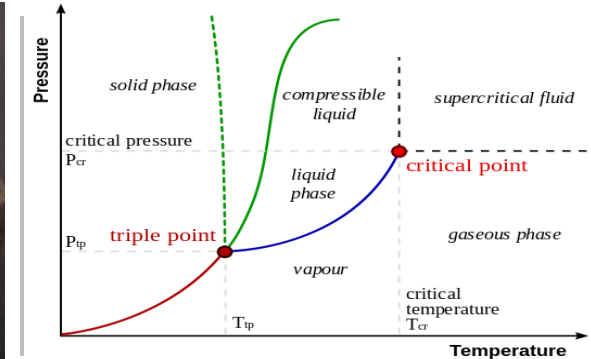
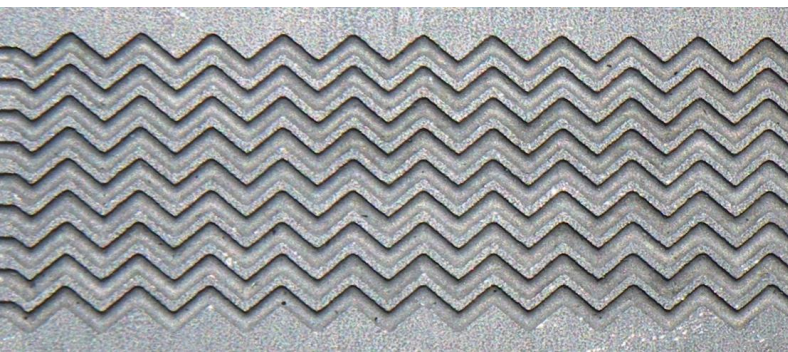


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## Supercritical CO<sub>2</sub> Heat Exchanger Fouling

Alan Kruizenga, Darryn Fleming,  
Matthew Carlson, Mitchell Anstey



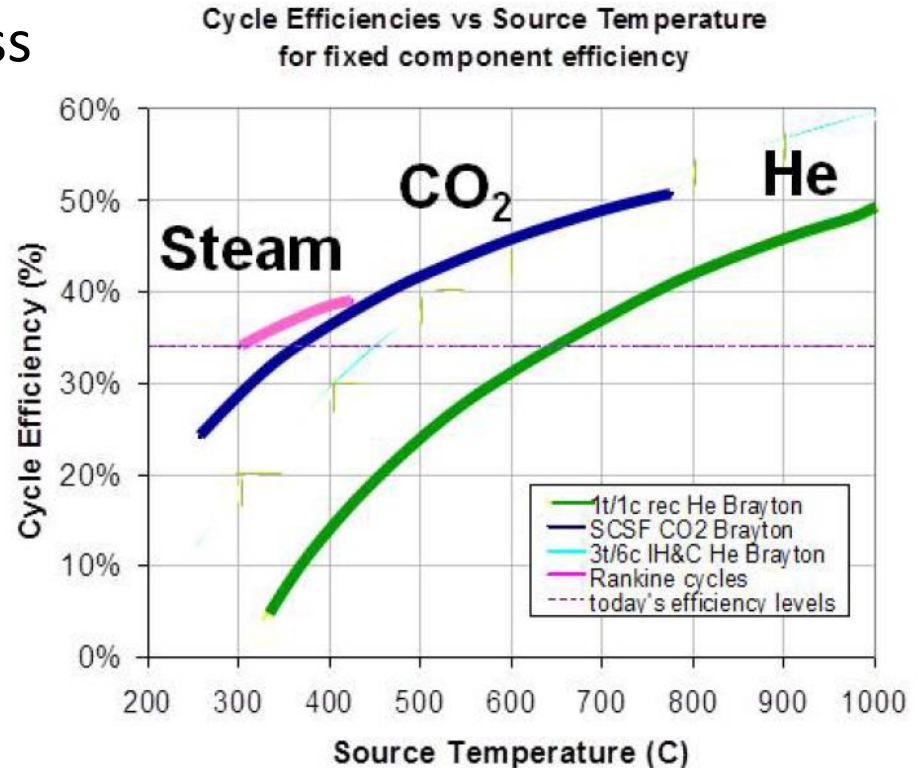
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# Outline

1. Introduction
  - a) Relative efficiency numbers for SCO<sub>2</sub>
  - b) Fouling mechanisms
2. Observed fouling in SCO<sub>2</sub>
3. Analysis and Discussion
4. Conclusion
5. Path Forward

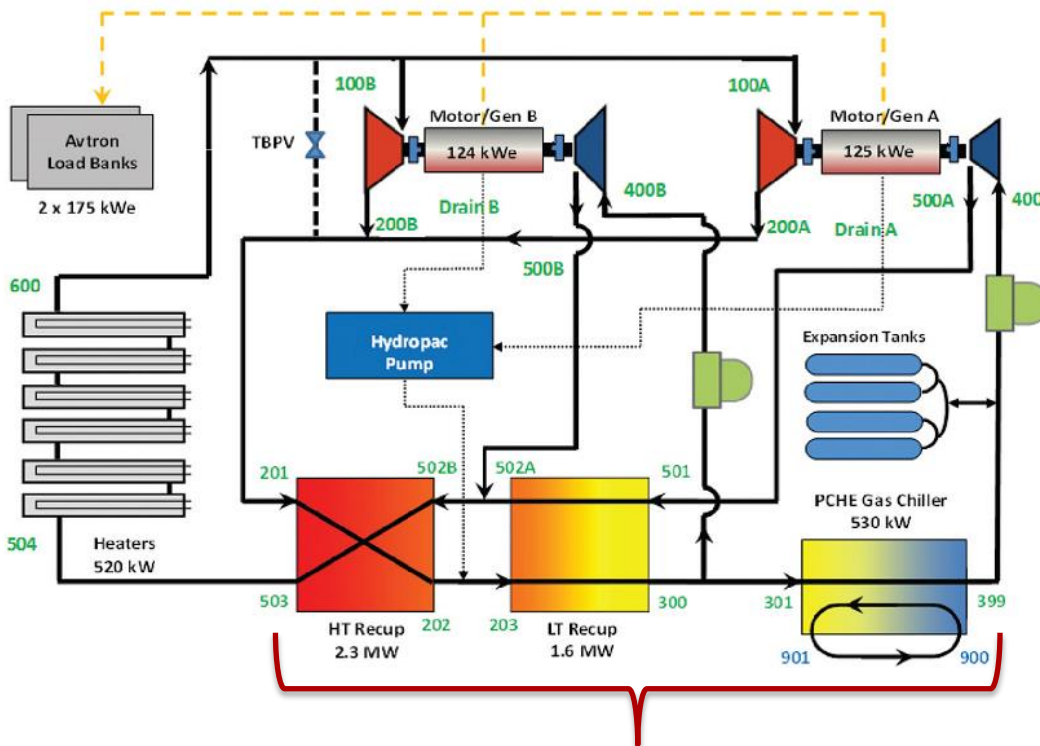
# The Case for $\text{SCO}_2$

- $\text{SCO}_2$  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)  $\rightarrow$  7.3 ¢/kW-hr



# SCO<sub>2</sub> Recompression Brayton Cycle (RCBC)

- SCO<sub>2</sub> 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

# Fouling Mechanisms and potential impacts

Type	Examples	Potential SCO <sub>2</sub> Brayton Impacts
Precipitation	Salt Scale (H <sub>2</sub> O) Oil Transport (CO <sub>2</sub> )	<ol style="list-style-type: none"> <li>1. Decreased heat exchanger performance.</li> <li>2. Cleaning / replacement of heat exchangers.</li> <li>3. Local thermodynamic property variation.</li> </ol>
Particulate	Fabrication Shavings	<ol style="list-style-type: none"> <li>1. Erosion of surfaces and sharp corners.</li> <li>2. Sedimentation of piping, headers.</li> <li>3. Plugging of heat exchanger channels.</li> </ol>
Chemical Reaction	Coking	<ol style="list-style-type: none"> <li>1. Reduced heat exchanger performance</li> <li>2. Localized hot-spots from high emissivity.</li> </ol>
Corrosion	Oxide Formation	<ol style="list-style-type: none"> <li>1. Reduction of material thickness.</li> <li>2. Spallation of weak oxide layers.</li> <li>3. Reduced heat exchanger performance.</li> </ol>
Solidification	Vent Line Freeze-up	<ol style="list-style-type: none"> <li>1. Blockage of vent lines and over-pressurization of other system components.</li> <li>2. Mechanical failure due to cold temperatures.</li> <li>3. Stuck mechanisms from material shrinkage.</li> </ol>



# Fouling Mechanisms and potential impacts

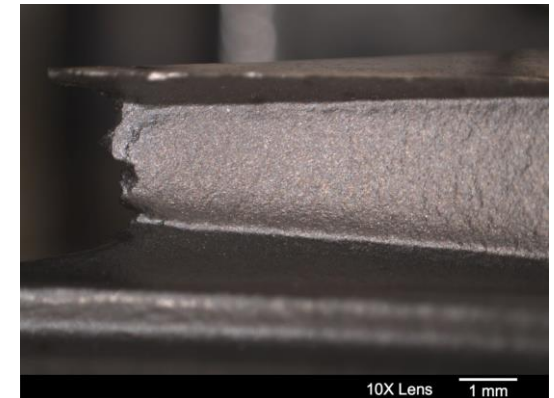
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More of this data has recently become available for a variety of conditions (temperatures, pressures) and alloys (Ferritic-Martensitic, Austenitic, and Nickel alloys) :

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

# Fouling Mechanisms and potential impacts

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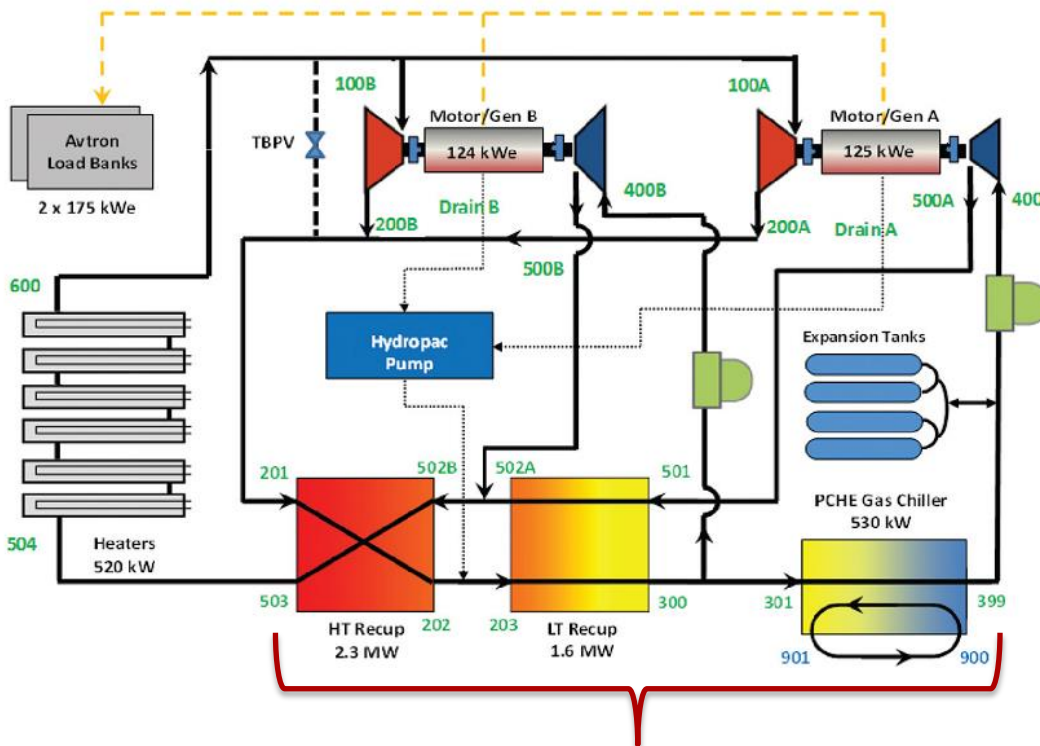
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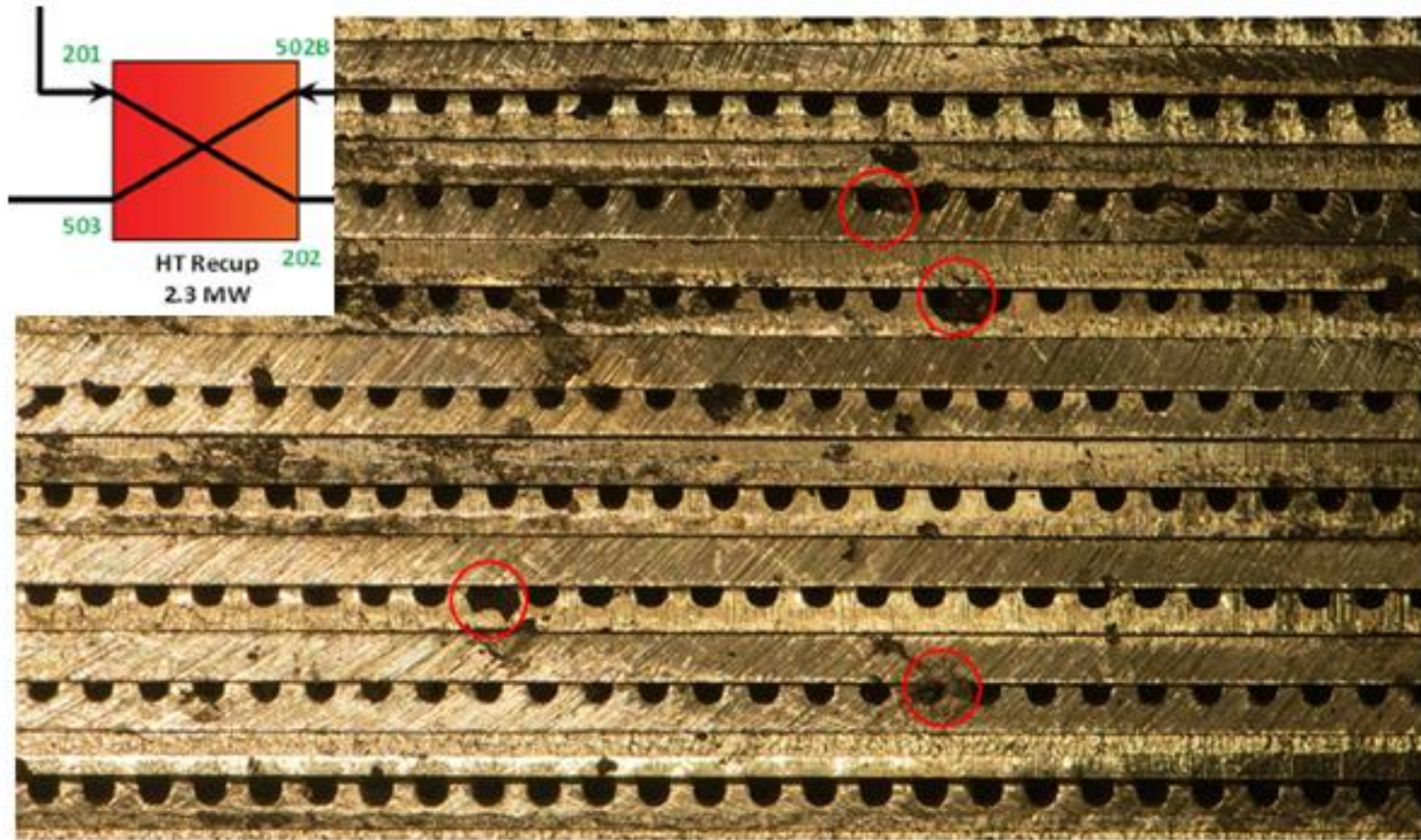
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PCHE style units

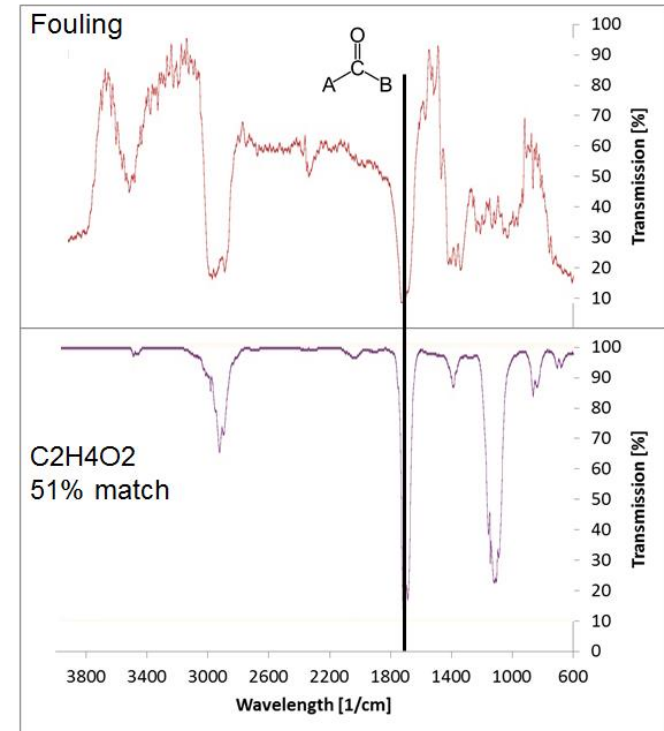
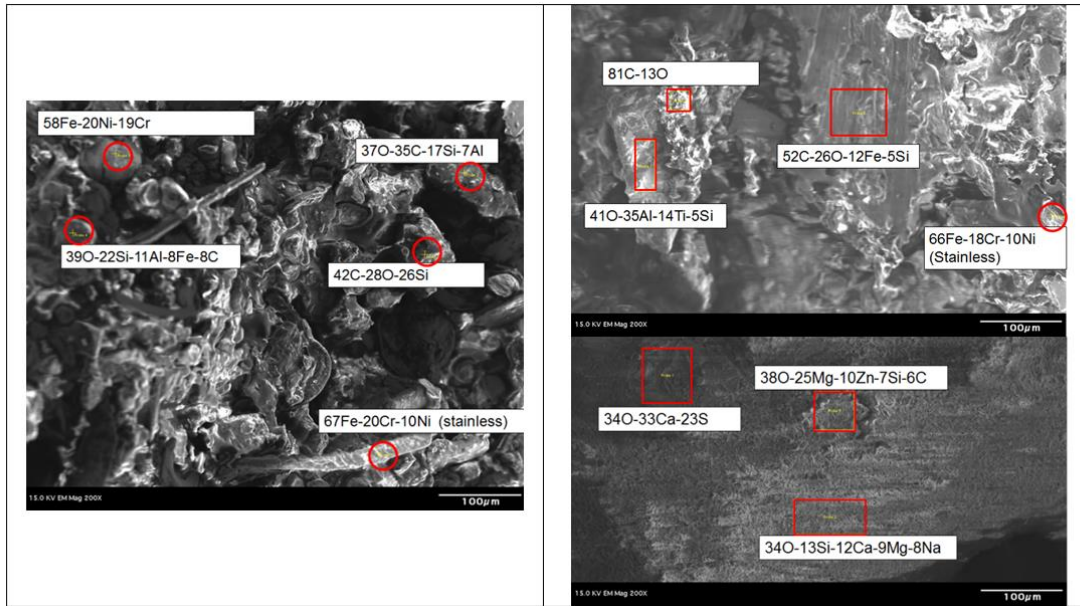
# Precipitation: $\text{SCO}_2$ Inlet Fouling



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



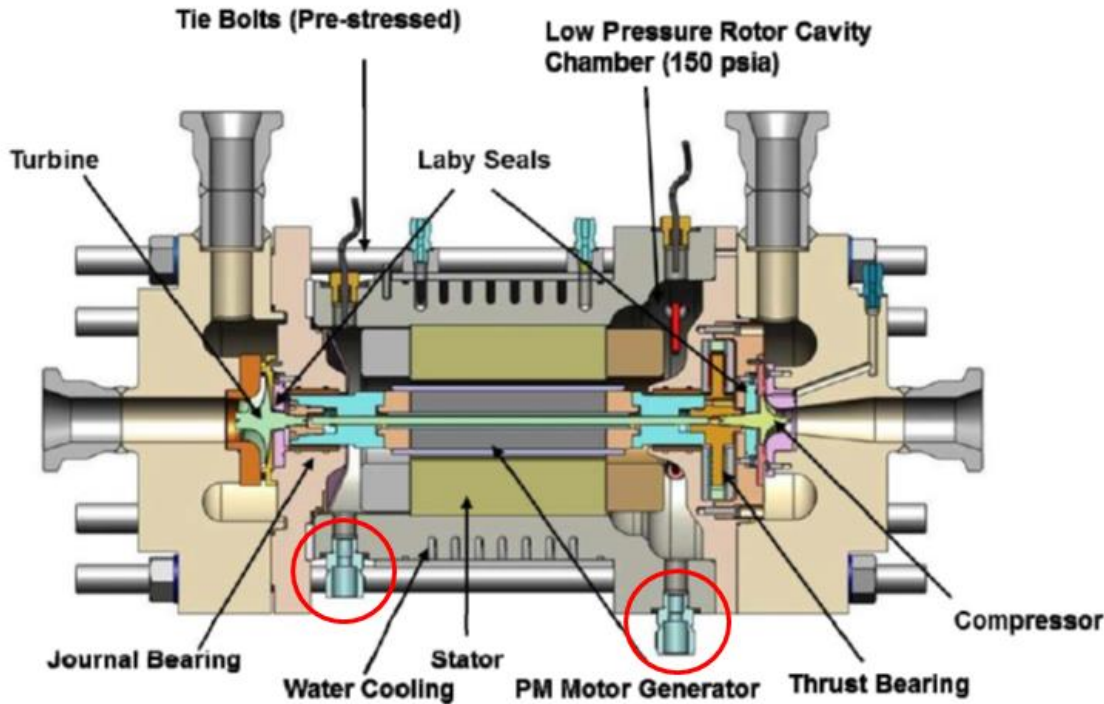
# Product analysis



- 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

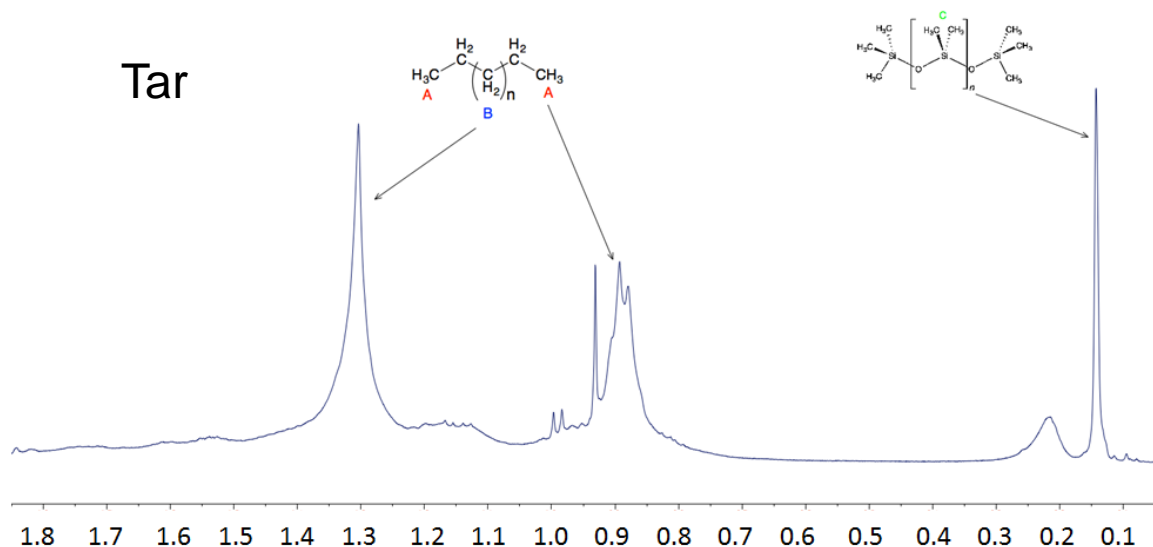
# Turbine-alternator-compressor (TAC)



- 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.





# 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<sub>2</sub>
  - 99.85% grade CO<sub>2</sub> has been used in the past
  - 99.95% grade CO<sub>2</sub> 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?<sup>1</sup>
  - Hydraulic: water cleaning, high pressure water blasting, ultrasonic cleaning?
  - Abrasive: rodding, drilling, sandblasting, pigging and scraping, turbinning?
  - Thermal: steam cleaning?
- What is the “Right” CO<sub>2</sub> 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?