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Development of a Prototypical Compact Heat Exchanger Test Apparatus within a Supercritical CO_2 Brayton Cycle

Raytheon Technologies
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U.S. DEPARTMENT OF ENERGY
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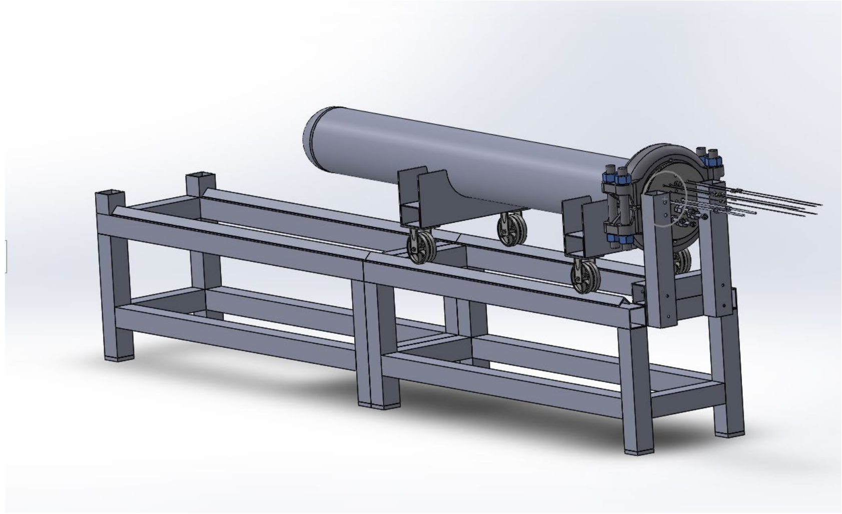
Project Introduction

Compact Heat Exchanger Performance Testing

- Partnership with Raytheon Technologies Research Corporation (RTRC) under ARPA-E HITEMMP Program
  - Topology optimization of compact heat exchangers
    - Sub-scale 10 kW and full-scale 50 kW modular HX
    - Modular form factor for deployment up to 250 kW HX (5x 50 kW)
  - Additive manufactured HX with Haynes 282 superalloy capable of operation at 800˚C and 3600 psi for >10,000 hours
  - Targeted sCO2 Compact HX State of the Art
    - 50 kW/m^3 (including core and header)
    - 15.1 kW/kg (sub-scale 10 kW HX)
- UW-Madison Thermal Hydraulics Laboratory to conduct performance characterization of additively manufactured compact heat exchanger(s)
- Developing a test apparatus for use within $WisCO_2$ Loop to operate at required conditions and record heat transfer and friction factor data

Test Rig Design for Raytheon HX Testing

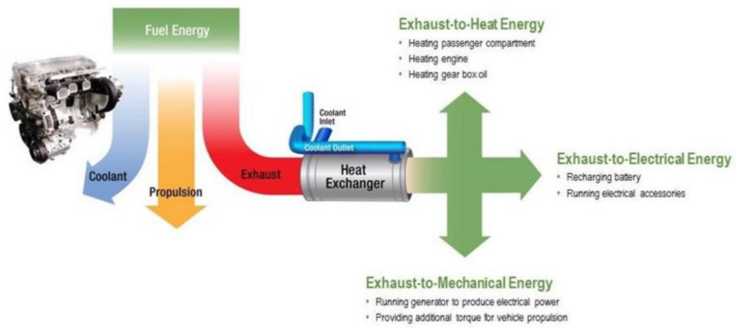


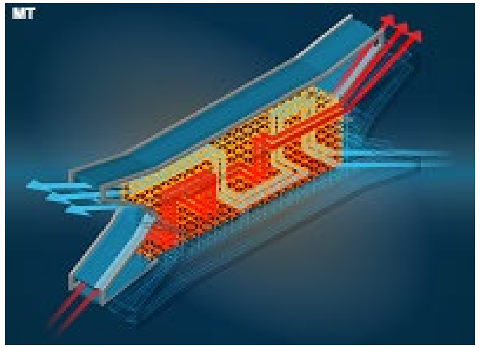
Existing WisCO2 Cart

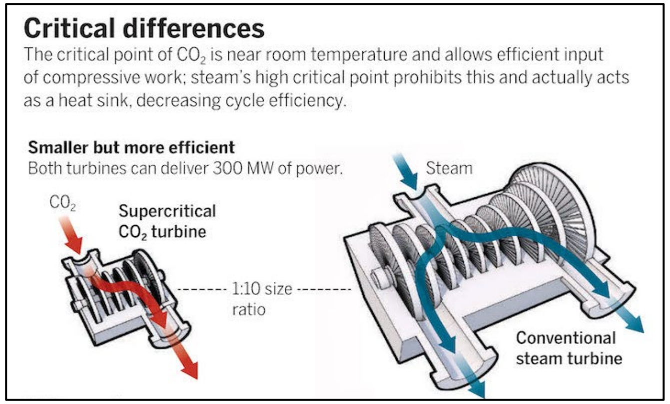
Applications

RTRC sCO2 Compact Heat Exchanger Use-Cases

1. Jet Engine Waste Heat Recovery
   - Turbine exhaust heat recovered in HX for heating of aircraft cabin, preheating hydraulic oil and combustion gases
2. Auxiliary Power Unit (APU)
   - Turbine exhaust gas utilized in sCO2 Brayton cycle for on-board electrical generation
     - Minimizing turbomachinery (HX) weight, volume, manufacturing cost, and pressure drop (Fanning friction factor) while maximizing heat transfer (UA and Colburn j-factor) and fuel savings
     - Haynes 282 Nickel Alloy offers superior allowable stress at elevated operating temperatures
     - Reducing aircraft Specific Fuel Consumption, capital cost/size, and CO2/NOx emissions



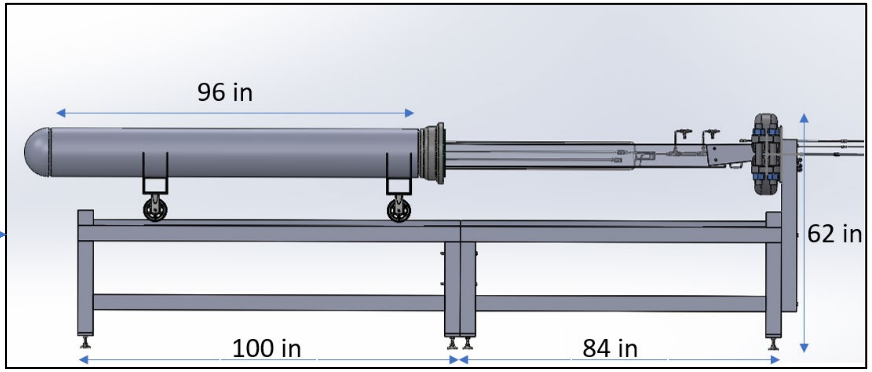




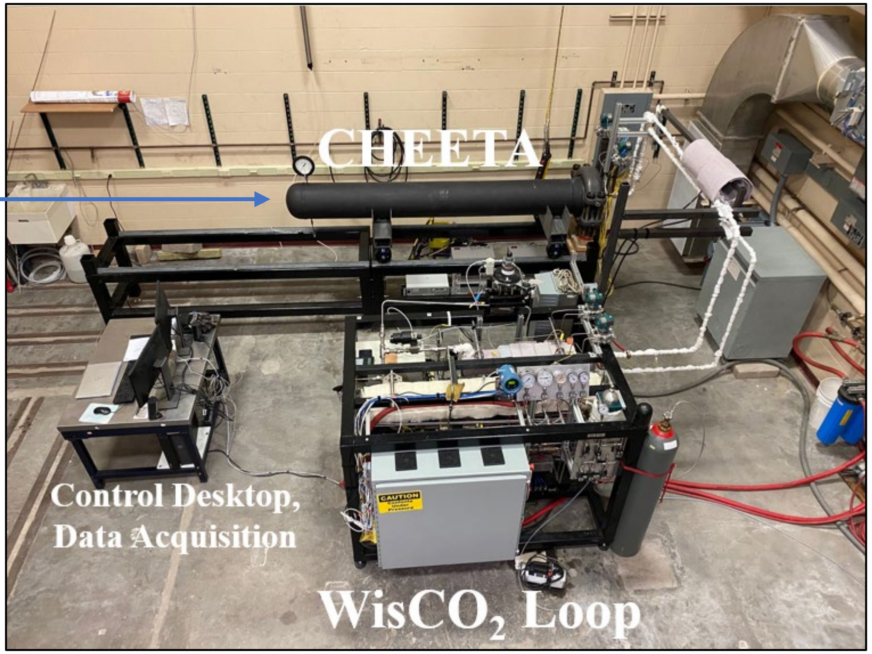
[1] L. Irwin, Y. Le Moullec, Turbines can use CO2 to cut CO2, Science (80-.). 356 (2017) 805–806. https://doi.org/10.1126/science.aam8281.

Objectives

- Testing and characterization of compact heat exchangers at relevant temperatures and pressures required the fabrication of the Compact Heat Exchanger Experimental Test Apparatus (CHEETA) at UW-Madison capable of operation exceeding 800 C and 3600 psi



- This new apparatus, incorporated with the $WISCO_2$ Loop enables performance characterization of additively manufactured, diffusion bonded, and various other types of compact heat exchangers in a versatile and safe laboratory environment



Project Outcomes

Full Program conditions met on 10 kW prototype HX performance testing operations, upcoming 50 kW additively manufactured HX performance characterization as well as diffusion bonded HX performance testing to be completed in Fall 2021

Q_C = 10.08 +/- .05 kW

Cold Inlet:
T_{avg} = 301.8 +/- 1.5 C
P_{avg} = 24841 +/- 70 kPa

Cold Outlet:
T_{avg} = 702.0 +/- 1.5 C
P_{avg} = 24836 +/- 70 kPa

$\dot{m}_{avg}$ = 0.0200 +/- 0.3% kg/s

10 kW Prototype HX

Effectiveness = 0.852 +/- .003

UA = 0.116+/- 0.002 kW/K

Q_{loss} = 0.135 +/- 0.05 kW

Hot Outlet:
T_{avg} = 379.5 +/- 1.5 C
P_{avg} = 8219 +/- 62 kPa

Hot Inlet:
T_{avg} = 799.5 +/- 1.5 C
P_{avg} = 8227 +/- 62 kPa

Q_H = 10.22 +/- .05 kW