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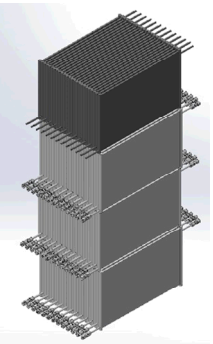

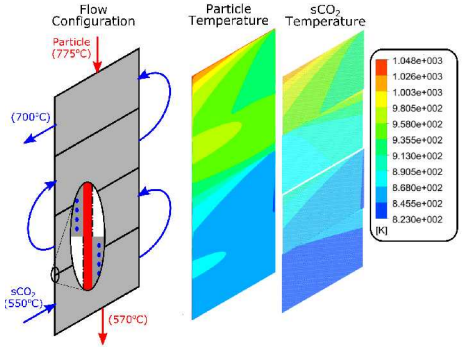

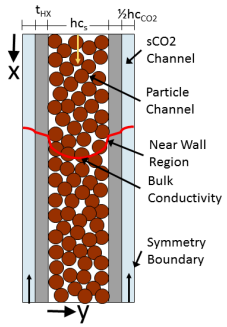

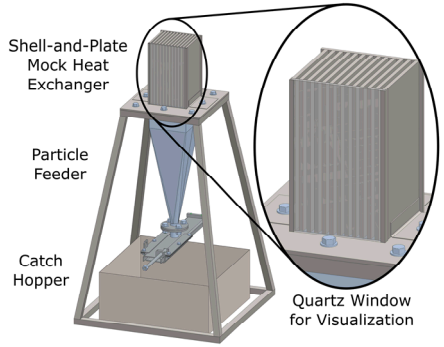

Heat Transfer Models of Moving Packed-Bed Particle-to-sCO_2 Heat Exchangers

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Sandia National Laboratories, Concentrating Solar Technologies (8823)

PowerEnergy2017-3377

Outline

- Introduction/Objectives
- Heat Exchanger Modeling
- High-Temperature Flow Visualization
- Conclusion/Future Work

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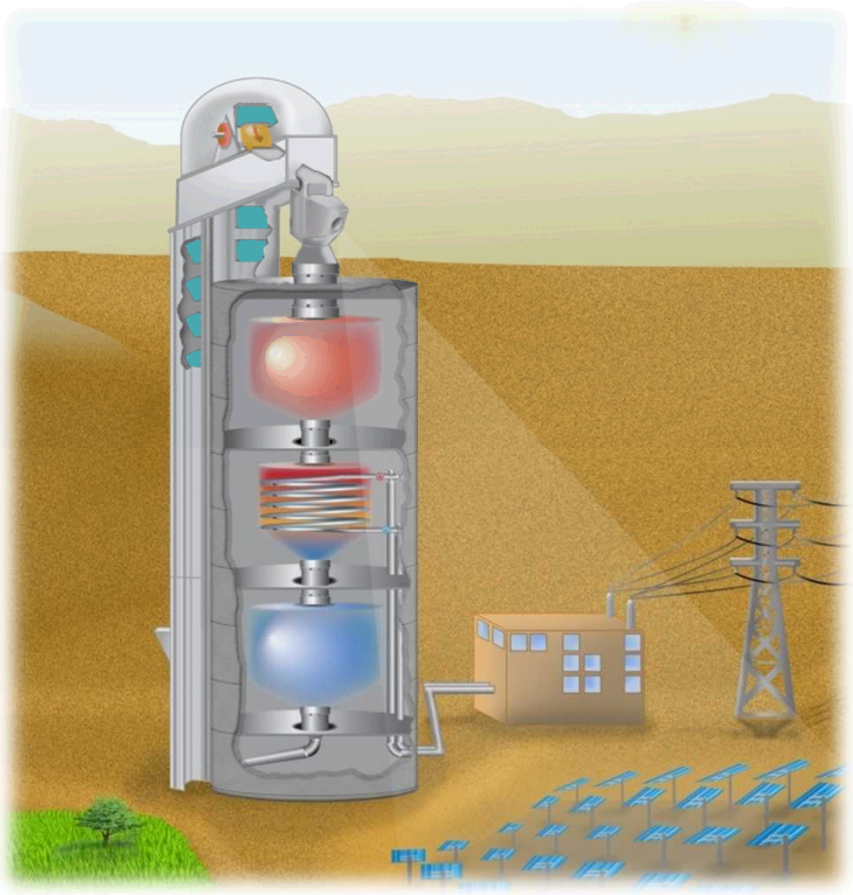
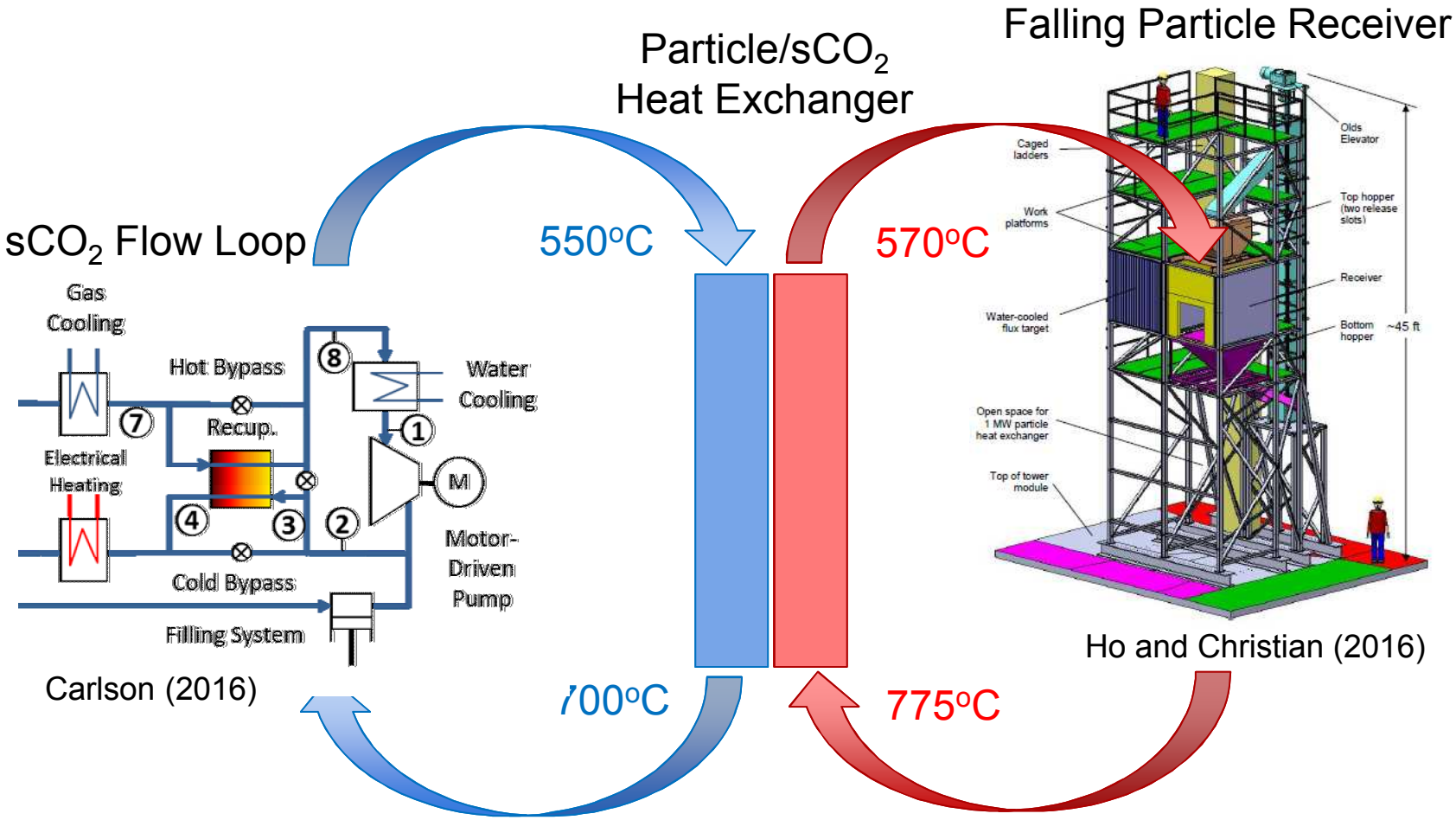
Particle receiver development has led to the need for an sCO_2-to-particle heat exchanger

- 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

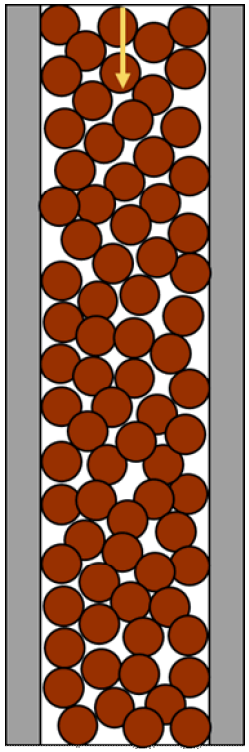


Objective

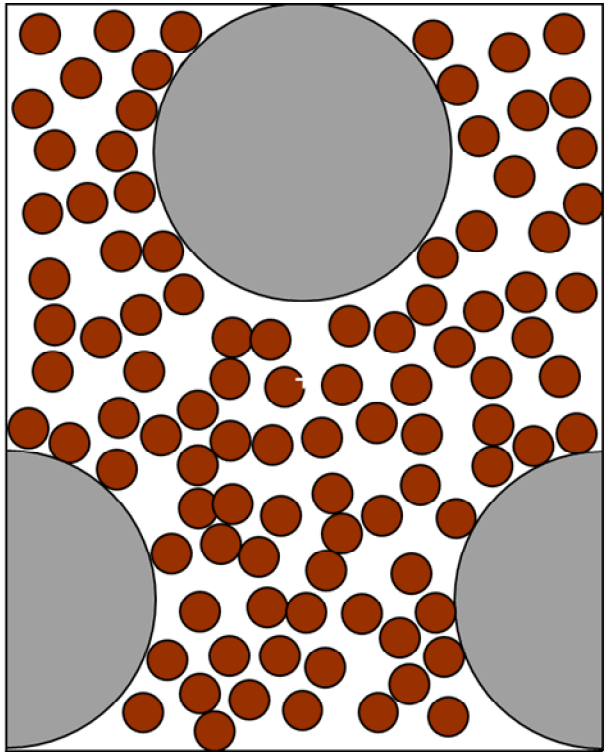


- Develop and test 100kW$_{th}$ prototype particle-to-sCO$_2$ heat exchanger

Moving Packed-Bed vs. Fluidized Bed

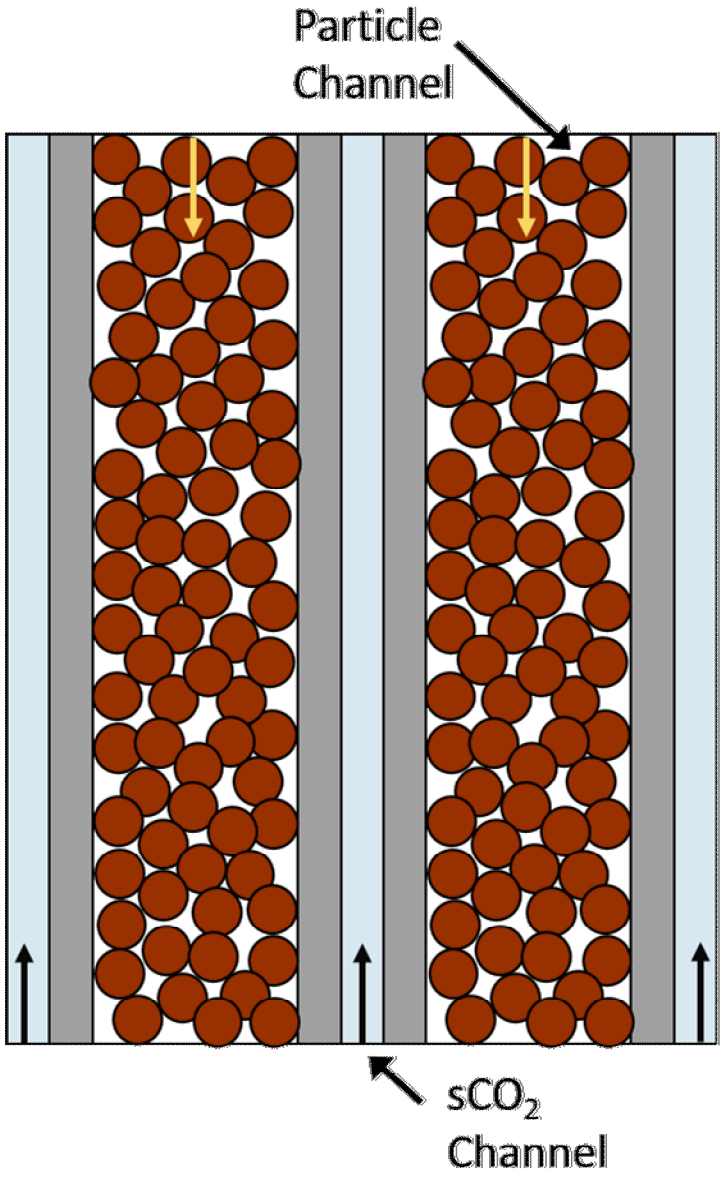


- Simple operation
- Reduced balance-of-plant



- High heat transfer coefficients
- Vast industry experience

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



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

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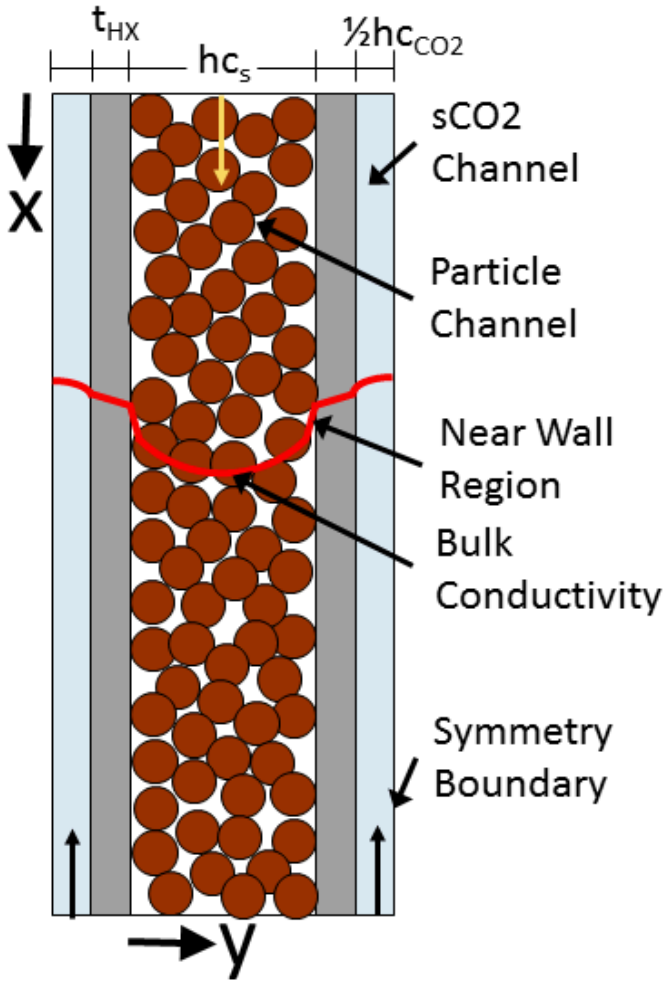
2-D Steady-State Model Formulation



2D S.S. Particle Conservation of Energy:

$$\rho_s v_s c_{p,s} \frac{\partial T_s}{\partial x} = \frac{\partial}{\partial y}\left(k_{s,eff} \frac{\partial T_s}{\partial y} \right)$$

1D S.S. sCO2 Conservation of Energy:

$$\rho_{CO_2} v_{CO_2} c_{p,CO_2} \frac{dT_{CO_2}}{dx} = \frac{2q''}{h_{CO_2}}$$

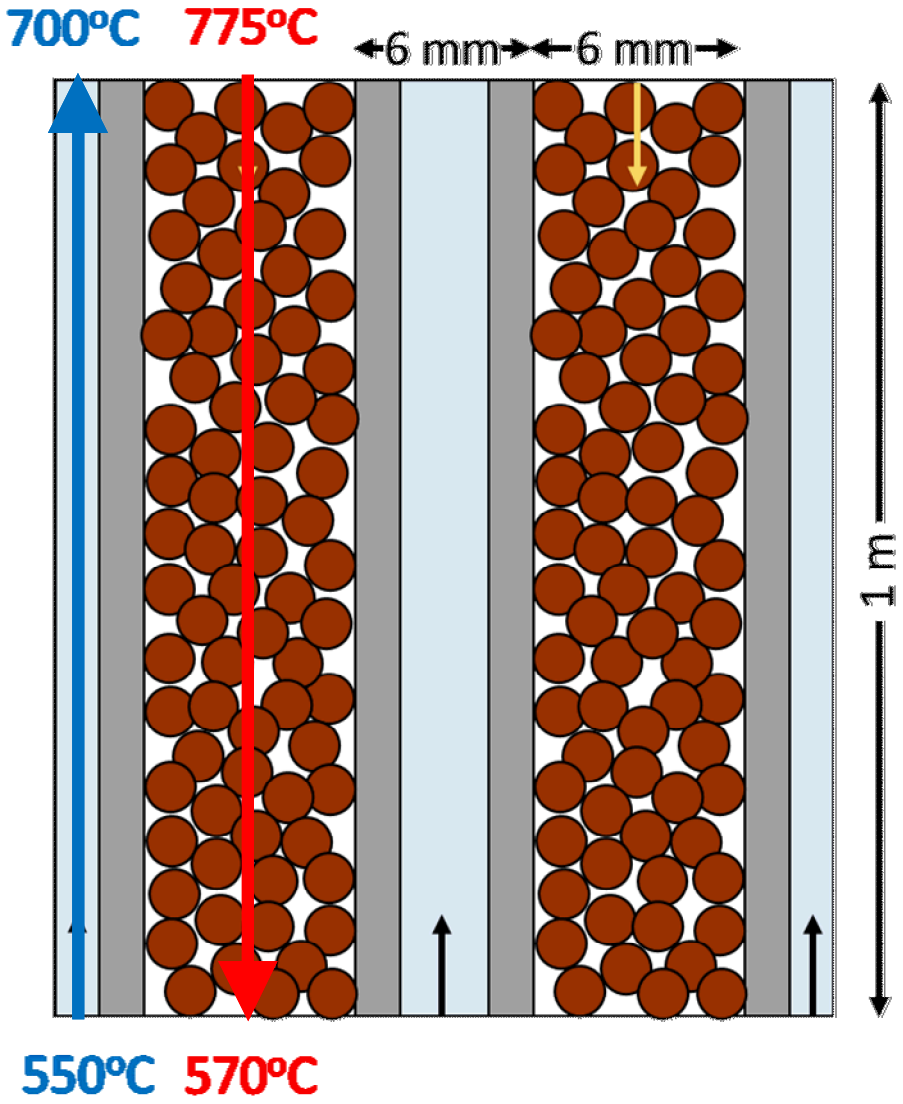
Regions Coupled Through Resistive Network:

$$q''(x) = k_{s,eff} \left. \frac{dT_s}{dy} \right|_{0,x} = \frac{1}{R''}\left(T_s(0,x) - T_{CO_2}(x) \right)$$

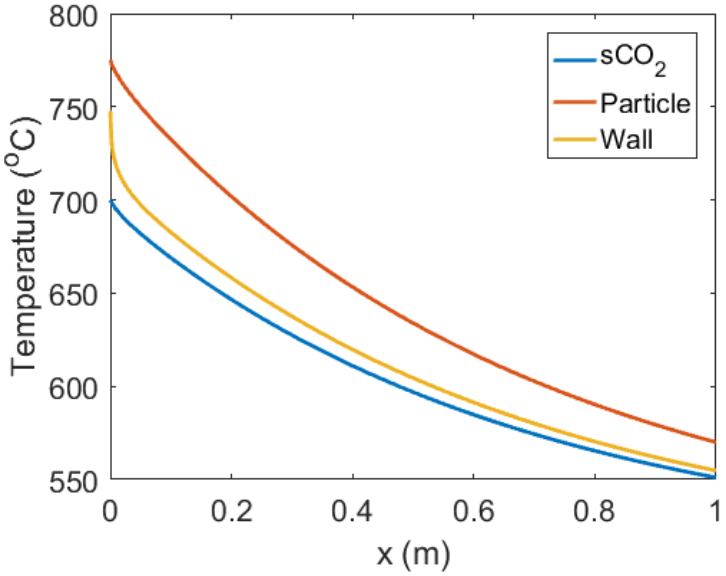
$$R''(x) = R_c'' + \frac{t_{HX}}{k_{HX}} + \frac{1}{h_{CO_2}}$$

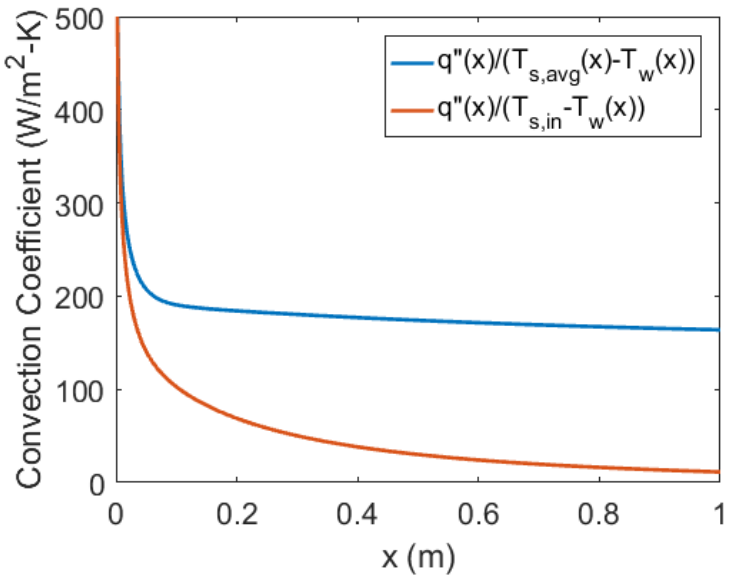
Solved using MATLAB ODE integrators and iterative shooting method

Geometry and Boundary Conditions



Single bank shell-and-plate heat exchanger performance

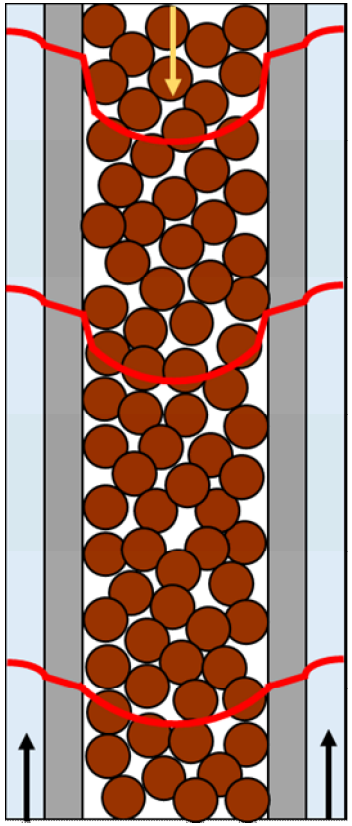




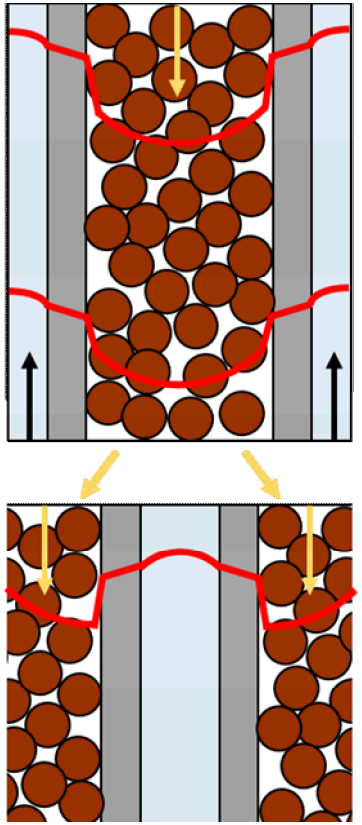
- Simulated overall heat transfer coefficient of **144 W/m²-K** and average particle-wall heat transfer coefficient **182 W/m²-K**

Multiple banks with offset plates enhances heat transfer

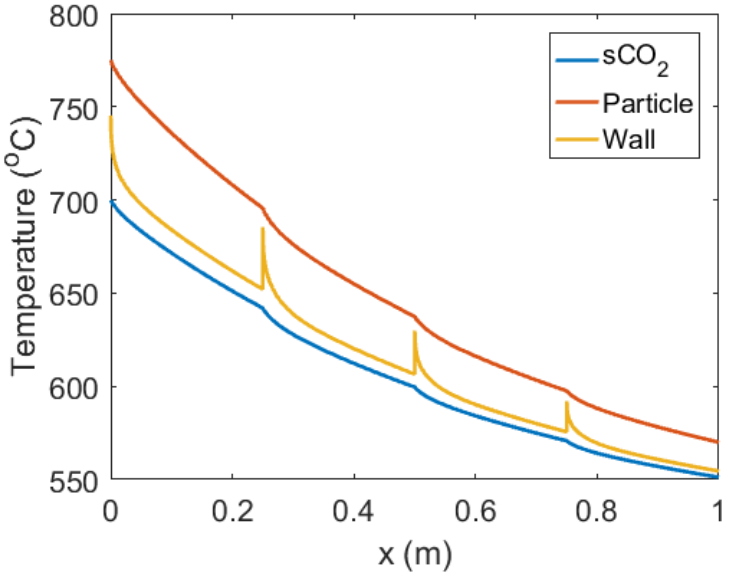
Single Continuous Channel

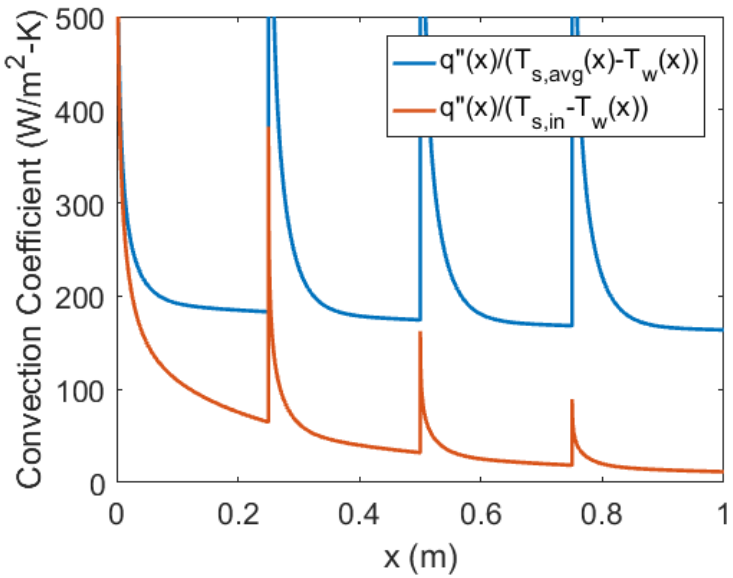


Multiple Banks with Offset Plates



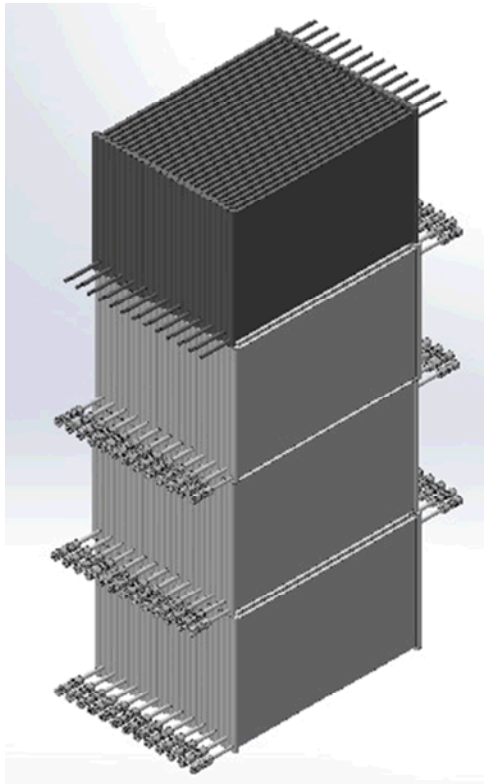
Four bank shell-and-plate heat exchanger performance

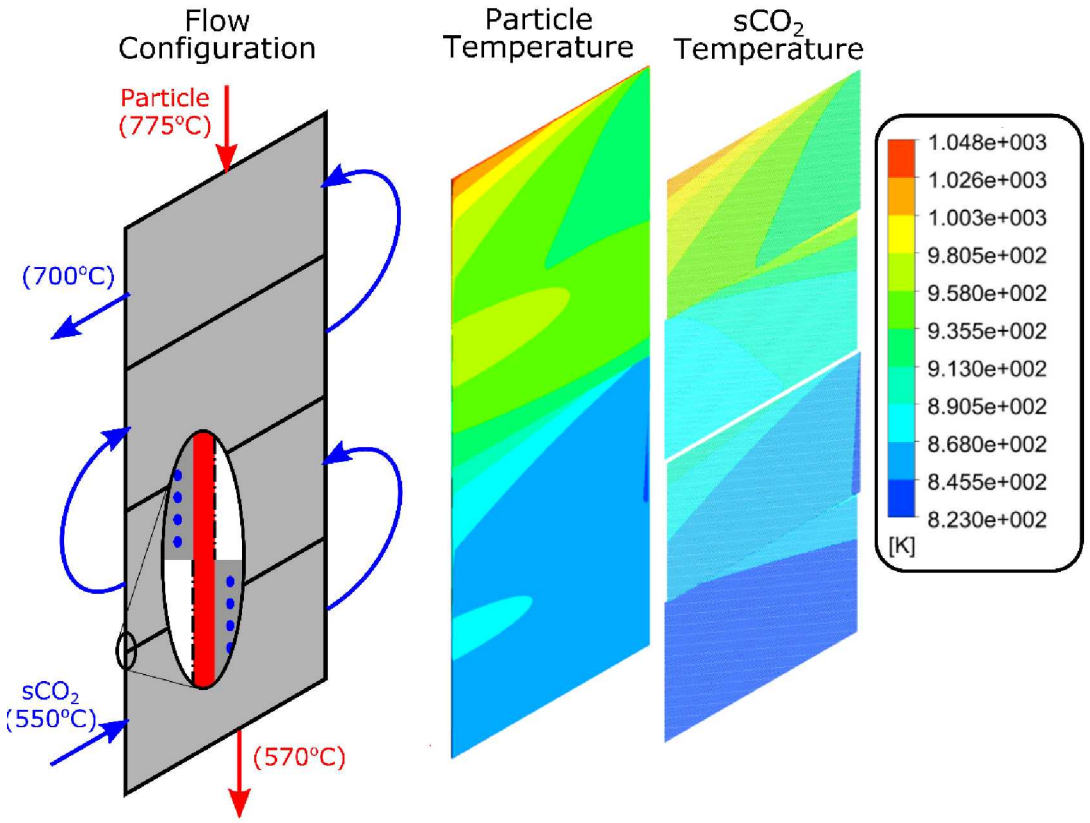




- Simulated overall heat transfer coefficient of **167 W/m²-K** and average particle-wall heat transfer coefficient **220 W/m²-K**
- **20% increase** over single channel configuration

3-D CFD model can capture mixed sCO_2 cross/counter flow configuration





- Approximately **10% reduction** in overall heat transfer coefficient (U) due to mixed cross/counter flow configuration compared to 2-D Model
- Particle outlet temperature non-uniformity is not significantly different between models

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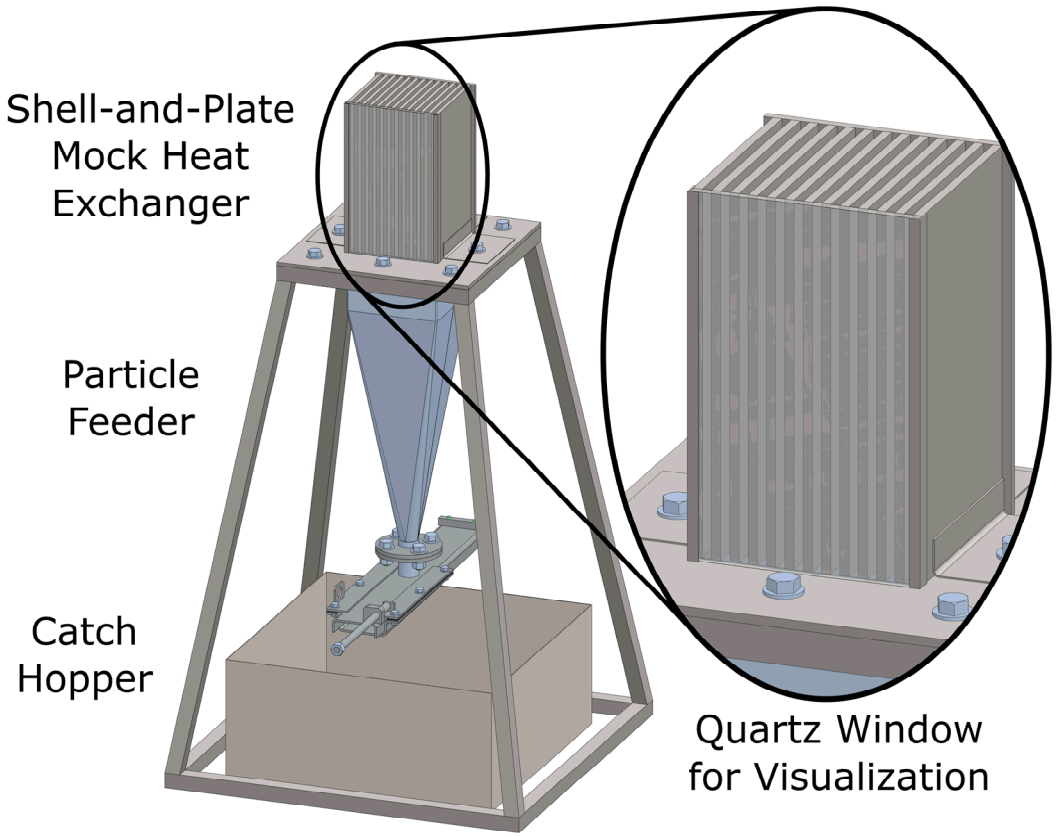
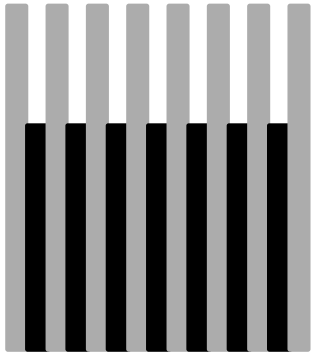
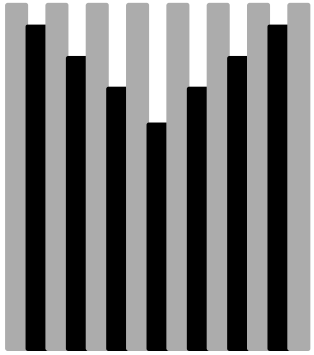
High-temperature particle flow visualization experiment



Mass Flow



Funnel Flow



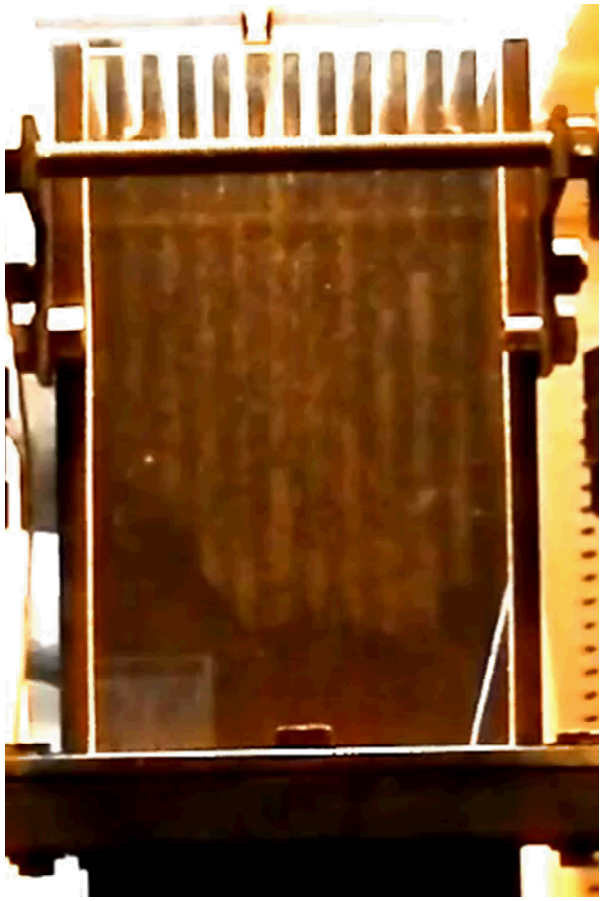
- High-temperature tests provide quantitative information about the feeder's ability to create uniform draw down (mass flow)

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

Sandia National Laboratories

Ambient

600°C



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

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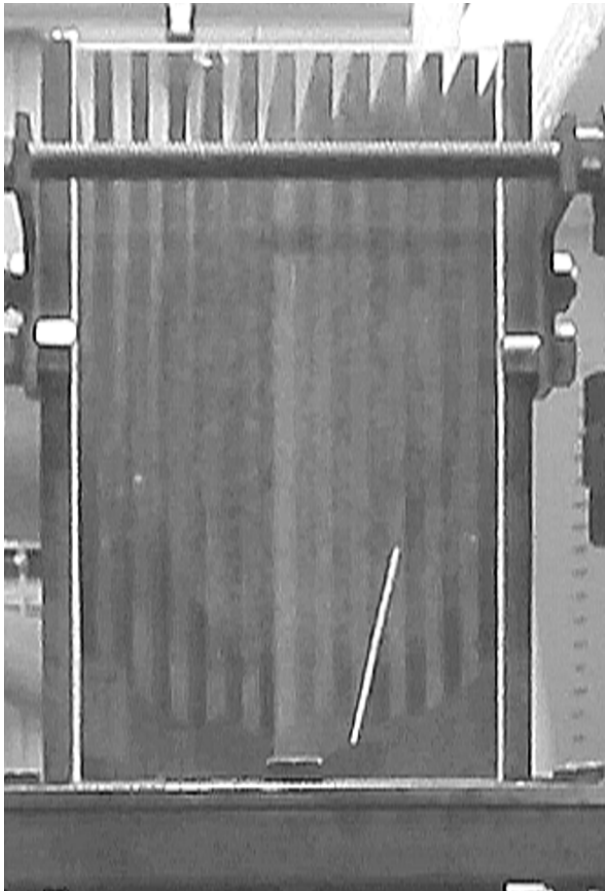
600°C



Conclusion

- Shell-and-plate moving packed-bed heat exchangers offer a simple alternative to fluidized beds
- Average particle-wall heat transfer coefficients in the range of 220 W/m^2-K are attainable
- Granular flow is significantly affected by operation at elevated temperature

- 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

Acknowledgements

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