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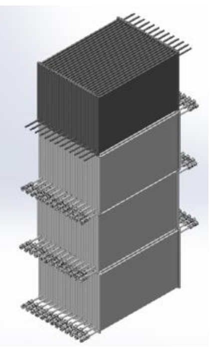

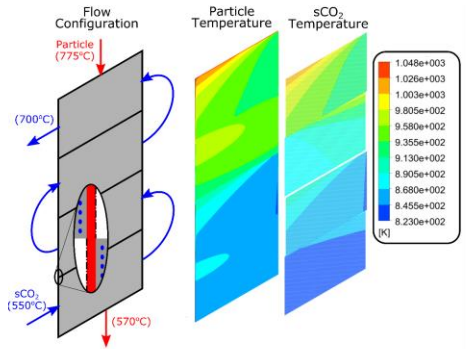

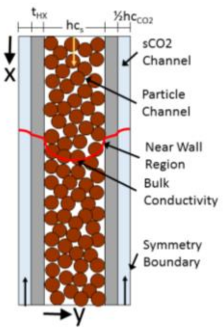

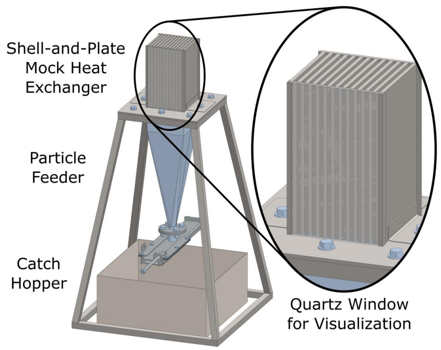

High-Temperature Flow Testing and Heat Transfer for a Moving Packed-Bed Particle/sCO_2 Heat Exchanger

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Sandia National Laboratories, Concentrating Solar Technologies (8823)

SolarPACES 2017

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

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Outline

- Introduction/Objectives
- Moving Packed-Bed Heat Exchanger Operation
- High-Temperature Particle Flow Testing
- Moving Packed-Bed Heat Transfer Coefficients
- Conclusion/Future Work

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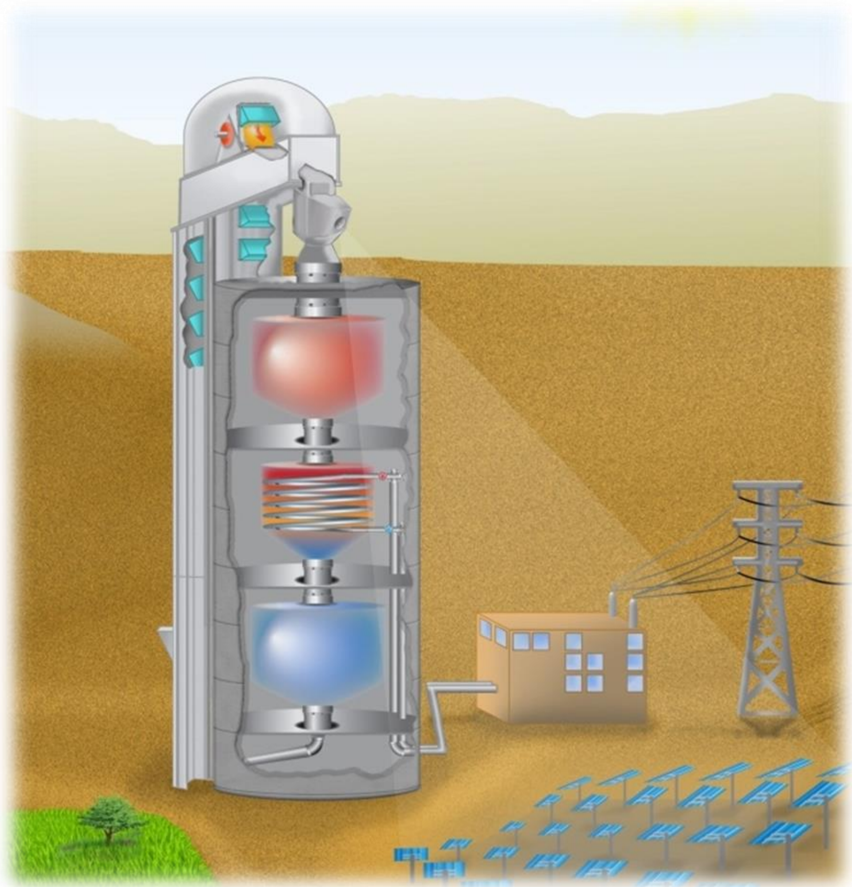
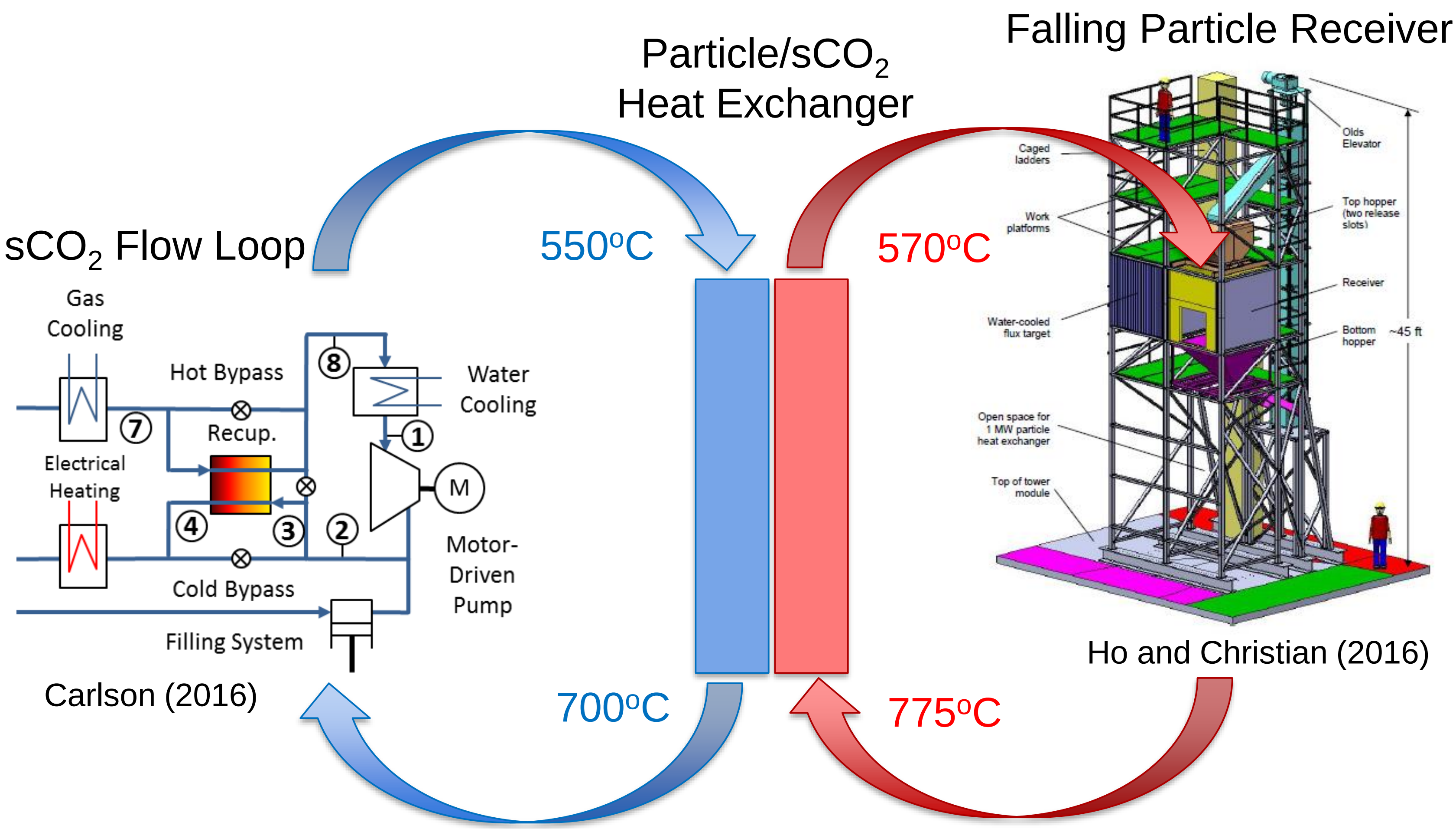
Particle receiver development has led to the need for an sCO_2-to-particle heat exchanger

- Particle-based CSP plants enable the use of sCO_2 power cycles
- Multiple particle receivers have been demonstrated at the megawatt scale
- Minimal work has been conducted on particle-to-sCO_2 heat exchangers



Objective



- Develop and test 100kW$_{th}$ prototype particle-to-sCO$_2$ heat exchanger

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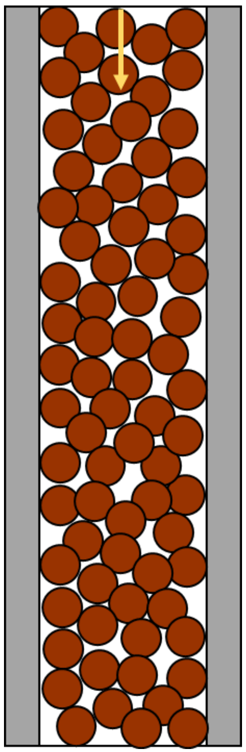
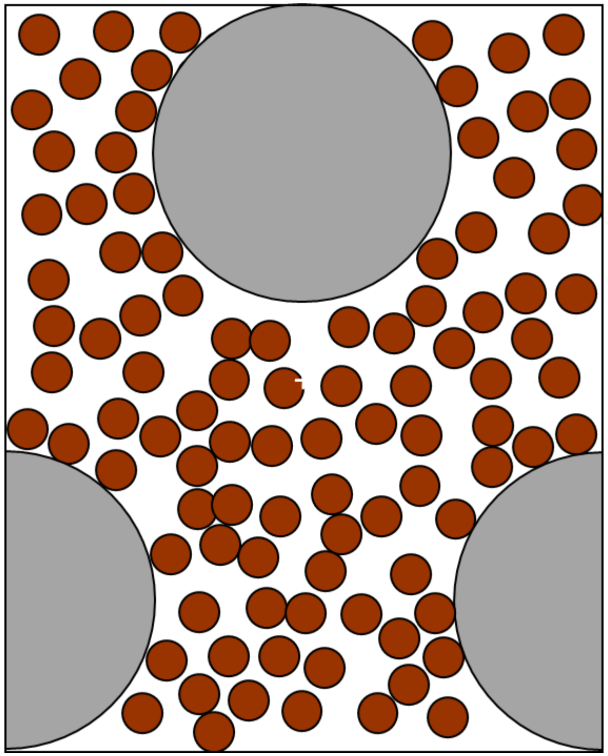
Moving Packed-Bed vs. Fluidized Bed

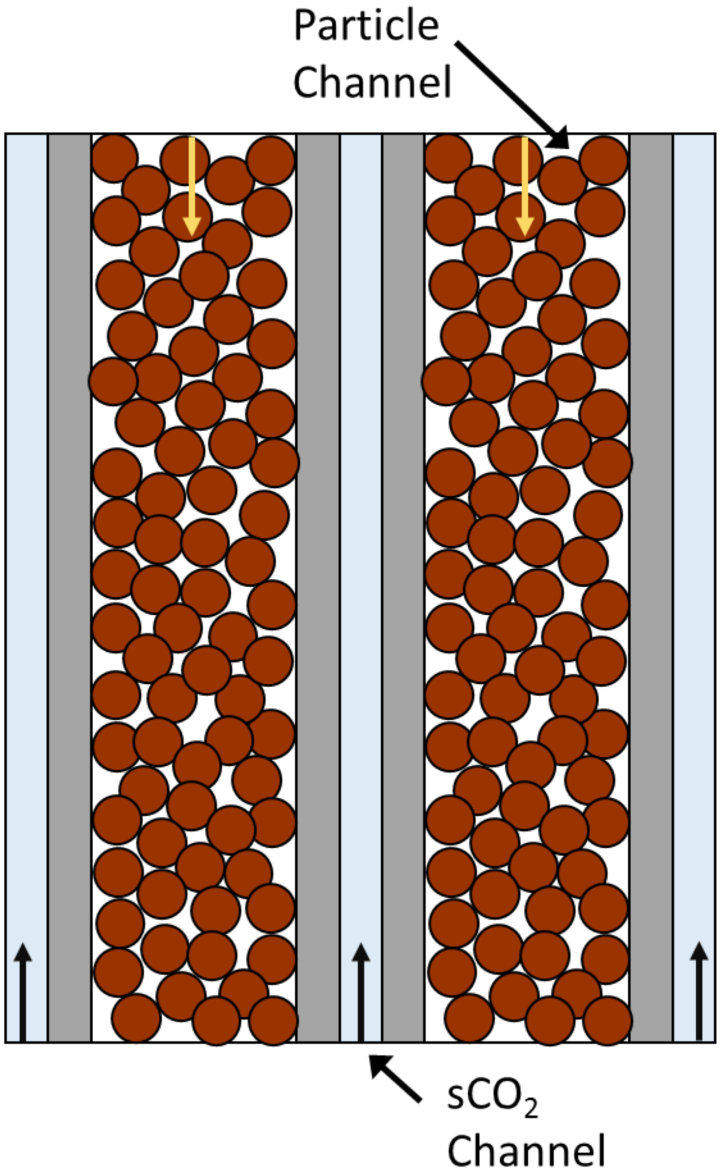


- Simple operation
- Reduced balance-of-plant

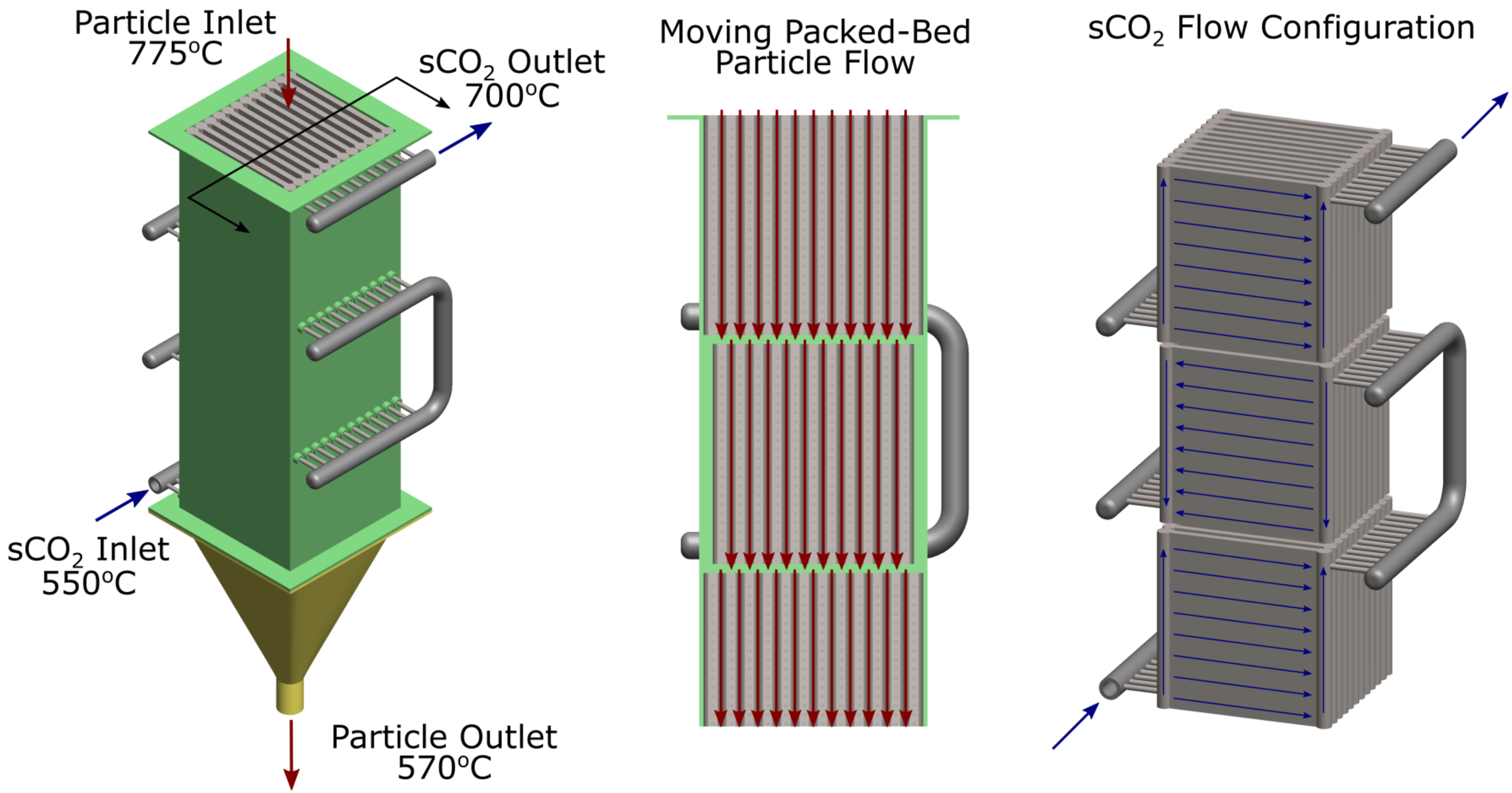


- High heat transfer coefficients
- Vast industry experience

Shell-and-plate moving packed-bed heat exchanger operation



Shell-and-Plate Moving Packed-Bed Heat Exchanger Design



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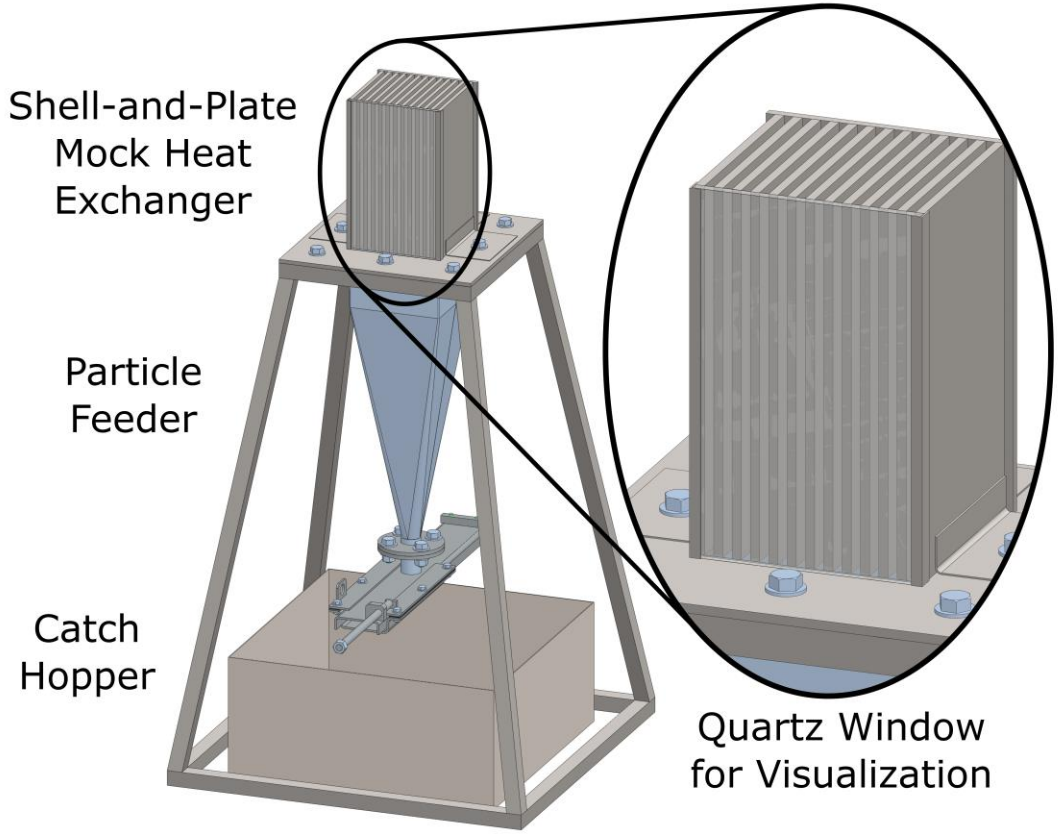
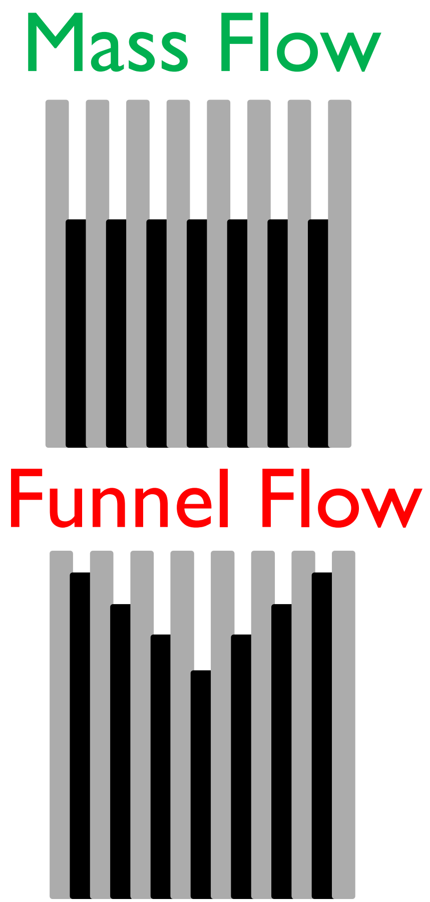
High-temperature particle flow visualization experiment





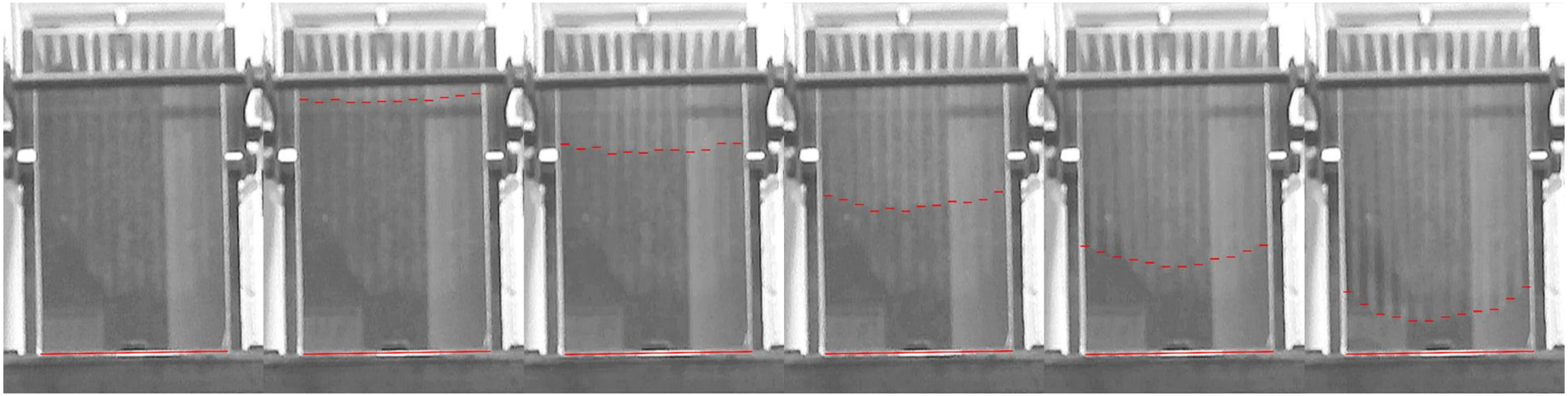
- High-temperature tests provide quantitative information about the feeder's ability to create uniform draw down (mass flow)

Comparison of shell-and-plate particle flow at ambient and elevated temperature

Ambient

600°C

High-temperature testing reveals slight preferential flow in central channels



Material	Feeder Angle	Gate Position (mm)	Mass Flow Rate (kg/s)	Average Velocity (mm/s)	Standard Deviation (mm/s)	St. Dev./Avg.
ID50	77	44.45	0.0849	3.39	0.421	12.4%
ID50	77	57.15	0.125	5.08	0.410	**8.07%**
ID50	77	69.85	0.174	7.02	0.409	5.84%

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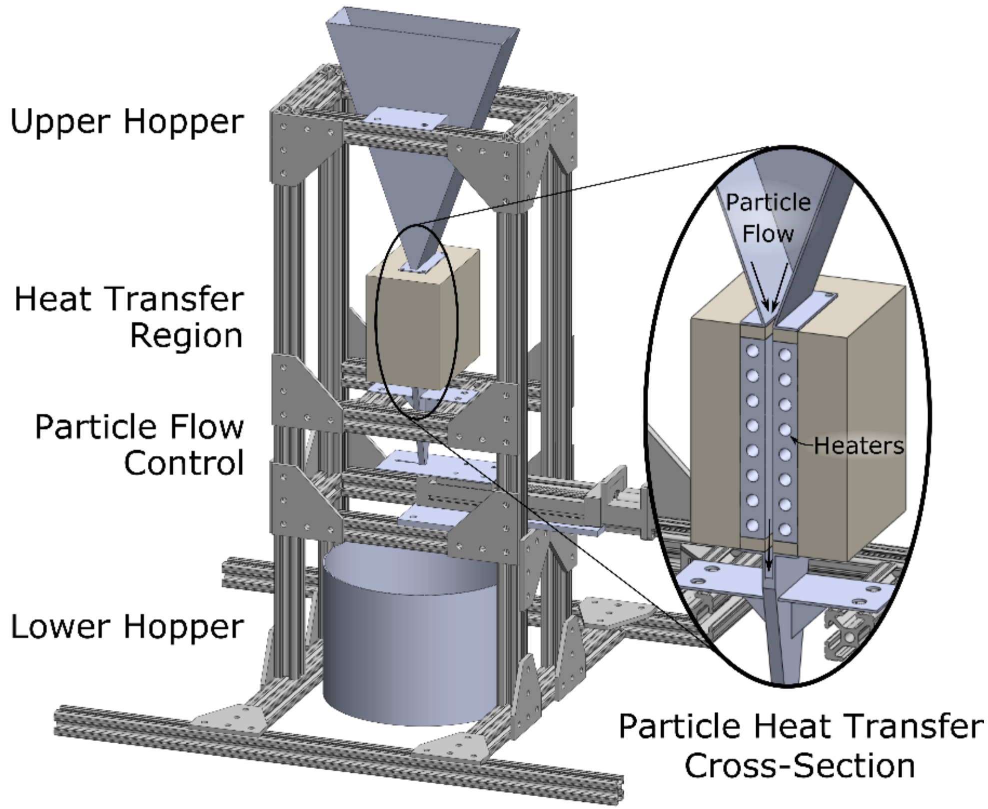
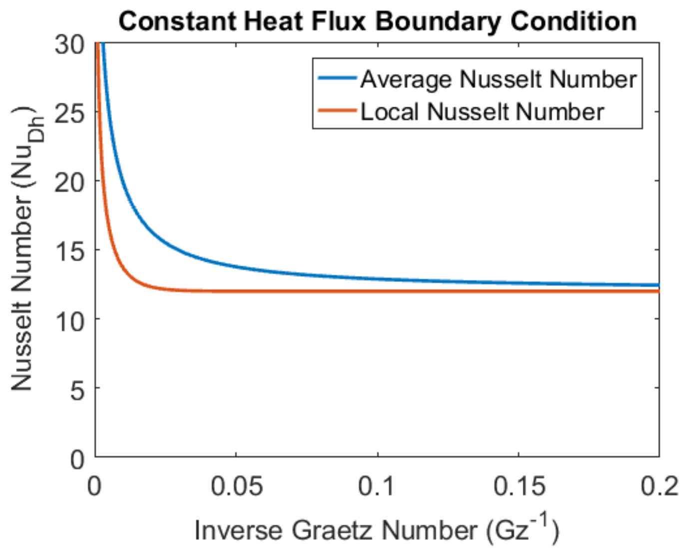
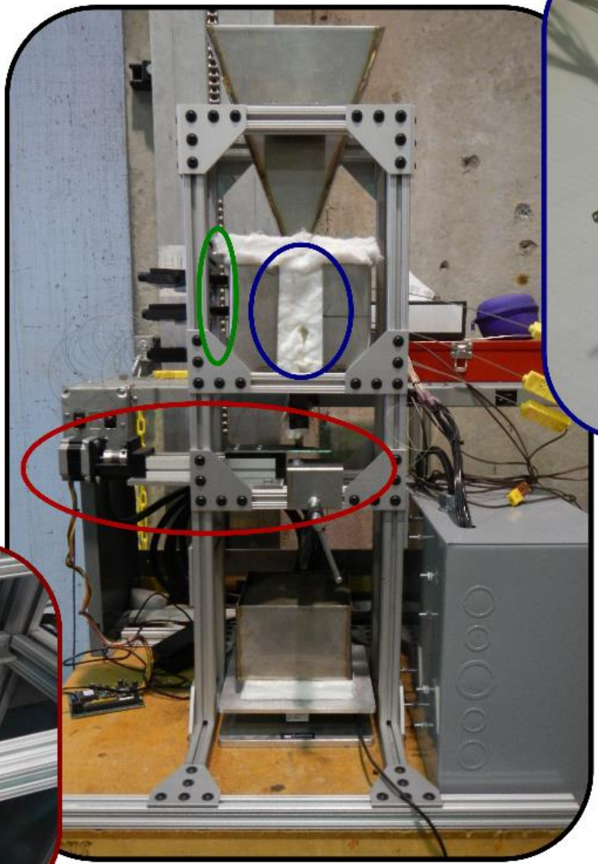
Measurement of moving packed-bed heat transfer coefficients can verify 100 kW_{th} design

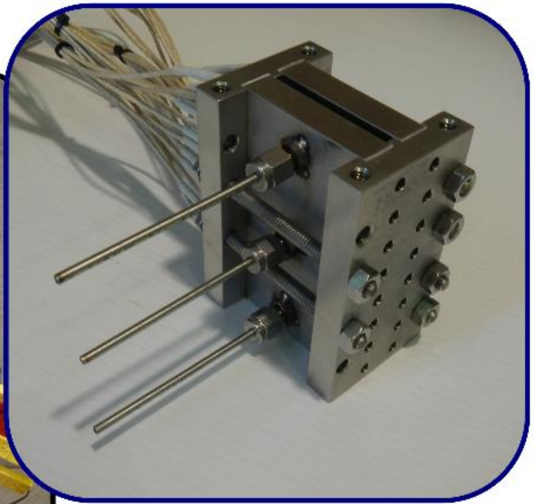


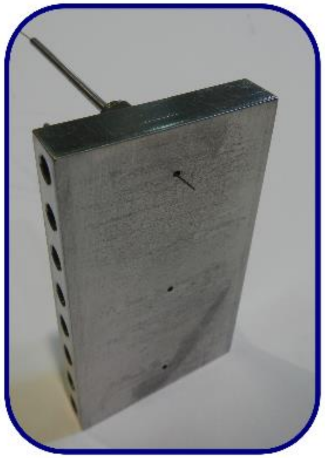


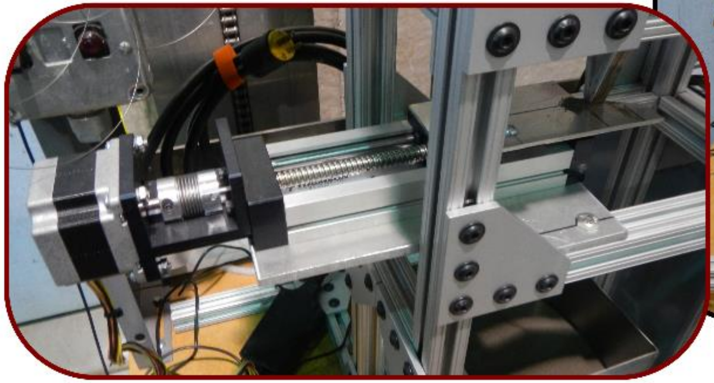
- Non-dimensional parameters are similar to 100 kW_{th} prototype

Details of constructed heat transfer experiment









Transient measurement of temperature approaching steady-state operation

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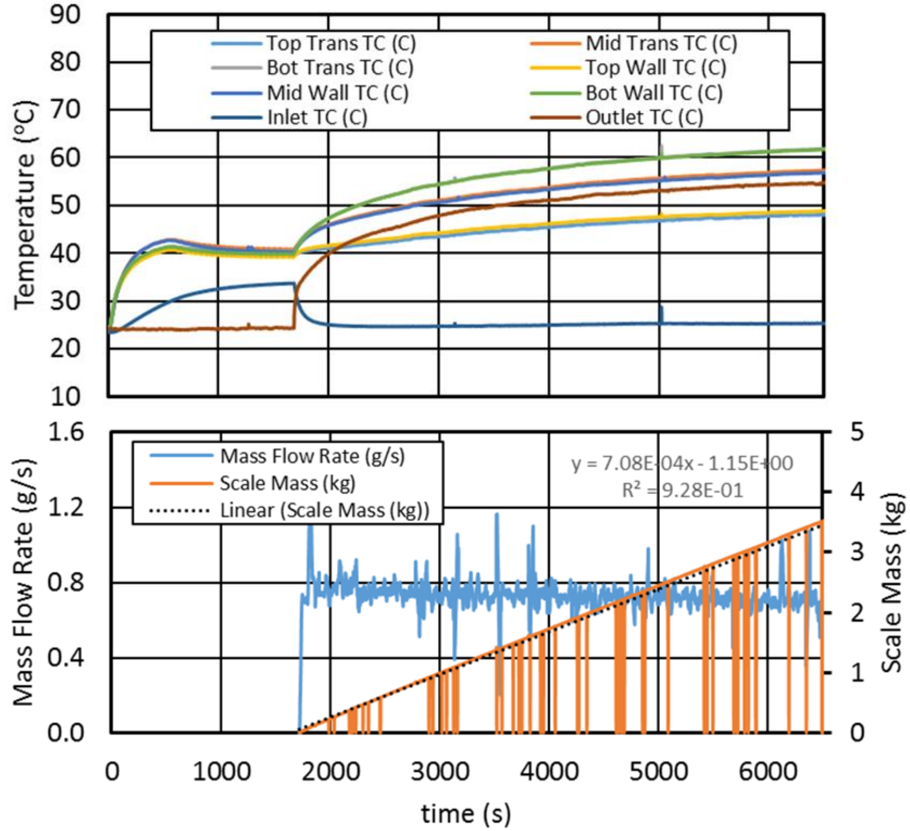
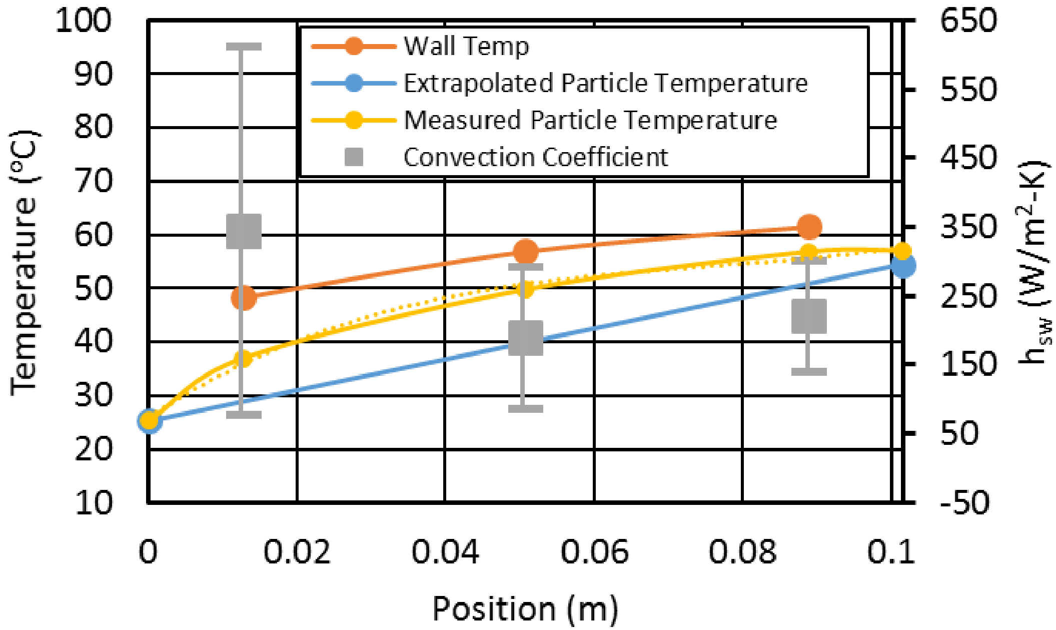


- Approximately 30 min of preheat is required to bring the experiment close to operating temperature without particle flow
- Experiment is ran to steady-state condition (~2 hrs.) before recording temperature measurements for calculating heat transfer coefficient

Heat transfer coefficients are calculated at three locations over the height of the vertical channel



Extrapolated Temperature

$$h_{sw} = \frac{Q_{heater}}{2 w_{ch} h_{ch} \left(T_w - T_{extrap} \right)}$$

Measured Temperature

$$h_{sw} = \frac{\dot{m}_s c_{p,s} \frac{dT_s}{dx}}{2 w_{ch} \left(T_w - T_{meas} \right)}$$

- Two methods of calculating heat transfer coefficient for bounding error of the experimental technique
- High uncertainty in entry region due to non-uniform heat addition
- Heat transfer coefficients asymptote to fully developed values near 200 W/m^2-K

Conclusion

- Shell-and-plate moving packed-bed heat exchangers offer a simple alternative to fluidized beds
- Granular flow is significantly affected by operation at elevated temperature
- Measured heat transfer coefficients agree with analytical solutions for thermally developing plug flow

- Future work:
  - We have begun procurement of the 100 kW_{th} particle-to-sCO2 heat exchanger, which will be integrated with the falling particle receiver and sCO_2 test loop

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SunShot
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Supporting Slides

Prior studies on moving bed heat transfer

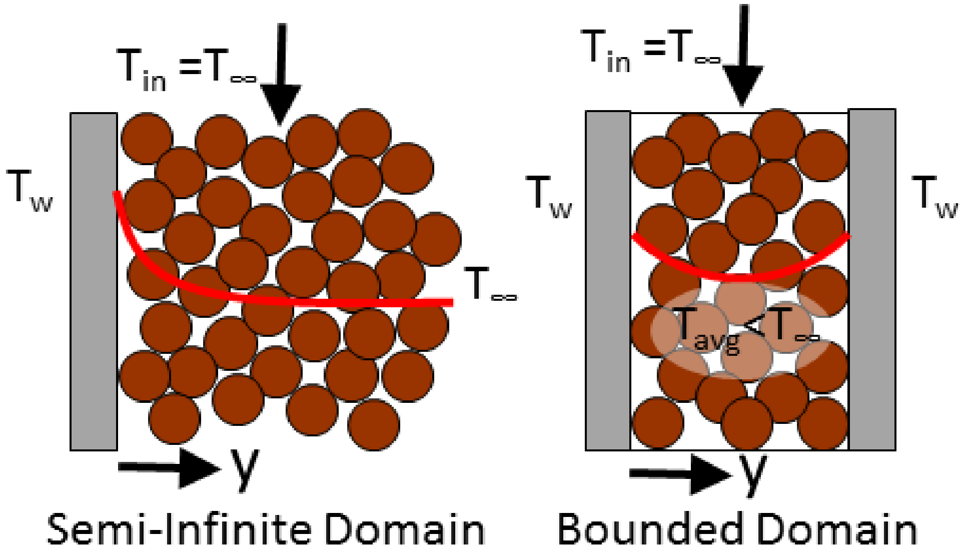
- DLR - Bauman and Zunft

  Measured heat transfer coefficients of moving packed beds around horizontal cylinders for steam cycles

- NCSU – Watkins and Gould

  Measured heat transfer coefficients for moving packed beds in vertical tubes for enclosed particle receivers

Definition of heat transfer coefficient must be consistent with flow boundary conditions



- The majority of the literature studies are external (semi-infinite) flows, which are not consistent with internal heat transfer coefficients
- Internal flow results in average particle temperature departing from free stream (inlet) temperature

Importance of the method of quantifying heat transfer coefficient for heat exchangers

Overall Heat Transfer Coefficient

$$Q = UA \cdot \Delta T_{lm}$$

$$U = \frac{Q}{A \cdot \Delta T_{lm}}$$

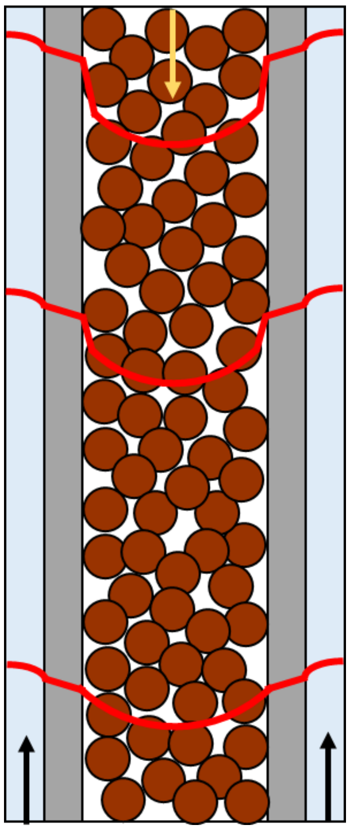
Log Mean Temperature Difference

$$\Delta T_{lm} = \frac{\left(T_{s,out} - T_{CO2,in}\right) - \left(T_{s,in} - T_{CO2,out}\right)}{\ln\left(\frac{T_{s,out} - T_{CO2,in}}{T_{s,in} - T_{CO2,out}}\right)}$$

- Log mean temperature (ΔT_{lm}) quantifies the average **local** temperature difference over the heat exchanger
- Calculated overall heat transfer coefficient (U) will be inconsistent with particle-wall heat transfer coefficients in literature depending on definition

Multiple banks with offset plates enhances heat transfer

Single Continuous Channel



Multiple Banks with Offset Plates