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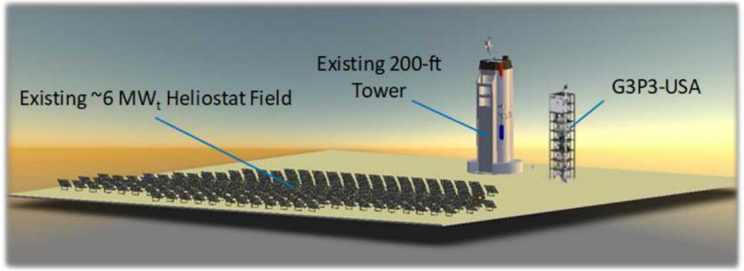
Evaluating the Effective Solar Absorptance of Dilute Particle Configurations



PRESENTED BY

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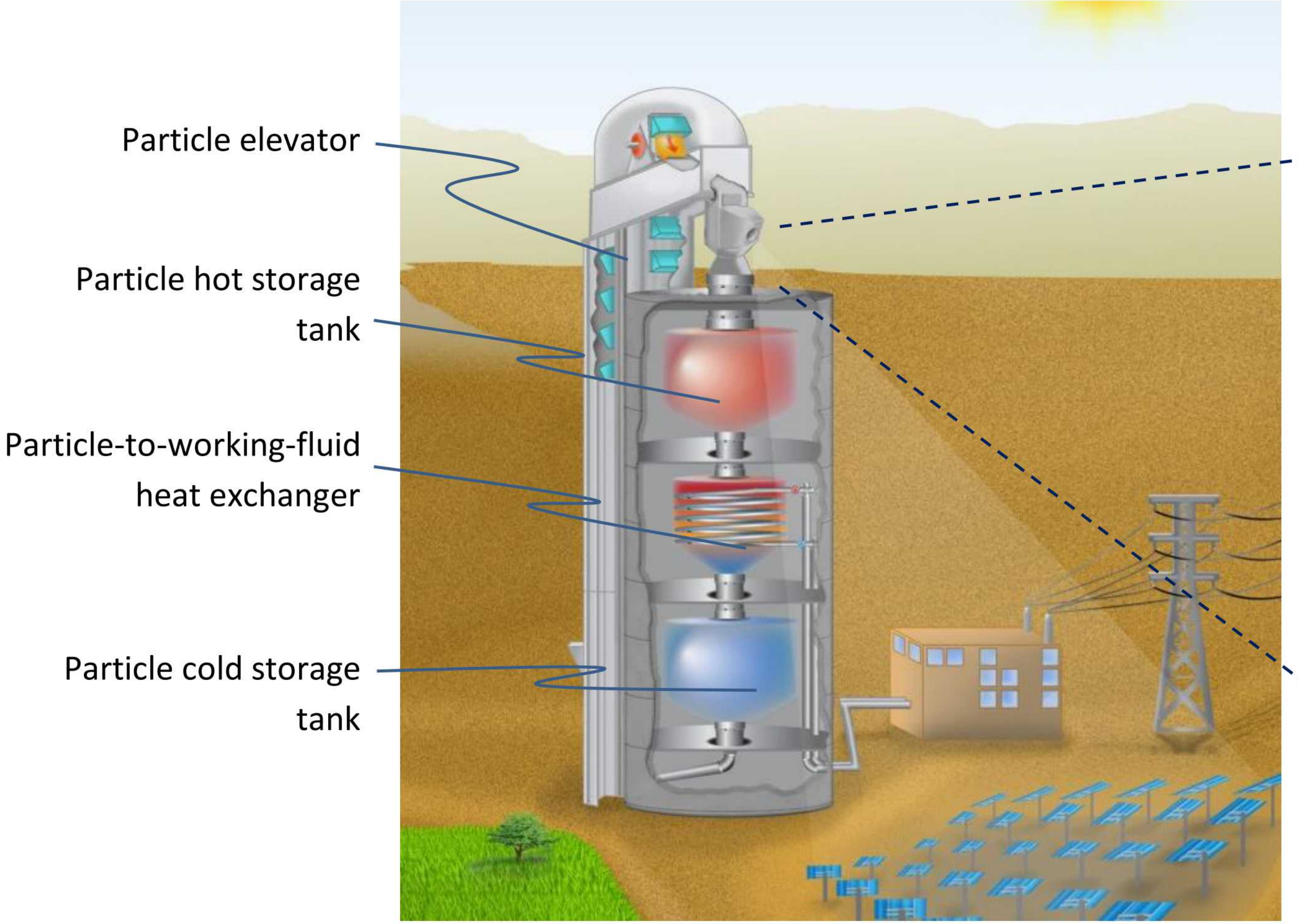
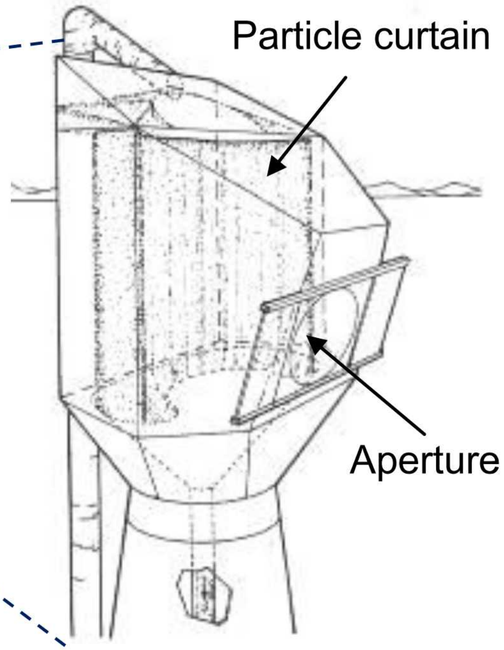
Overview

- Introduction and Objectives
- Modeling Approach
- Results
- Conclusions

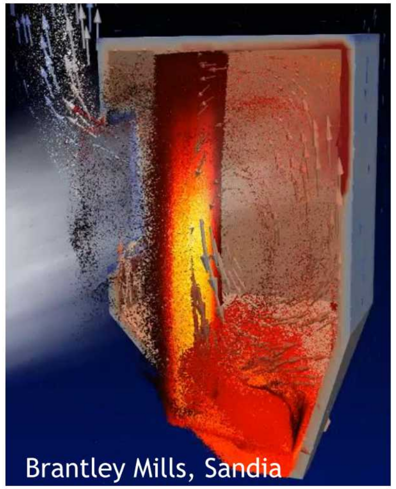
Introduction

High-Temperature Falling Particle Receiver





Falling particle receiver



Goal: Achieve higher temperatures, higher efficiencies, and lower costs

Objective

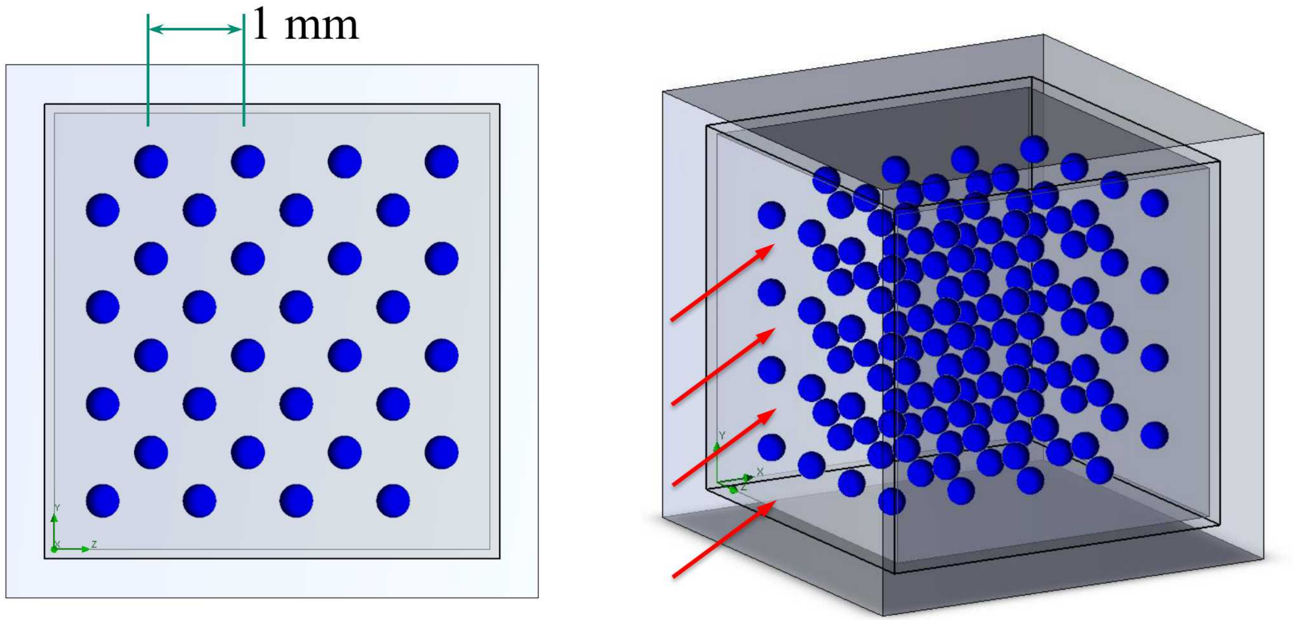
- Develop ray-tracing models to evaluate the effective solar absorptance of dilute discrete particle configurations for different particle materials and volume fractions
    - E.g., CARBO beads
        - High intrinsic solar absorptance (~0.9)
        - High cost (~$1/kg)
    - E.g., Sand
        - Low intrinsic solar absorptance (~0.5)
        - Low cost (~$0.01 - $0.10/kg)

CARBO ceramic beads (sintered bauxite)

Riyadh red sand (left) and CARBO beads (right)

Model Domain

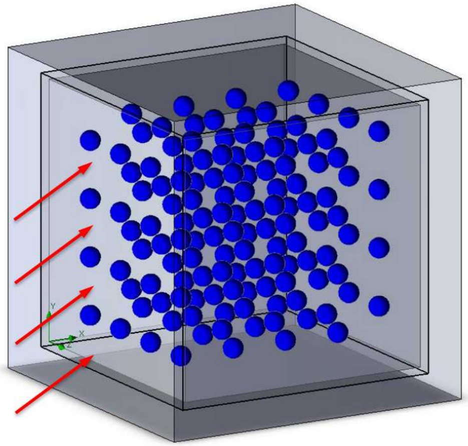
Representative Elementary Volume of Particles

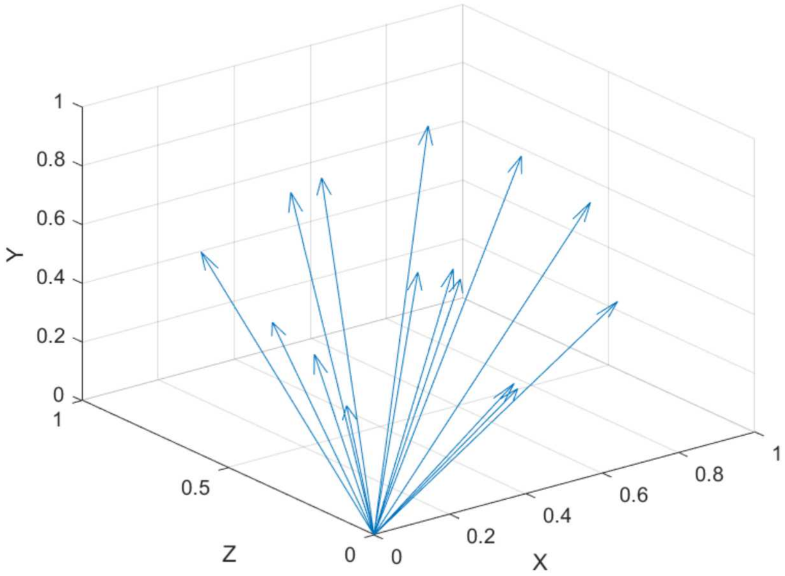


- Staggered array of spherical particles (350 microns)
- Rays enter from left wall
- Left and right boundaries are blackbody walls (fully absorbing)
- Lateral walls are symmetry radiative surfaces (specularly reflecting)

Parameter	Value
Cube dimension (m)	0.0045
Particle diameter (m)	3.50E-04
Particle surface area (m^2)	3.85E-07
Particle volume (m^3)	2.24E-11
Particle cross-sectional area (m^2)	9.62E-08
Area of cube normal to x (m^2)	2.03E-05
Particle-to-particle centerline spacing (m)	0.001
Total number of particles	128
Total volume of particles (m^3)	2.87E-09
Total surface area of particles (m^2)	4.93E-05
Total projected particle area normal to x (m^2)	3.08E-06
Total volume of cube (m^3)	9.11E-08
Solids volume fraction (-)	3.15E-02
Opacity in x-direction (-)	1.52E-01

Ray Tracing



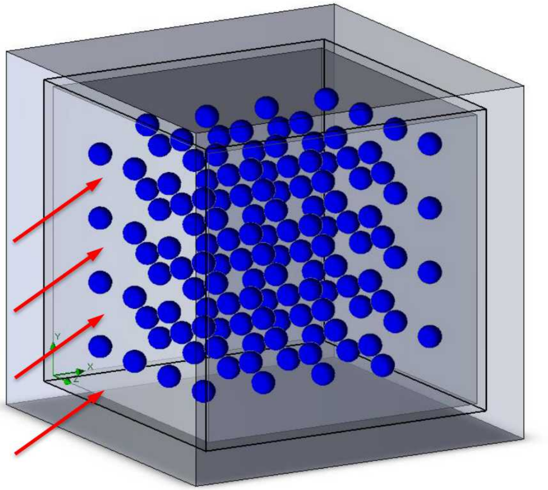


$$\alpha' = \frac{\alpha}{1-\tau} = \frac{\alpha}{\alpha+\rho}$$

Metric: Effective absorptance of non-transmitted radiation through the particles

- 500,000 rays were emitted from the left plane with a total power of 1W
- Multiple realizations with different ray directions were simulated

Thermal Modeling



1 MW/m^2

All walls maintained at 20 °C

Parameter	Value
Particle density (kg/m^3)	3,600
Particle specific heat at 700 °C (J/kg-K)	1,200
Thermal conductivity (W/m-K)	2

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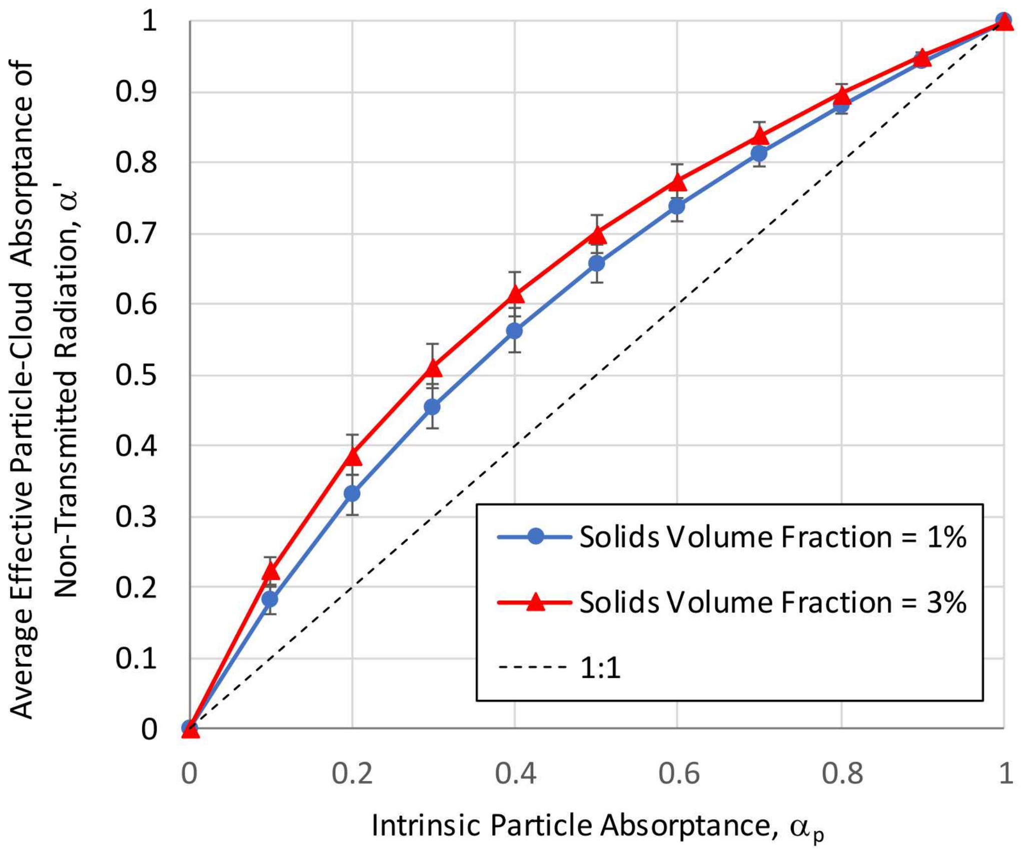
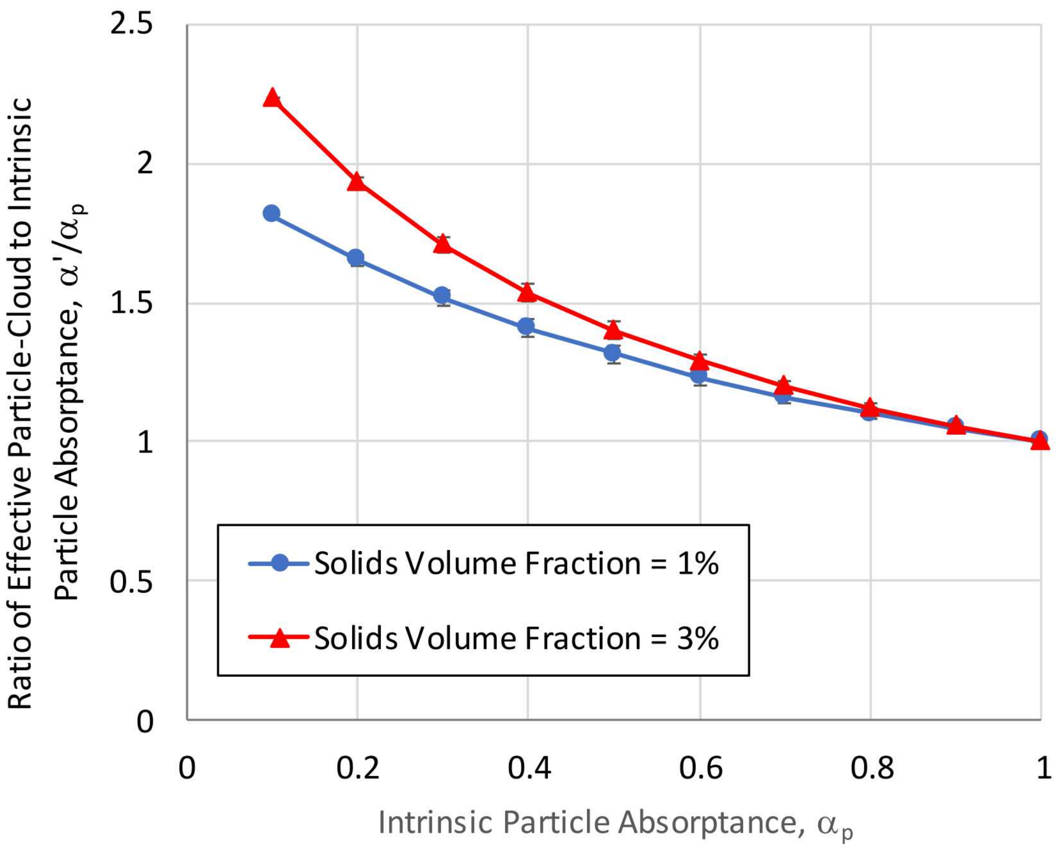
Effective Particle Cloud Absorptance



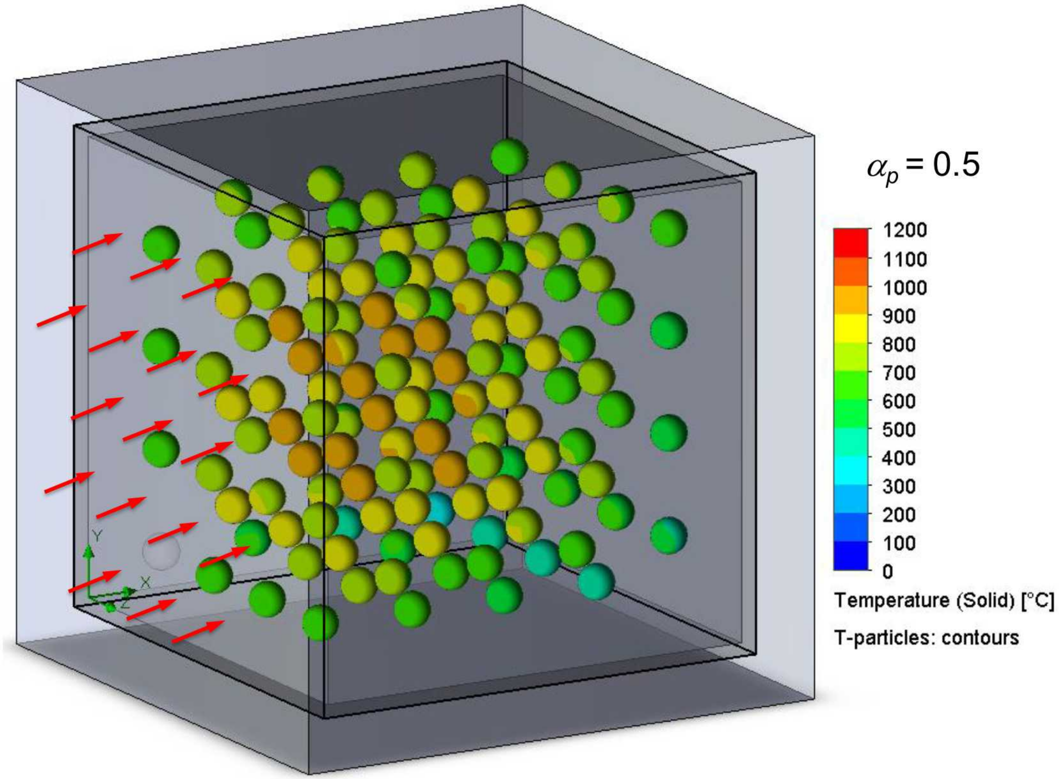


- Effective particle cloud absorptance greater than intrinsic particle absorptance
- There is an optimum solids volume fraction that maximizes effective particle cloud absorptance

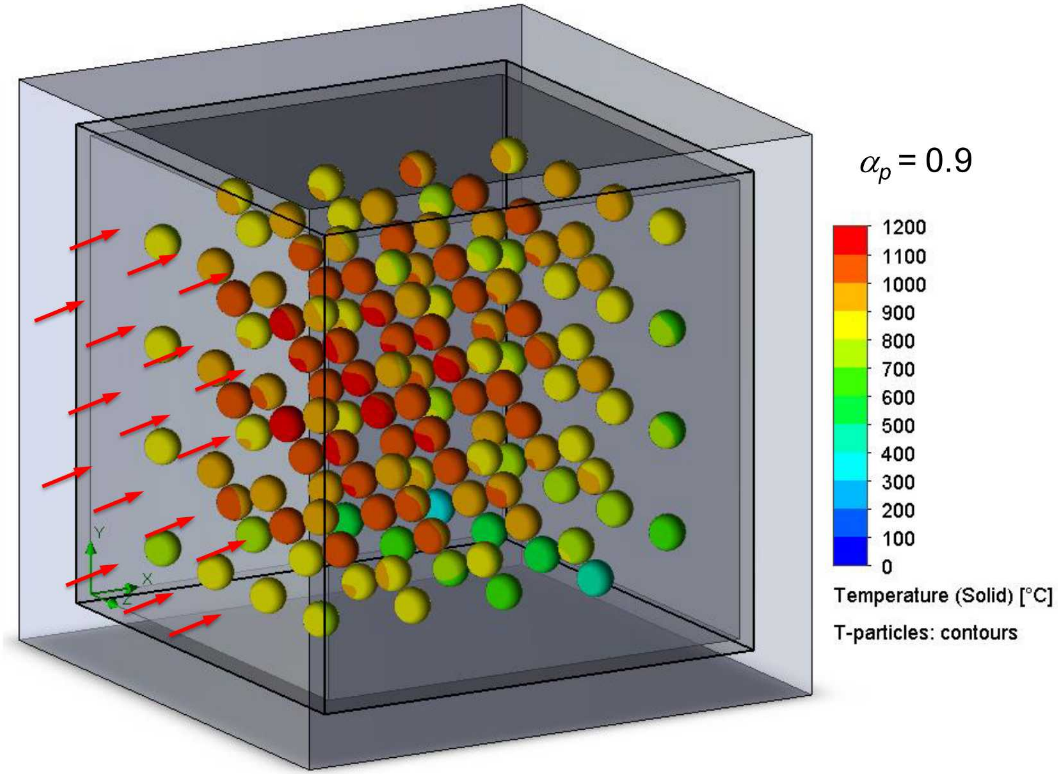
- Relative increase in effective particle-cloud absorptance is greater for lower intrinsic particle absorptance values

Thermal Results (1 MW/m^2 irradiance; all walls held at 20 °C)

α_p = 0.5 (e.g., sand)



α_p = 0.9 (e.g., CARBO beads)



- Steady-state particle temperatures are several hundred degrees higher for an intrinsic particle absorptance of 0.9 versus 0.5
- Temperatures can vary by several hundred degrees within the particle cloud due to particle shading
- Steady-state temperature gradients within each particle were simulated to be up to ~60 °

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Conclusions

- The simulated effective particle-cloud absorptance was greater than the intrinsic particle absorptance in all cases (except when the intrinsic absorptance was 0 or 1) due to light-trapping effects of the discrete particles
- An optimal solid volume fraction exists to maximize effective solar absorptance
- Simulated steady-state particle temperatures could be up to several hundred degrees higher for an intrinsic particle absorptance of 0.9 versus 0.5
- Significant temperature gradients existed within both the stationary particle cloud and the particles themselves
  - Dynamic flow and mixing of particles within an actual falling particle receiver will likely reduce these temperature gradients

Acknowledgments

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