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CFD Simulation and Performance Analysis of Alternative Designs for High-Temperature Solid Particle Receivers

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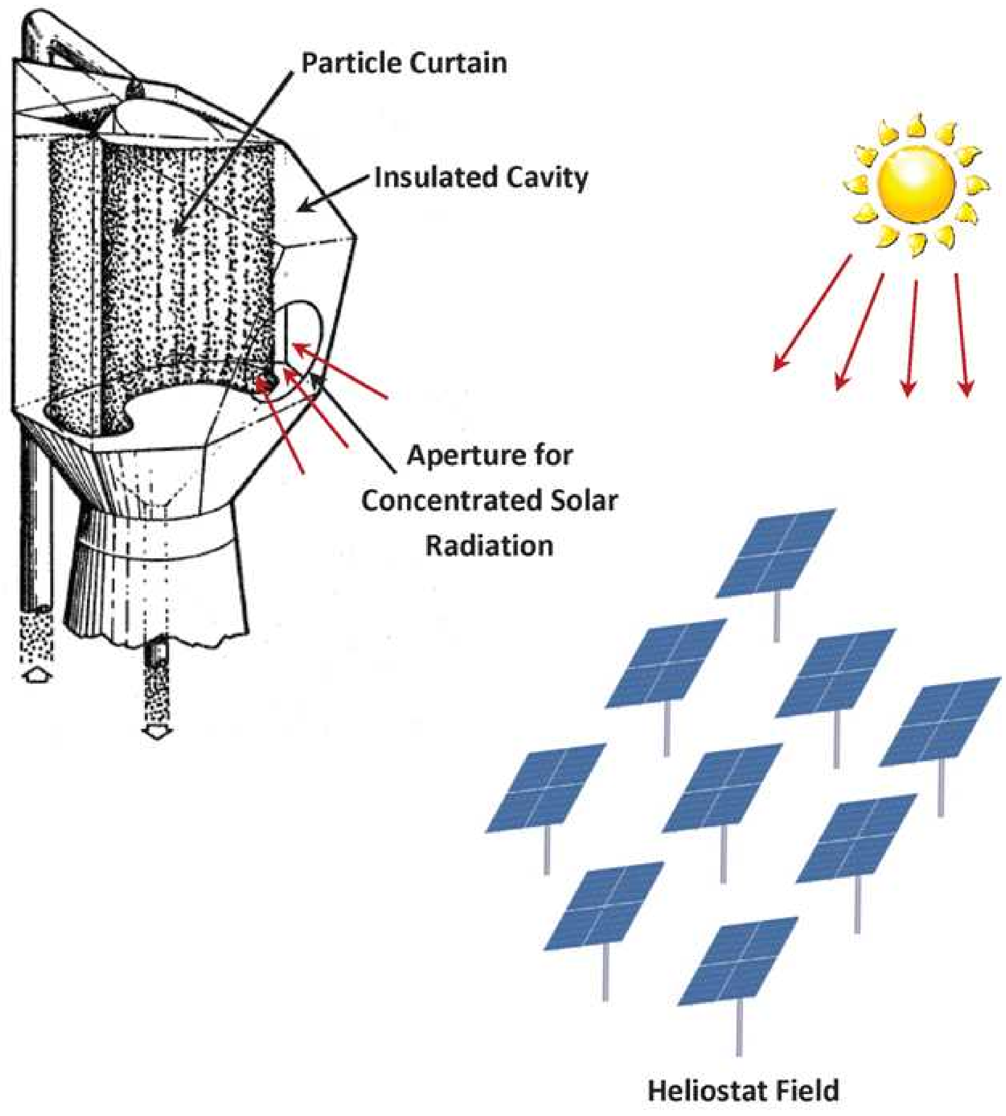
Overview

- Introduction
- Receivers and Heliostat Fields
- CFD Modeling Approach
- Results and Analysis
- Summary and Ongoing Work

Solid Particle Receivers



Objectives

- **Compare alternative designs for solid particle receiver**
  - Face-down receiver
  - North-facing receiver
- **Use rigorous computational fluid dynamics models**
  - Account for actual radiance from heliostat field as a boundary condition on the aperture
  - Include particle interaction and recirculation

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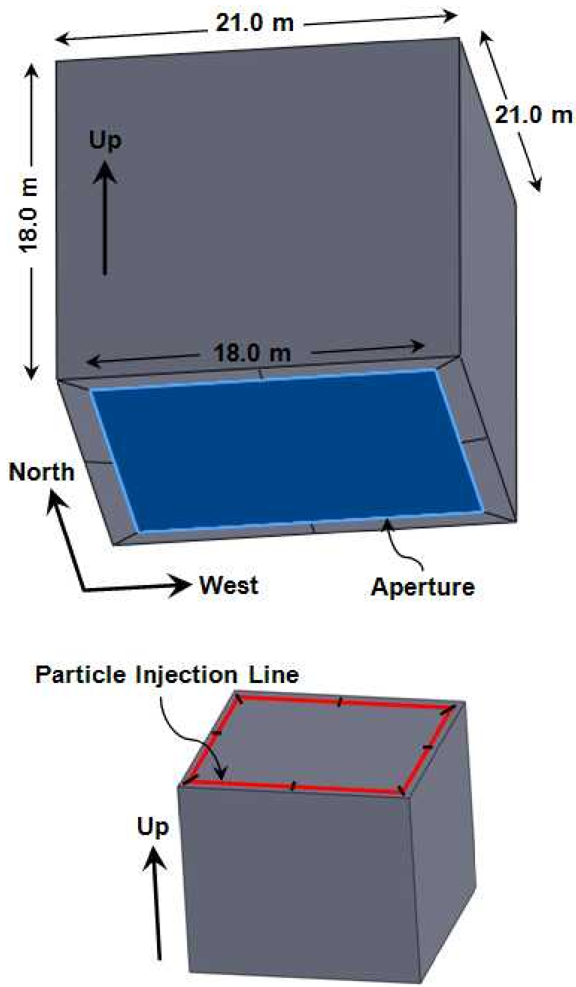
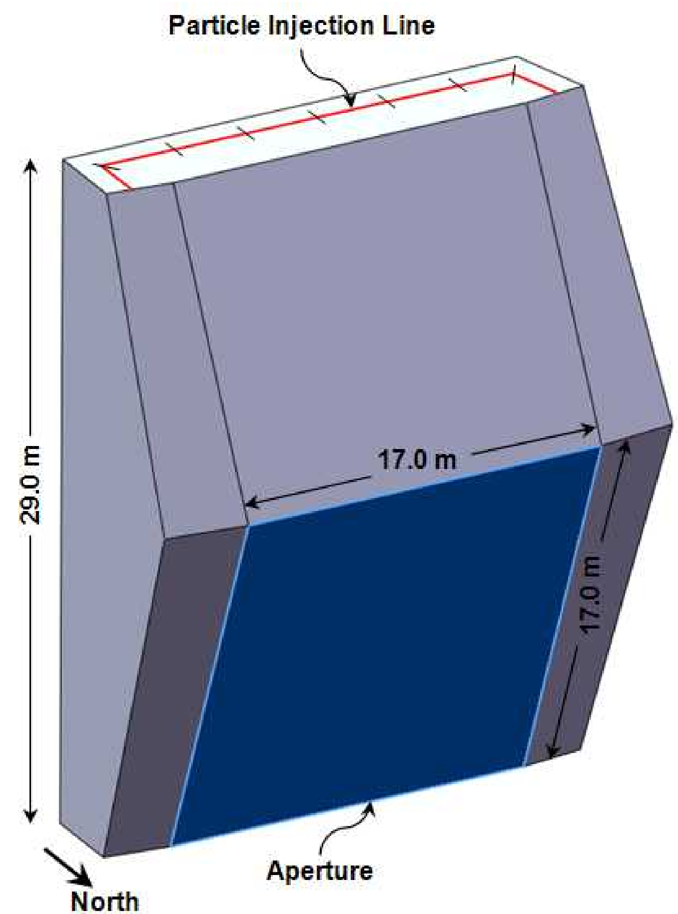
Receiver Designs

Face-Down Receiver



North-Facing Receiver



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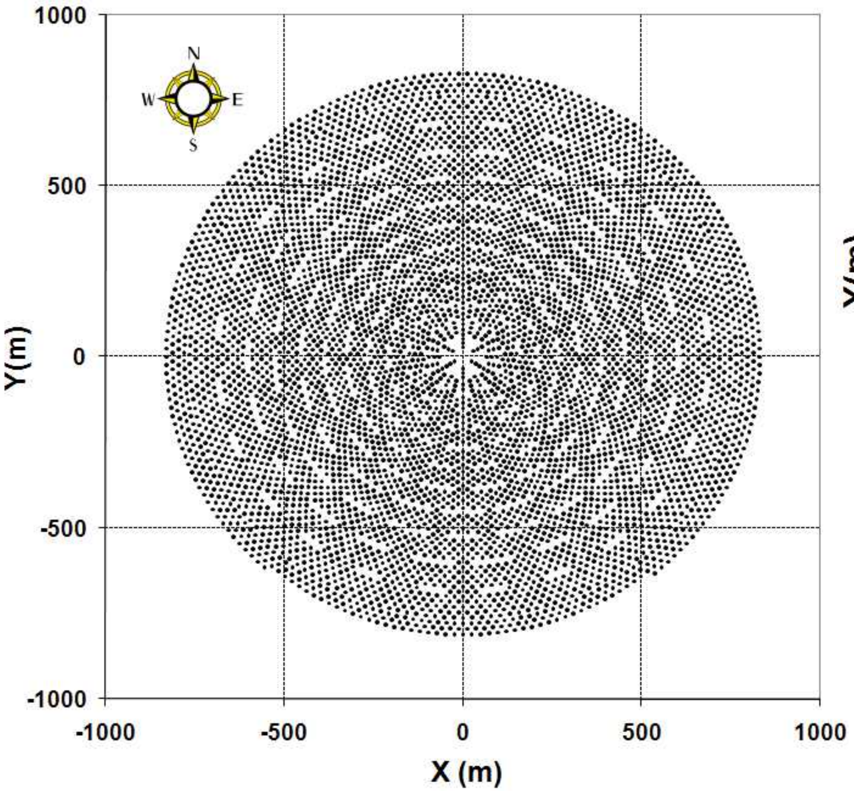
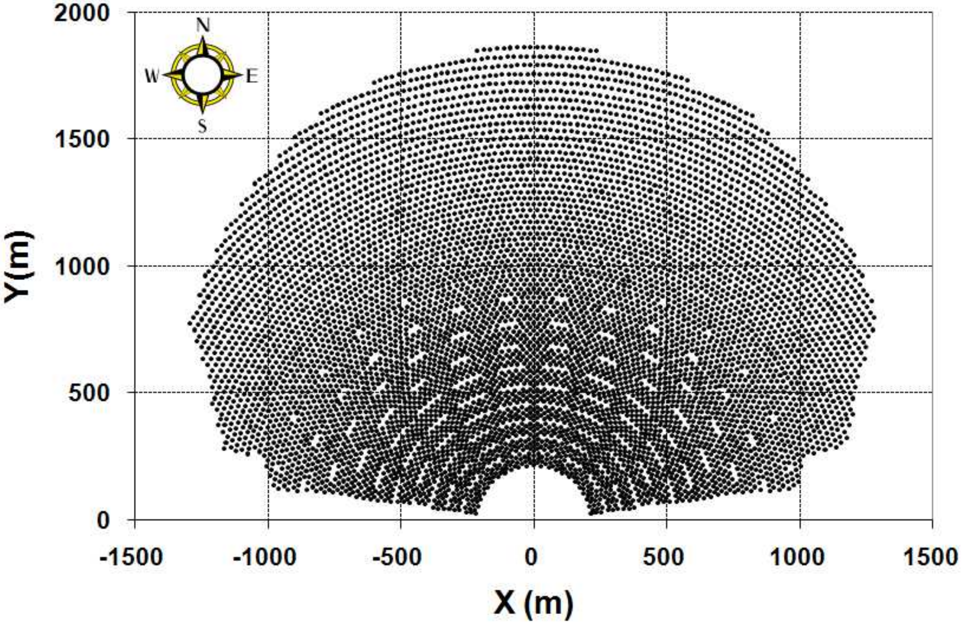
Heliostat Fields

Surround-Field



5,922 Heliostats
417 MWth at Solar Noon, 3/22
Tower Height = 280 m

North-Field



7,183 Heliostats
487 MWth at Solar Noon, 3/22
Tower Height = 290 m

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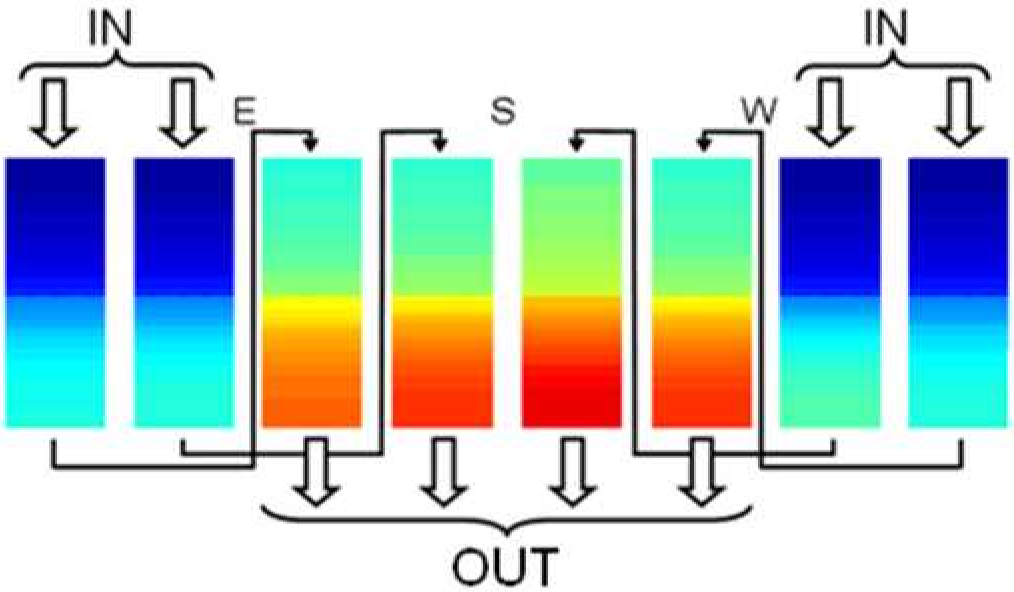
Particle Recirculation

Recirculation Pattern for Solar Noon



Mass Flow Rates:

- North-Facing Receiver = 582 kg/s
- Face-Down Receiver = 596 kg/s

From: Röger, M., L. Amsbeck, B. Gobereit, and R. Buck. 2011. "Face-Down Solid Particle Receiver Using Recirculation". In press, J. Sol. Energy Eng.

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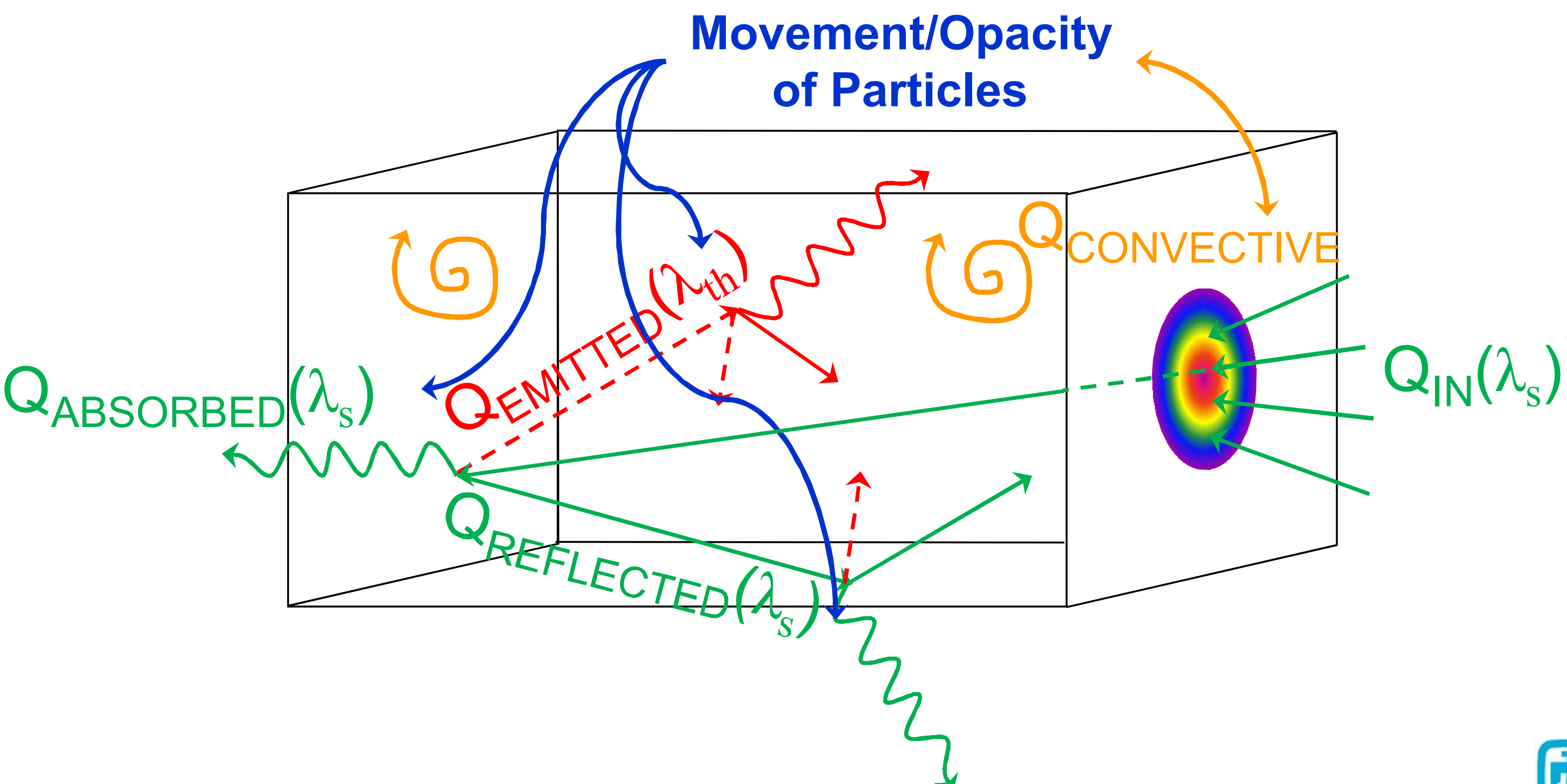
Radiance Boundary Conditions

Particles in receiver requires full coupling of solar and thermal processes.



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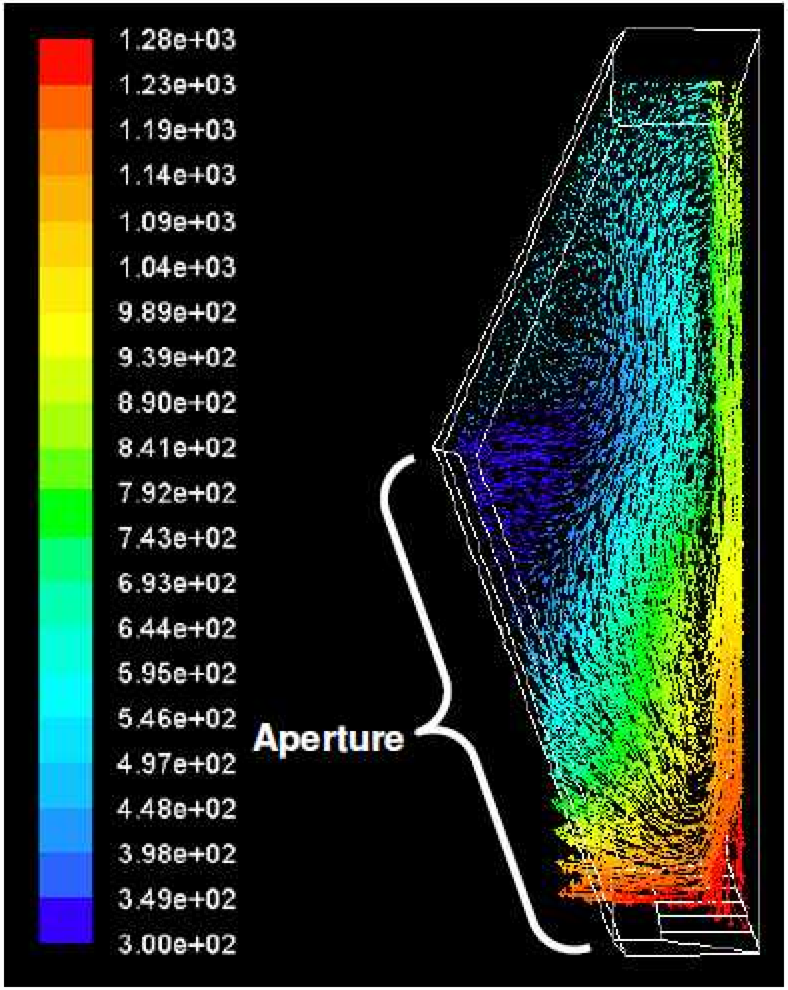
Results – Solar Noon on March 22

	North-Facing Receiver	Face-Down Receiver
Particle Injection Temperature	300°C	300°C
Particle Equilibrium Temperature at Outlet	819°C	769°C
Radiative Losses	6.5%	**11.4%**
Convective Losses	**20.9%**	9.6%
Thermal Efficiency	72.3%	78.9%

Air Velocity Vectors Colored by Air Temperature (K)

North-Facing Receiver



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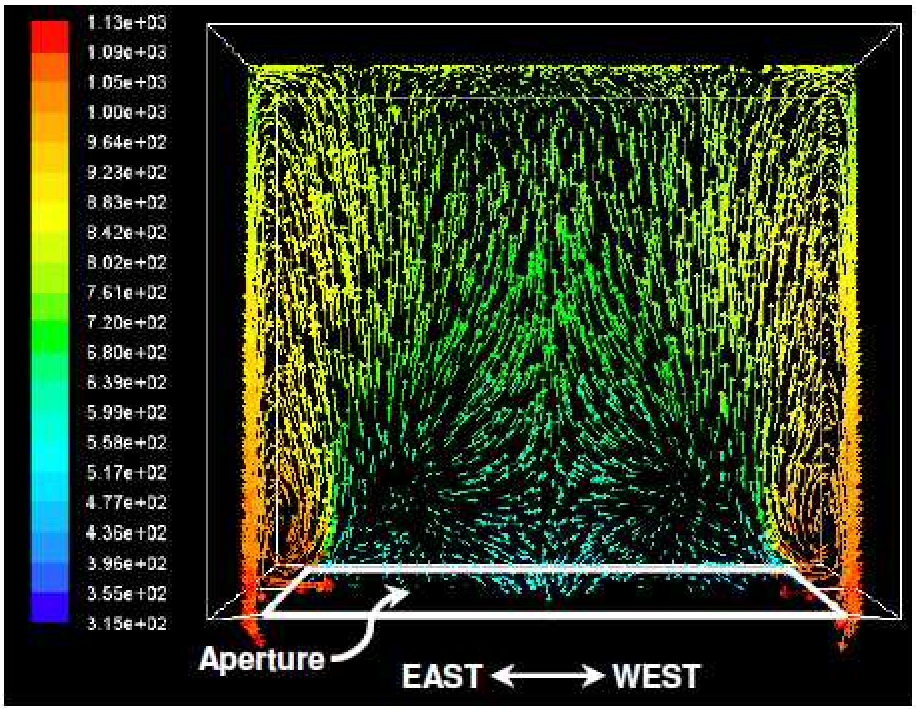
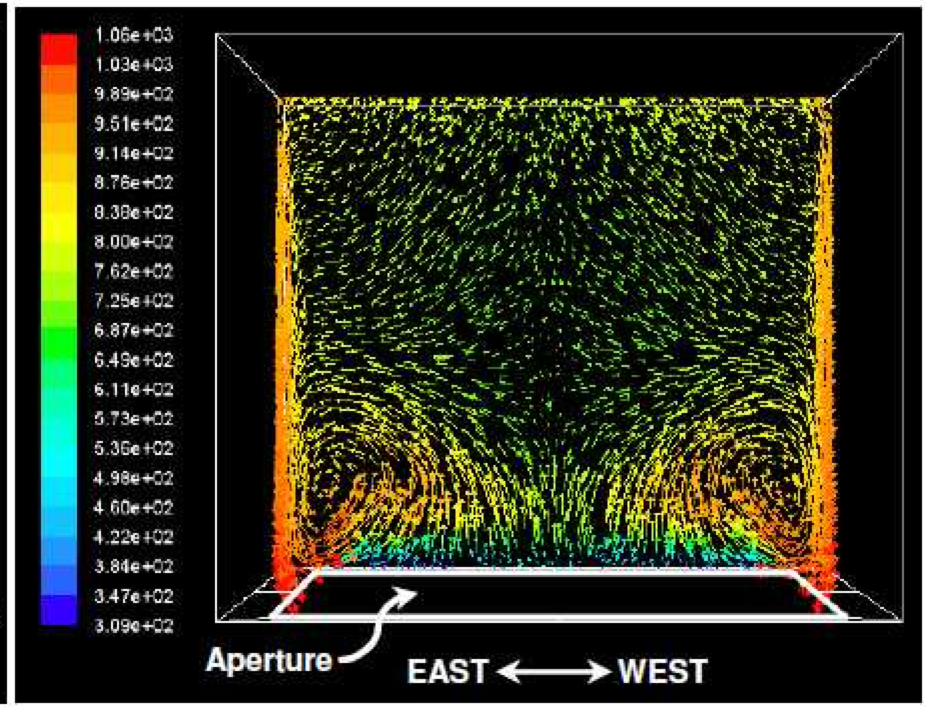
Air Velocity Vectors Colored by Air Temperature (K)

Face-Down Receiver



Plane at Aperture Center



Plane 7.5m South of Aperture Center

Results – Solar Noon on March 22

	North-Facing Receiver	Face-Down Receiver
Particle Injection Temperature	300°C	300°C
Particle Equilibrium Temperature at Outlet	819°C	769°C
Radiative Losses	6.5%	**11.4%**
Convective Losses	**20.9%**	9.6%
Thermal Efficiency	72.3%	78.9%
Particle Curtain Opacity	98.6%	76.1%

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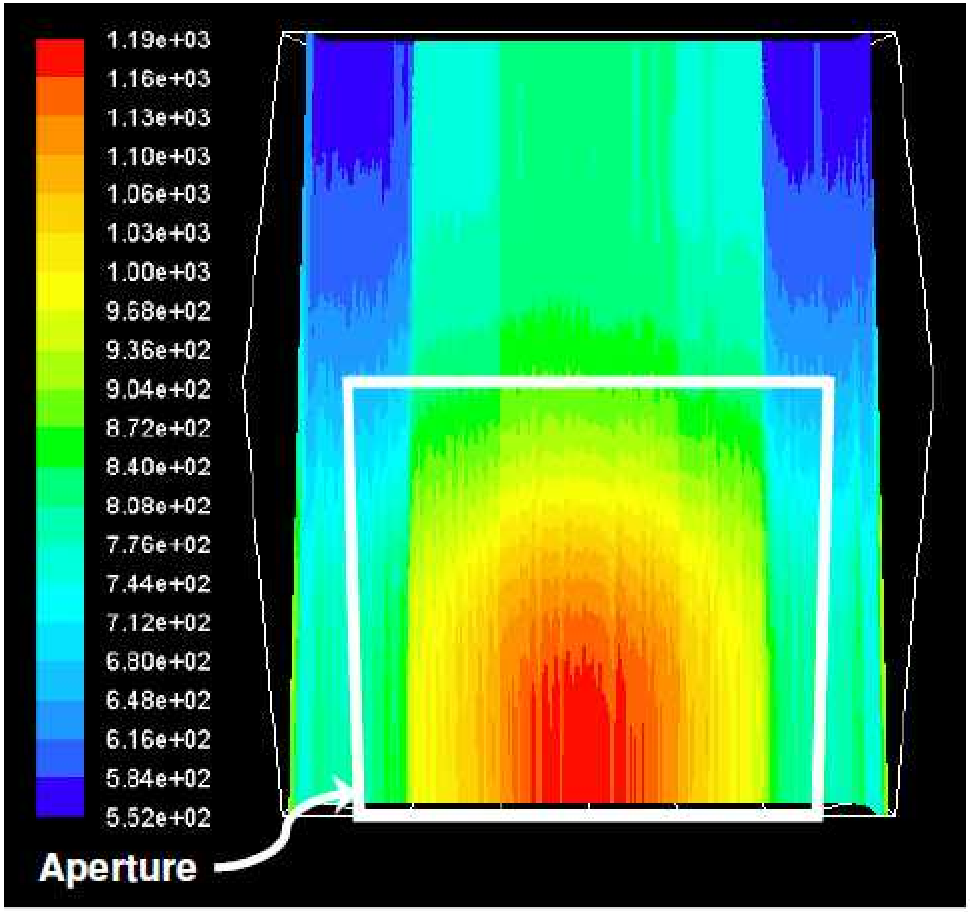
Particle Tracks Colored by Particle Temperature (K)

North-Facing Receiver



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Summary

- Solid particle receivers capable of yielding temperatures > nitrate-salt HTF

- Rigorous CFD simulations of alternative receiver designs performed

Results	North-Facing Receiver	Face-Down Receiver
Radiative Losses	6.5%	**11.4%**
Convective Losses	**20.9%**	9.6%
Thermal Efficiency	72.3%	78.9%

Ongoing Work

- **Reduce losses from both receiver configurations:**
  - Aperture nod angle and size
  - Particle curtain location
  - Particle curtain opacity (Chen et al., 2007; Siegel et al., 2010)
  - Particle recirculation pattern (Röger et al., 2011)
  - Particle diameter (Chen et al., 2007)
  - “Suction-recirculation” device (Kolb, 2009)
  - “Aerowindow” (Tan et al., 2009)

Supplemental Slides

Assumptions for Optimization of Receivers and Heliostat Fields

Heliostat Costs	$177 /m^2$
Tower Costs[1]	$557,000 x exp(1.2·$h_T$/110m)
Receiver Cost	$109,000 /MWth
Land Cost	$3 /m^2$
Annuity	0.0988
O&M Costs	2 %/year of total investment
Heliostat Reflective Area	121 m^2 per heliostat (11m x 11m)
Heliostat Reflectivity	0.87
Heliostat Slope Error	1.835 mrad (mirror normal)
Heliostat Facet Canting	All canted to slant range
Receiver Aperture Shape	Rectangular
Required Peak Output	350 MWth
Site Latitude	34.5°N

[1] h_T: tower height in m

Röger, M., L. Amsbeck, B. Gobereit, and R. Buck. 2011. "Face-Down Solid Particle Receiver Using Recirculation". In press, J. Sol. Energy Eng.

Receiver and Heliostat Field Optimization Results

	North-Facing Receiver	Face-Down Receiver
Field Type	North	Surround
Power into Receiver at Solar Noon	487 MWth	417 MWth
Number of Heliostats	7,183	5,922
Tower Height	290 m	280 m
Aperture Nod Angle (Down from Horizontal)	20°	90° (face-down)
Aperture Size	17m x 17m	18m x 18m

Particle Properties

Density	3550 kg/m^3
Specific Heat (J/kg/K)	$-7.309\times10^{-4}T^2 + 1.608T + 372.4$, *for* $273 < T \leq 1173K$ 1255, *for* $T > 1173K$
Thermal Conductivity	2.0 W/m/K
Emissivity	0.93
Scattering Factor	0.3
Mean Diameter	697 μm

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