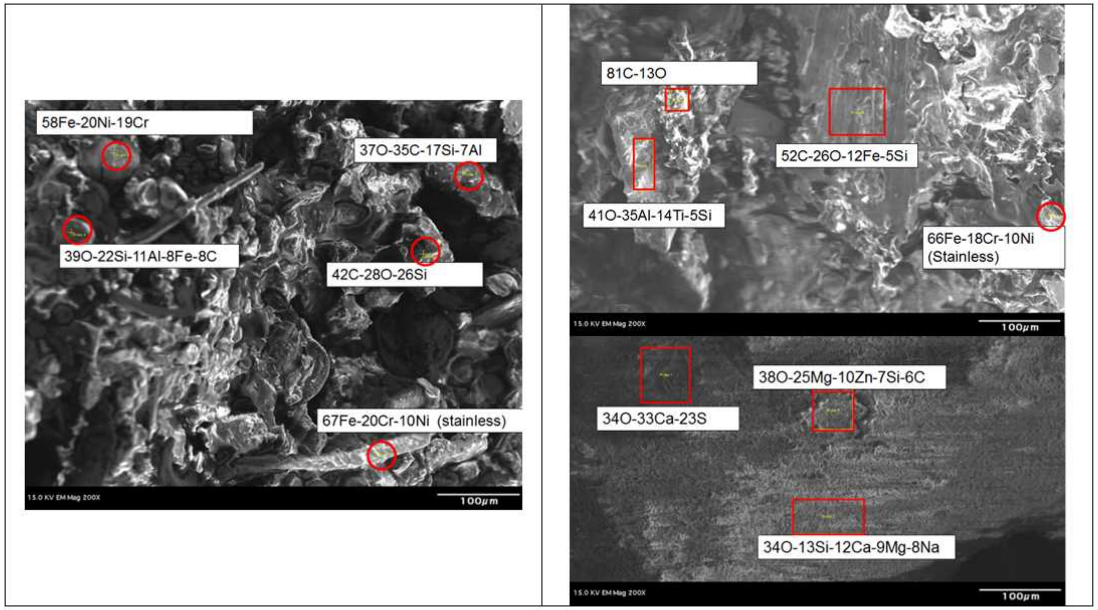
Precipitation: SCO_2 Inlet Fouling

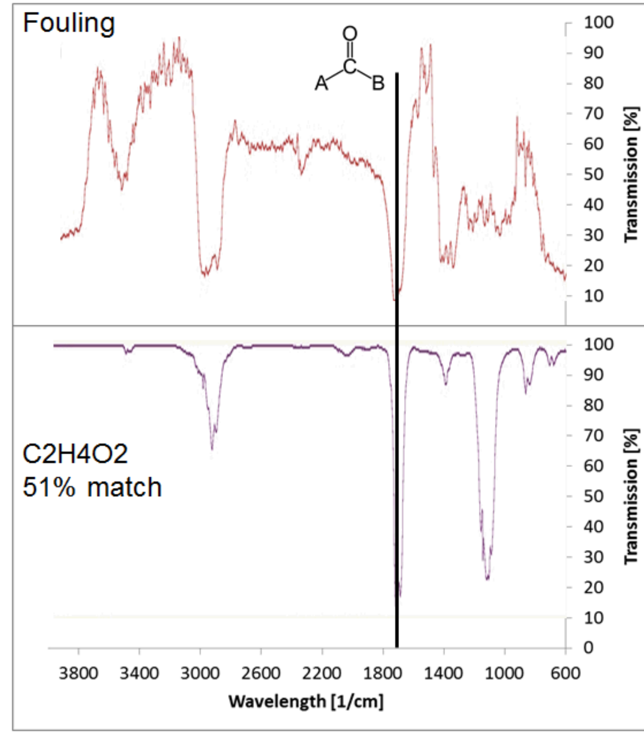


High pressure, low/intermediate temperature inlet (502B)

Product analysis

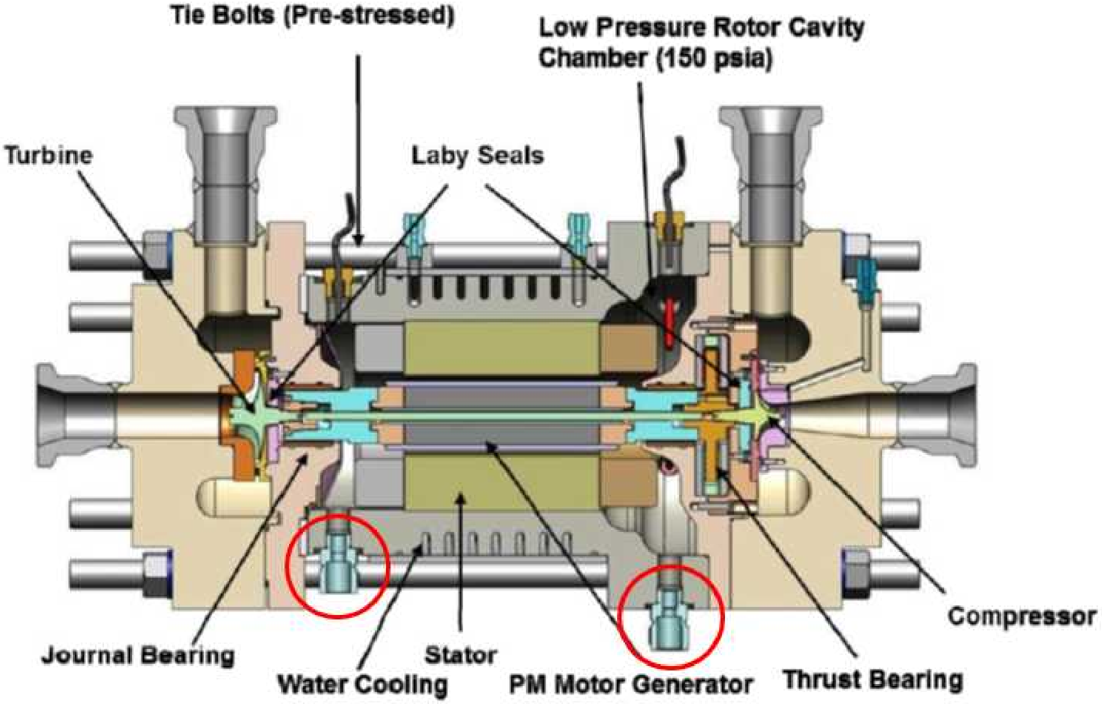


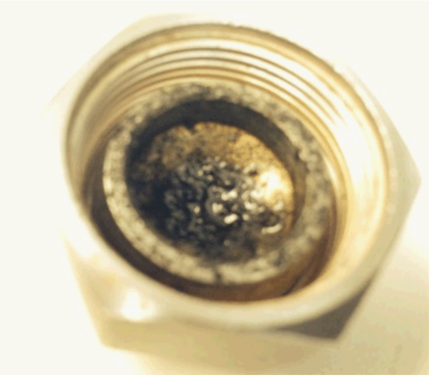
- SEM analysis indicates dirt, stainless steel, and carbon-based products.
- Turbomachinery have experienced erosion; heat exchangers due to small size behave as a filter for products



- Clear hydrocarbon match using FT-IR.
- Oil-free components and pumps were used to ward-off hydrocarbon fouling

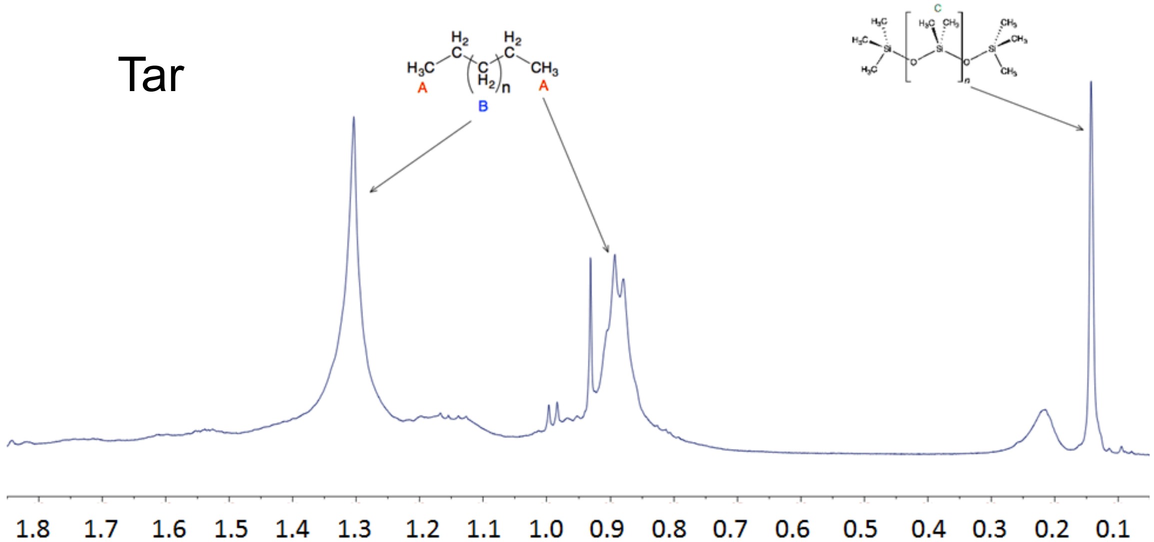
Turbine-alternator-compressor (TAC)





- Lower pressure cavities within the TAC are perfect place for saturated solutions to crash out
- Gram-sized samples were found in drain cavities

Tar Analysis

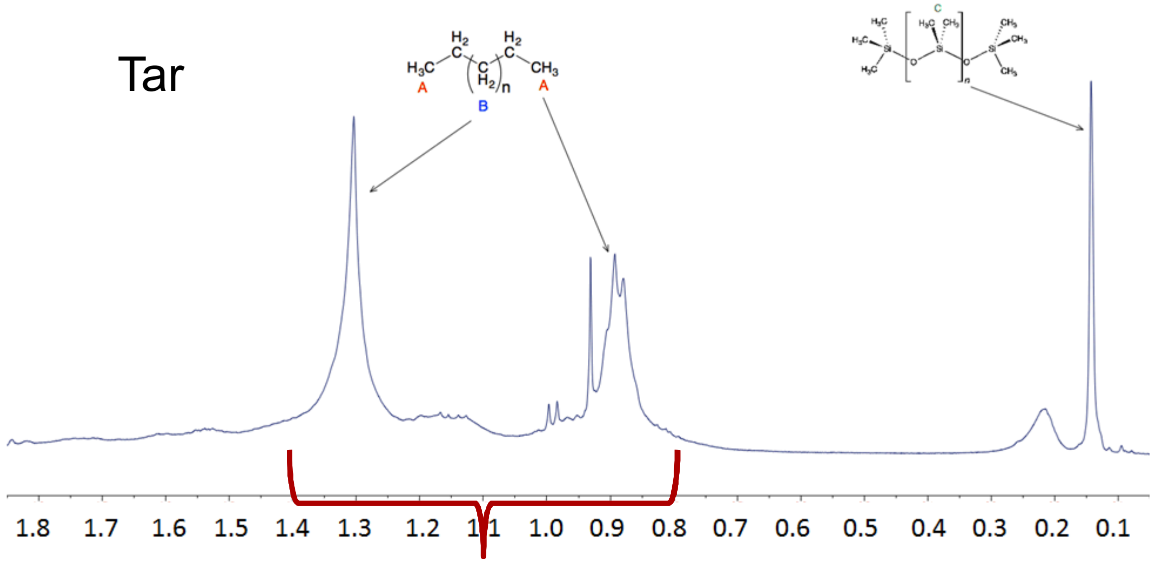


Analysis:

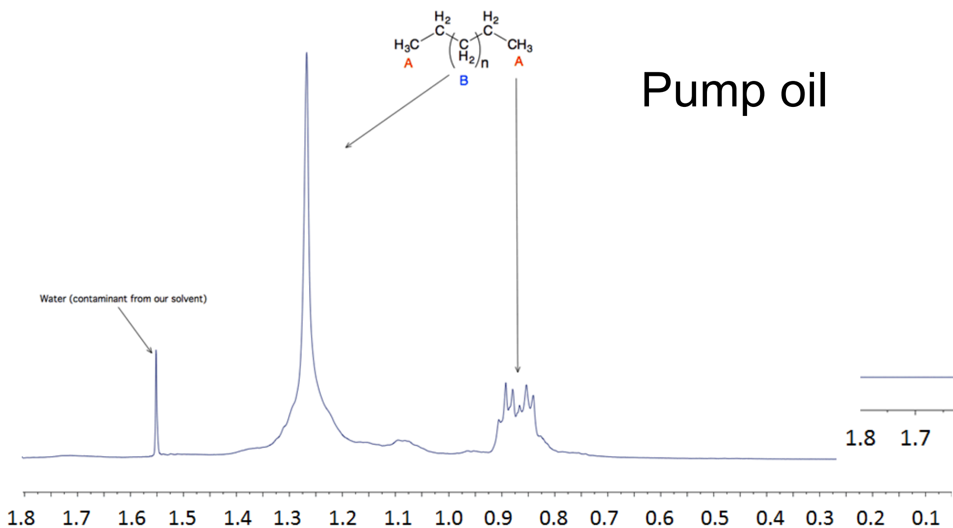
- Sequentially exposed to organic solvents: hexane, diethyl ether, toluene, acetone, dimethylformamide, and dimethylsulfoxide
- Nuclear Magnetic Resonance Spectroscopy (NMR): hexane solution was evaporated leaving behind colorless oily residue.

Tar Analysis

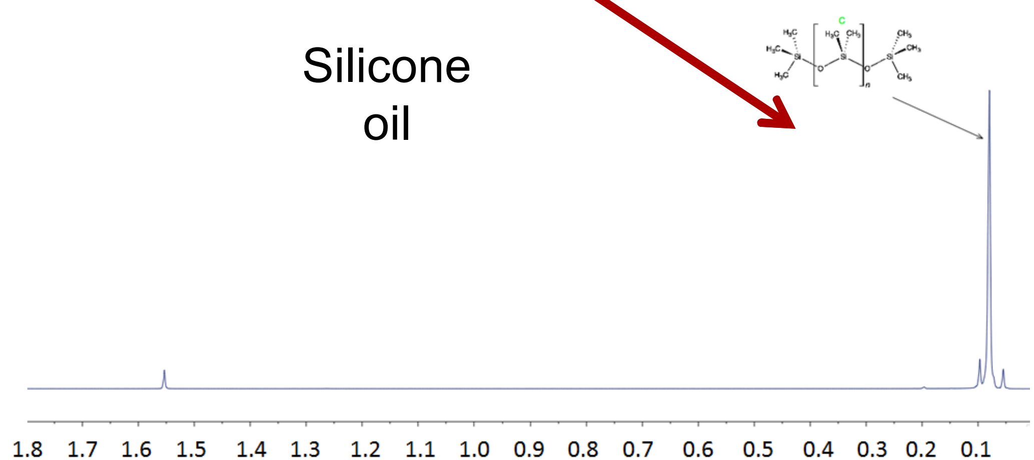
Tar



Pump oil



Silicone oil



Take away thoughts

- Cleaning procedure of piping/components/wetted surfaces
  - Historically it has been an alcohol wipe until clean
  - Use of solvents such as hexane will be pursued
- Purity of CO_2
  - 99.85% grade CO_2 has been used in the past
  - 99.95% grade CO_2 is being used currently, but there are still concerns over impurity content
  - Based on the number of fills and tests, hydrocarbon impurity of 5ppm would contribute 22 grams over RCBC lifetime.

Conclusion

- Observed inlet fouling was observed on PCHE units
  - Mixtures of stainless steel, dirt, and hydrocarbon
- Accumulation of a oil (hydrocarbon and silicone) was found in the turbine-alternator-compressor shaft cavity
- Products accumulate relatively quickly; tens to hundreds of hours
- Source of products are unclear, but could be due to inadequate cleaning of wetted surfaces and impurities from gas bottles.

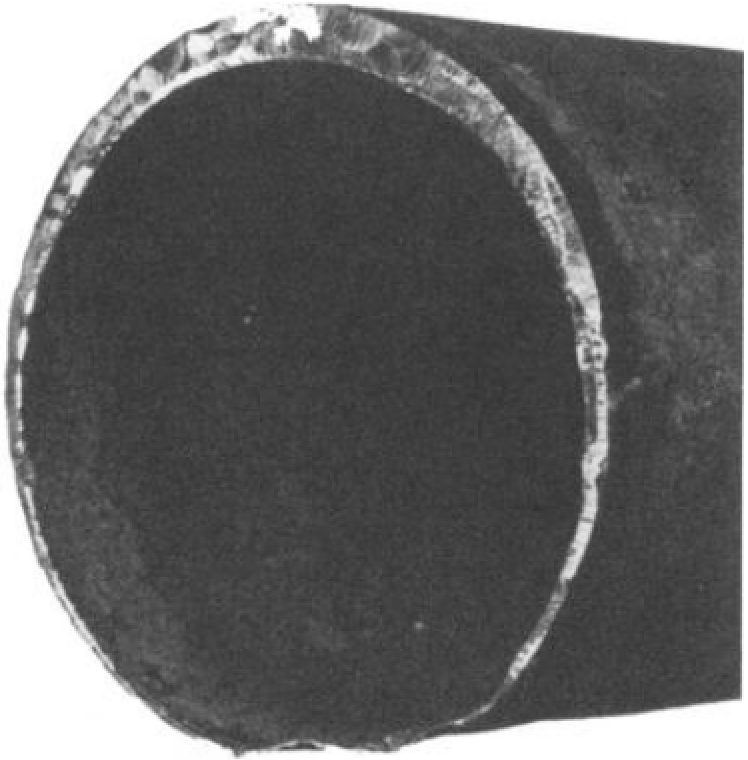
Questions as we look forward

- Best O&M practice for PCHEs if plugging/fouling continues?[1]
  - Hydraulic: water cleaning, high pressure water blasting, ultrasonic cleaning?
  - Abrasive: rodding, drilling, sandblasting, pigging and scraping, turbining?
  - Thermal: steam cleaning?
- What is the “Right” CO_2 chemistry?
  - Likely an optimally determined balance of materials needs between the heat exchangers and turbomachinery.
  - Over time this will evolve as more operating experience is gained.

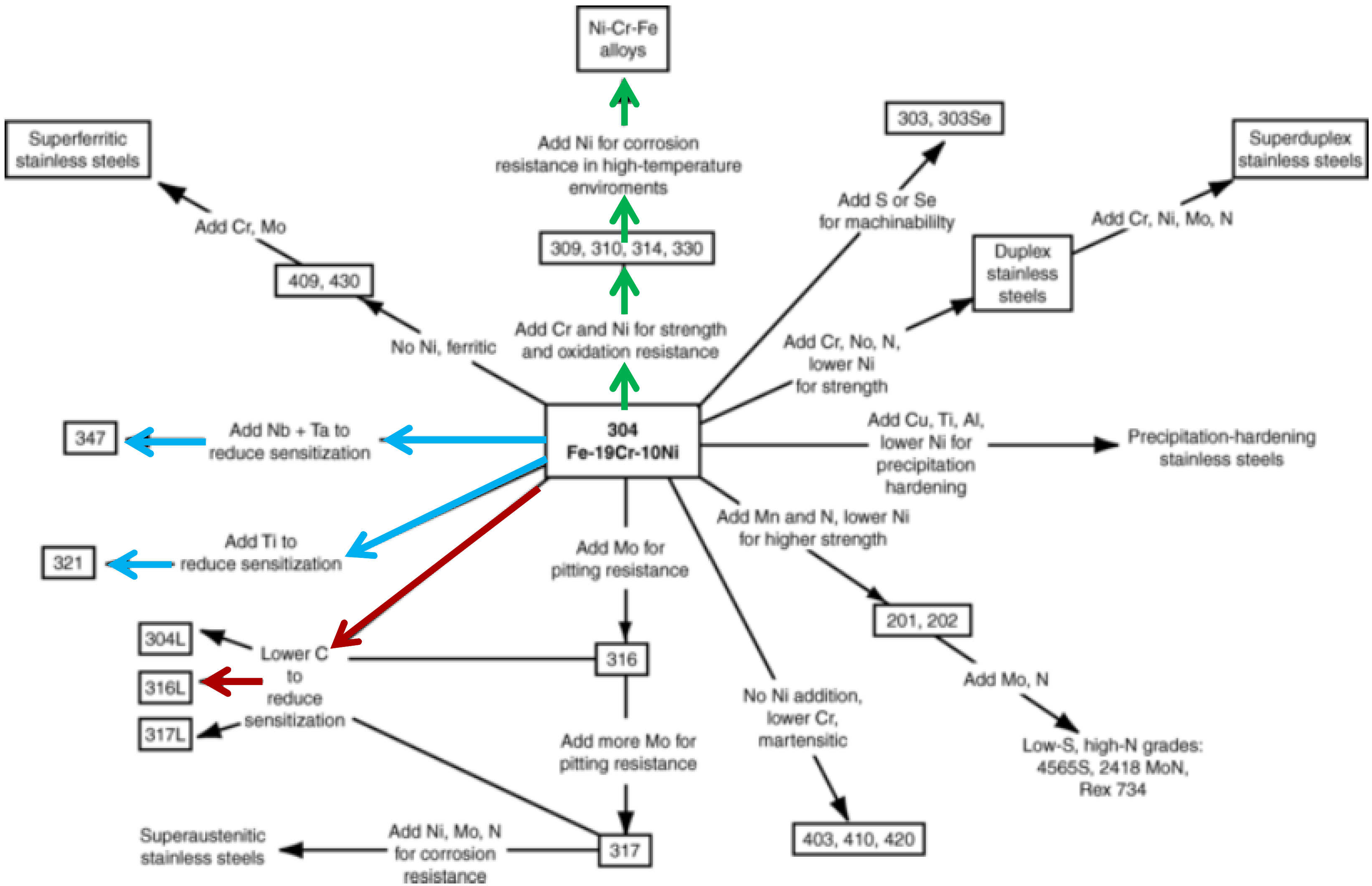
Questions?

Heat Exchanger Fouling and Cleaning

- Fouling and Cleaning is always a hot topic in Rankine plants.

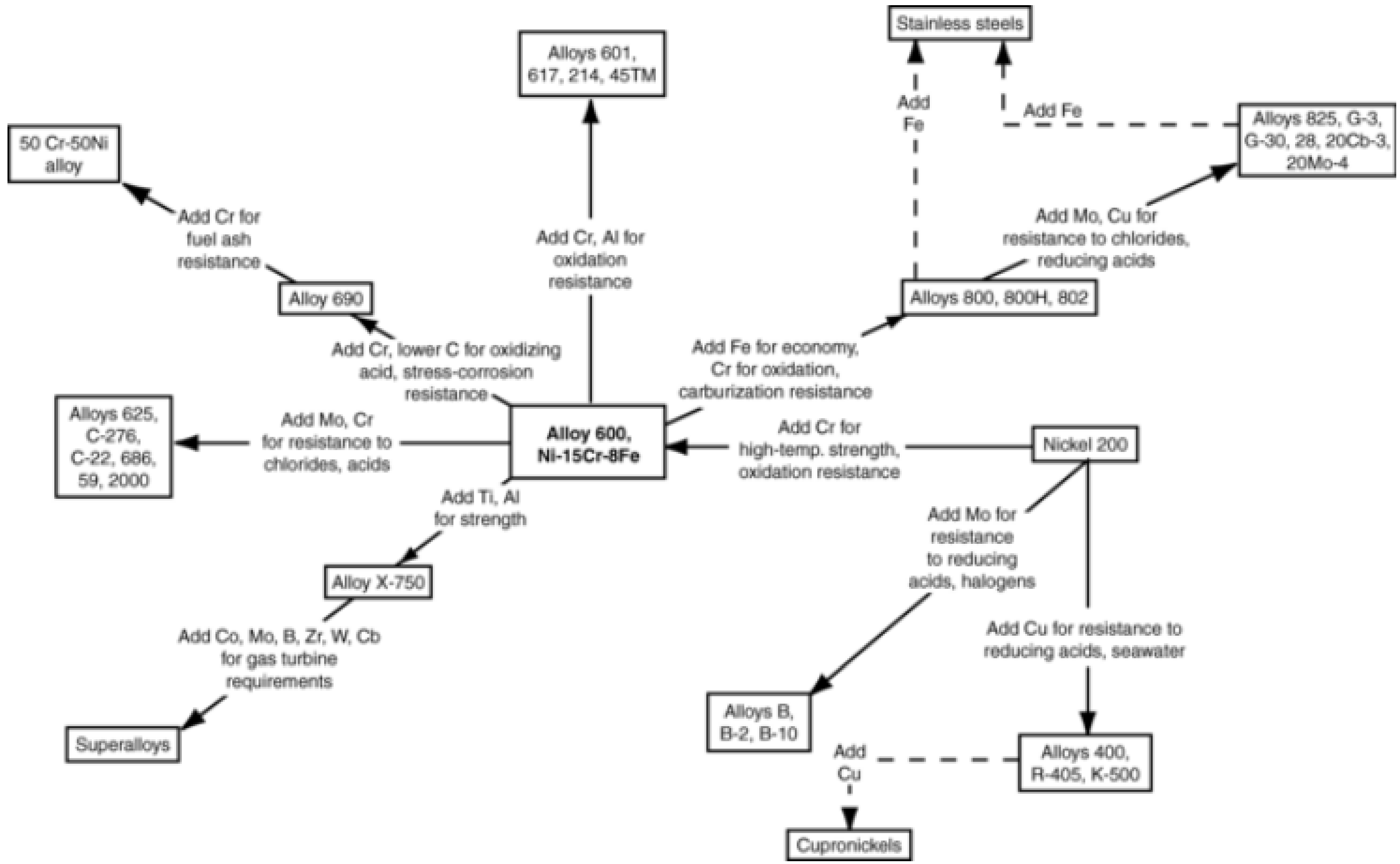


Stainless Steel Selection



Asm International, H. C. (1990). ASM handbook. Materials Park, OH, ASM International.

Corrosion Resistance of Nickel Alloys



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