Particle-to-sCO_2 Heat Exchanger Design for Gas Phase System

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Gen3 CSP Summit

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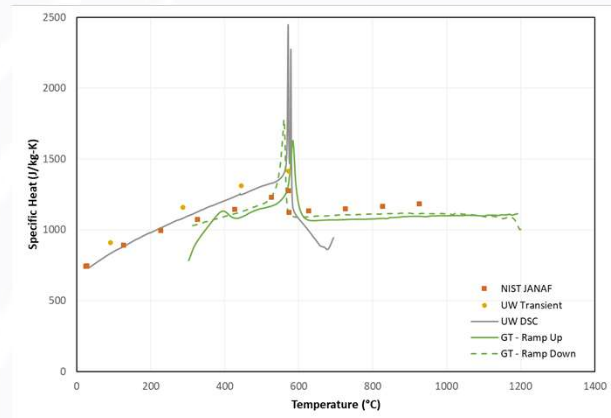
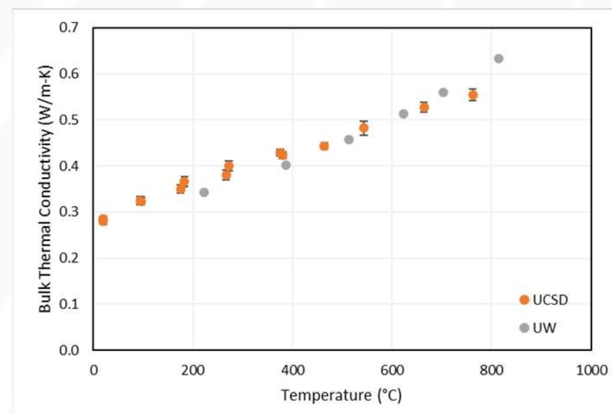
Award # DE-EE0008368

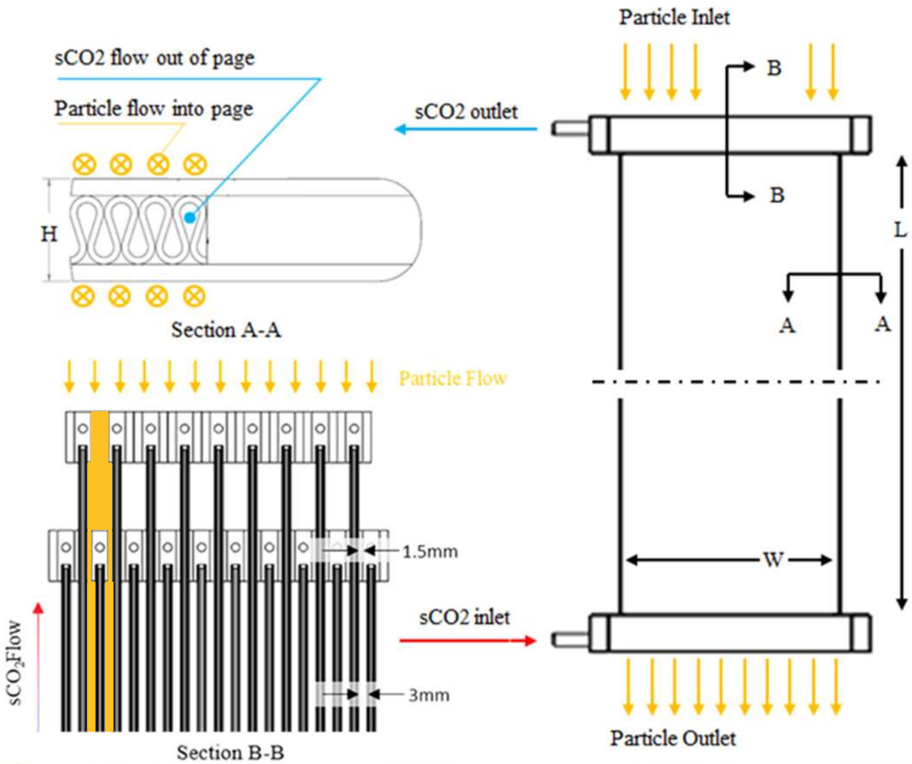
Particle Selection

- High purity (99.8%) silica sand
  - Low cost ($30-50/ton)
  - Abundantly available in U.S. Midwest
  - Mean diameter selected = 310µm
- Material properties measured by various sources
  - Specific heat
    - Quartz inversion at 573°C observed
  - Bulk effective thermal conductivity
  - Bulk solids flow properties
    - Material is incompressible and effectively free flowing
    - Wall friction increases with temperature
  - Surface durability
    - Loss rates measured for H230 and SS316 projected a thickness loss of <0.2mm over 30-year operating life

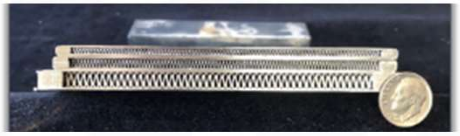


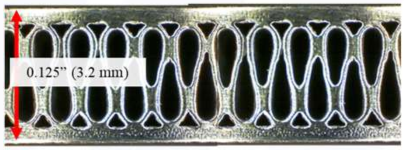


Heat Exchanger (HX) Design



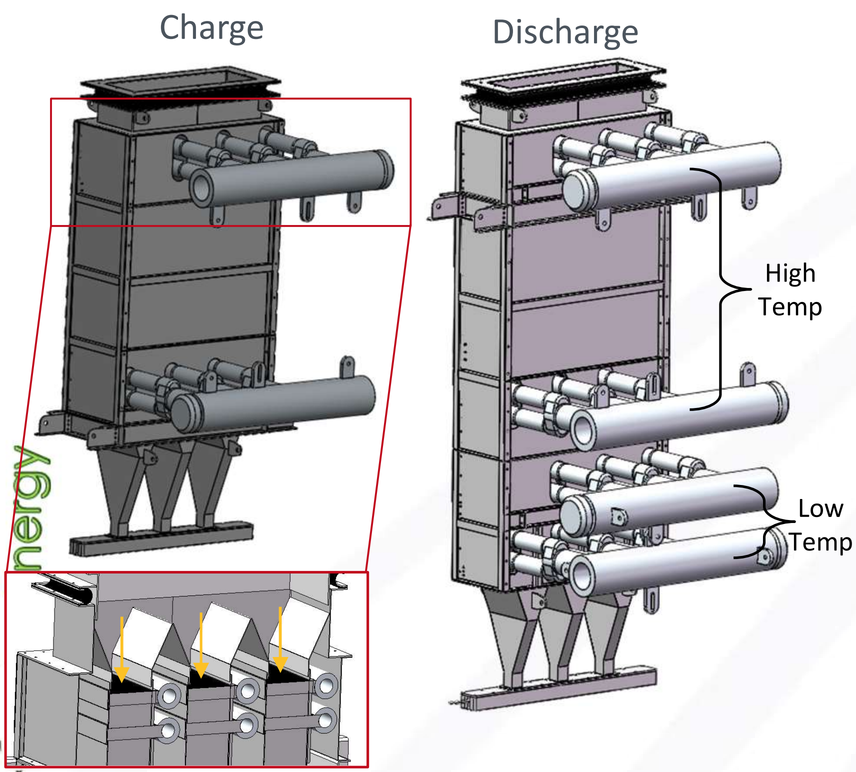
- Employ Brayton's internally finned heat exchanger (HX) cells
- Pure counterflow design
- Moving packed bed sand flow along external cell surfaces
- 2 key aspects:
  - Overall HX configuration
  - sCO_2 containment for 30-yr operational life
- Vertically staggered cell arrangement
  - Allows small particle-side flow heights of 3mm



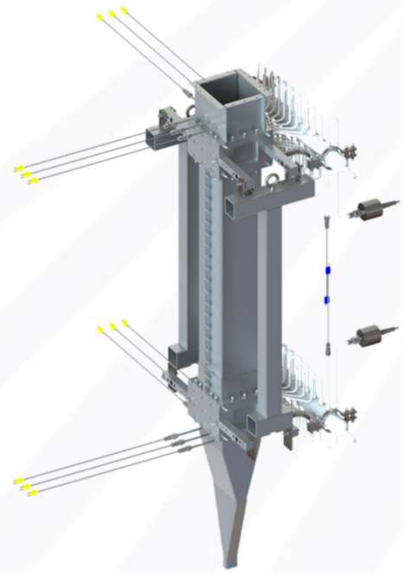


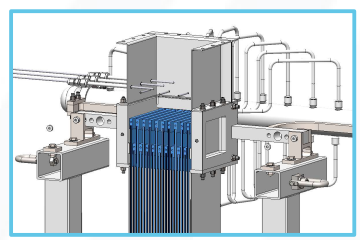
Heat Exchanger (HX) Design

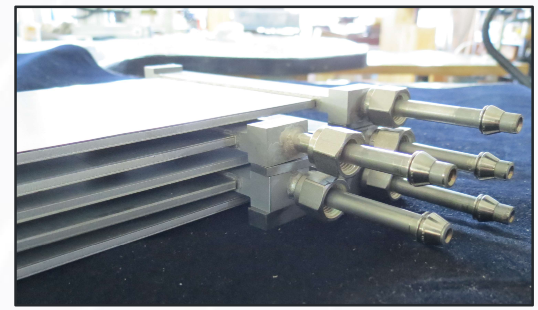
Commercial/Phase 3

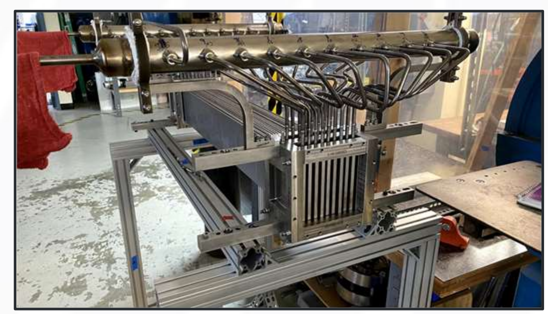


Test Article









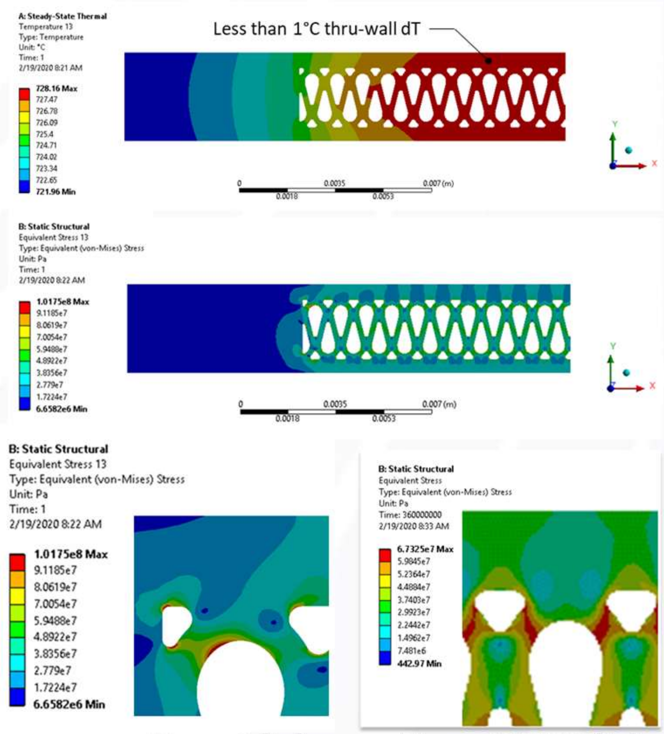
Cell Life Modeling

Design Requirements
- Charge Pressure: 25 MPa
- Maximum Temperature:
  - Charge: 730°C
  - HT Discharge: 700°C
  - LT Discharge: 583°C
- Service Life
  - Charge: 100,000 hours, 10,000 cycles
  - Discharge: 262,000 continuous hours

Approach
- Transient CFD and FEA Analysis
- Idaho National Laboratory's Revised ASME BPVC Section III, Division 5, Subsection HB, Subpart B

Design and Analysis Review
- Detailed Design Review with DOE, NREL, Solex, and Worley, Feb. 20, 2020

Charge TES HX Cross Section at Life Limiting Location JB1



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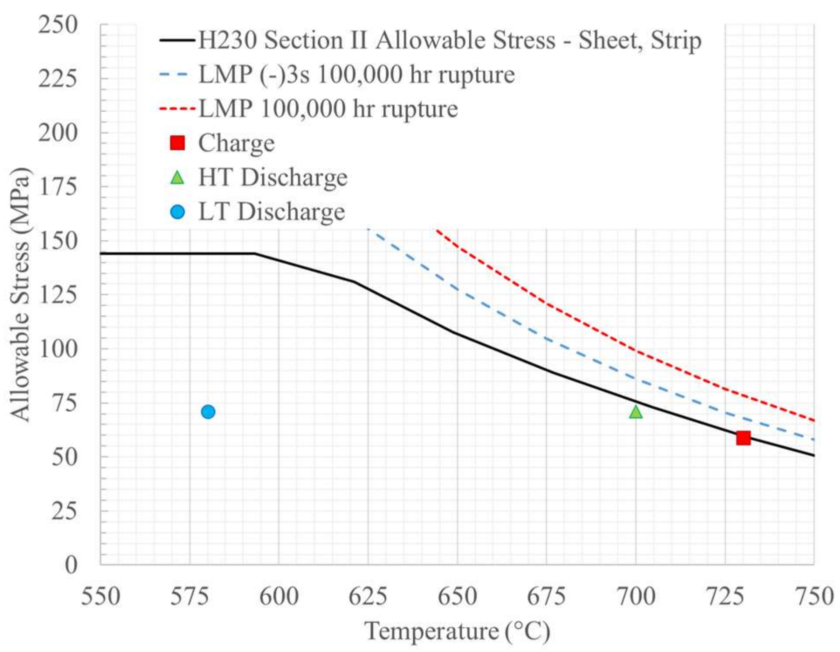
Slide 5

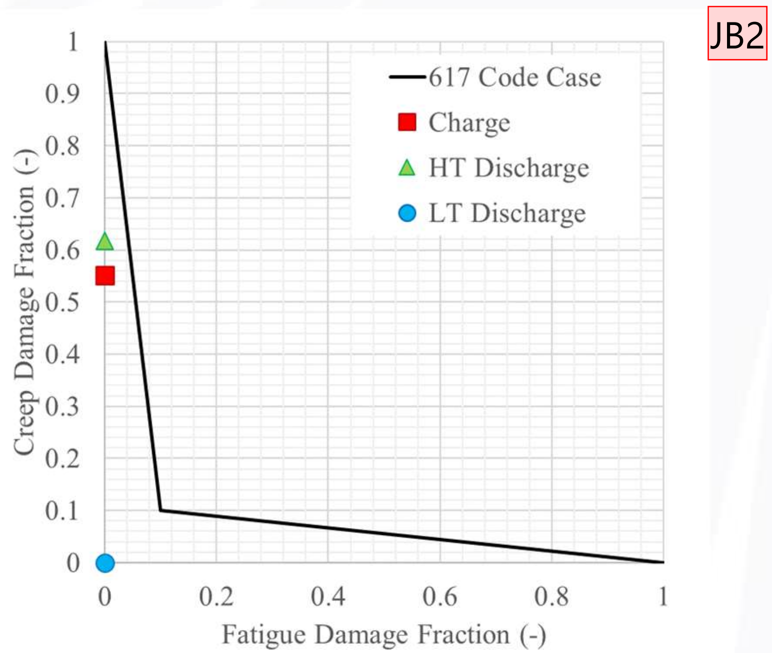
JB1 Bottom two figures show difference between elastic and ineleastic modeling efforts, both were employed. Just noting this because its not obvious

Jake Boxleitner, 8/16/2021

Cell Life Modeling

- ASME Allowable Stress and Linear Summation of Creep and Fatigue





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Slide 6

JB2 It will be worthwhile to add the linear summation of creep and fatigue damage accumlaution formulat to this figure and speak to its definition, moral of the story is that the design under spec'd service conditions are creep limited.

Jake Boxleitner, 8/16/2021

Cell Life Testing

Challenge
Modeling efforts assume parent material and isotropic material properties across the brazed joint.

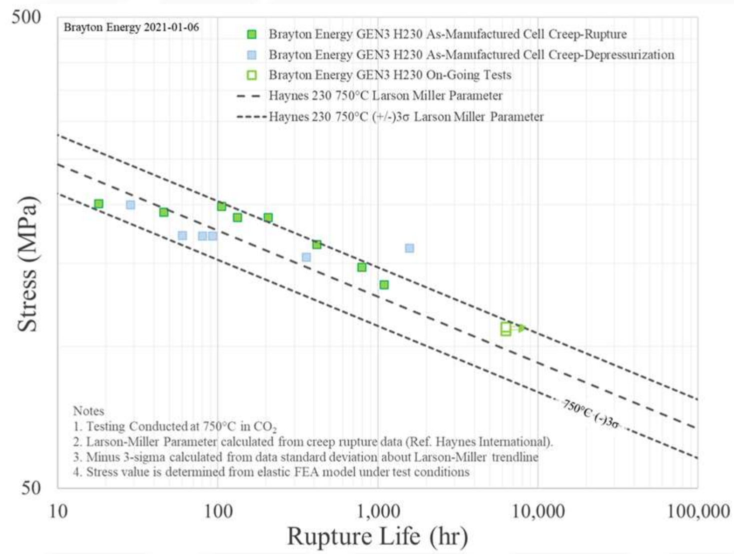
Test Specifications
- Test Article Envelope: (4.5” x 4.0” x 0.125”) and (4.5” x 32” x 0.125”)
- Working Fluid: CO_2
- Elevated Temperature: 750°C
- Elevated Pressure: 10-45 MPa – dependent on desired test duration/cycle count

Procedure
- Creep – Raise temperature and pressure to test specification
- Creep-Fatigue – Raise and hold temperature then cycle pressure between test specification and atmosphere.

Goals
- Validate modeling strategy
- Validate manufacturing processes

Creep Results

JB3



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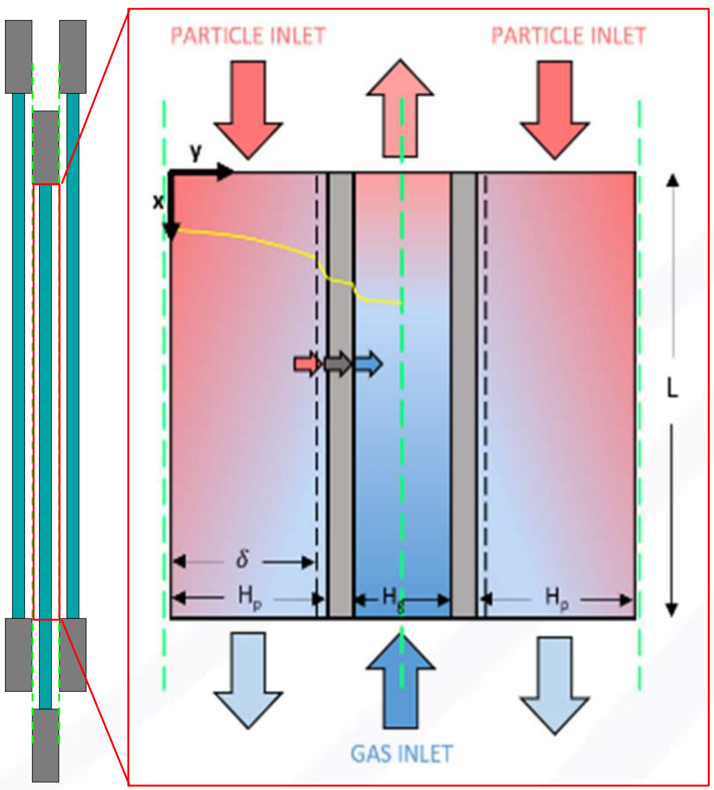
Slide 7

JB3 It will be important to clarify the axis in this figure. Rupture life is a measured quantity and stress is an interpreted value based on FEA models given the measured test pressure.

Jake Boxleitner, 8/16/2021

HX Performance Modeling



Particles

$$\frac{\partial}{\partial y}\left(k_p \frac{\partial T_p}{\partial y}\right) = \rho_p U_p c_{p,p} \frac{\partial T_p}{\partial x}$$

Gas

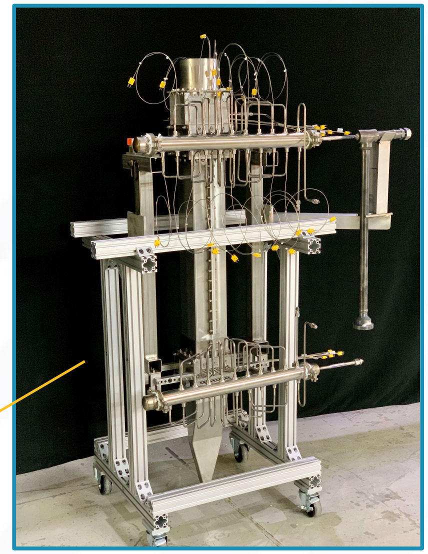
$$q''_{wall} W = \frac{\dot{m}_g}{2} c_{p,g} \frac{dT_g}{dx}$$

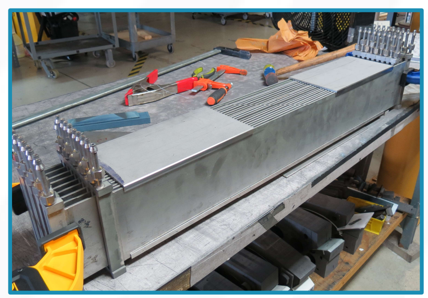
Coupling Thermal Resistance

$$R_T = \underbrace{\frac{t_{wa}}{k_{wa} W \Delta x}}_{\text{Near-wall particle flow contact resistance}} + \underbrace{\frac{t_{wall}}{k_{wall} W \Delta x}}_{\text{Wall conduction}} + \underbrace{\frac{1}{\eta_0 h_g p_{conv} \Delta x}}_{\text{Gas convection}}$$

- Analytic and numeric models employed to simulate HX performance
- HX sizing performed in tandem by Solex using their internal software
  - Good agreement (within 5%) between different models

Subscale HX Performance Testing





- ~16kW$_t$ subscale test article
- Utilize CO_2 circulator skid constructed at Brayton
- Can operate in charging and discharging mode
- Objectives:
  - Gain experience in fabrication
  - Validate performance models
  - Demonstrate operability

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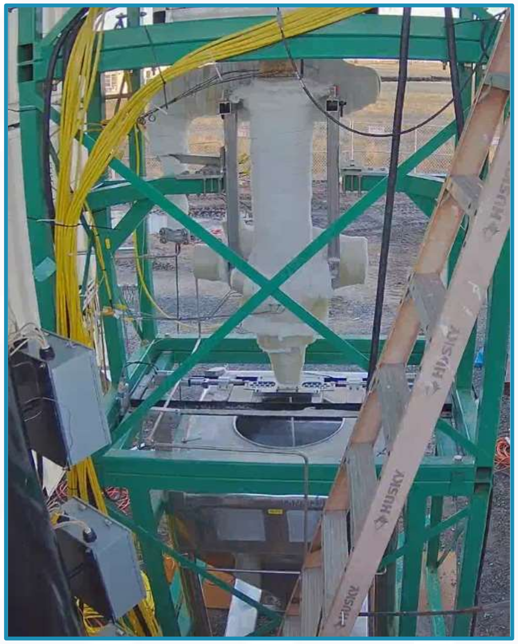
Summary/Future Work

- Vertically staggered arrangement of heat exchanger cells allows:
  - Pure counterflow design
  - Small particle-side flow heights of 3mm
- Brayton Energy's internally-finned HX cells designed to satisfy 30-yr operating life based on INL's revised BPVC
- Additional HX performance testing and model refinement forthcoming



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Thank you!

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