Assessment of a Falling Solid Particle Receiver with Numerical Simulation

Birgit Gobereit, Lars Amsbeck, Reiner Buck,
Hans Müller-Steinhagen, Robert Pitz-Paal

Birgit.Gobereit@dlr.de, DLR Stuttgart, Germany

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Contents

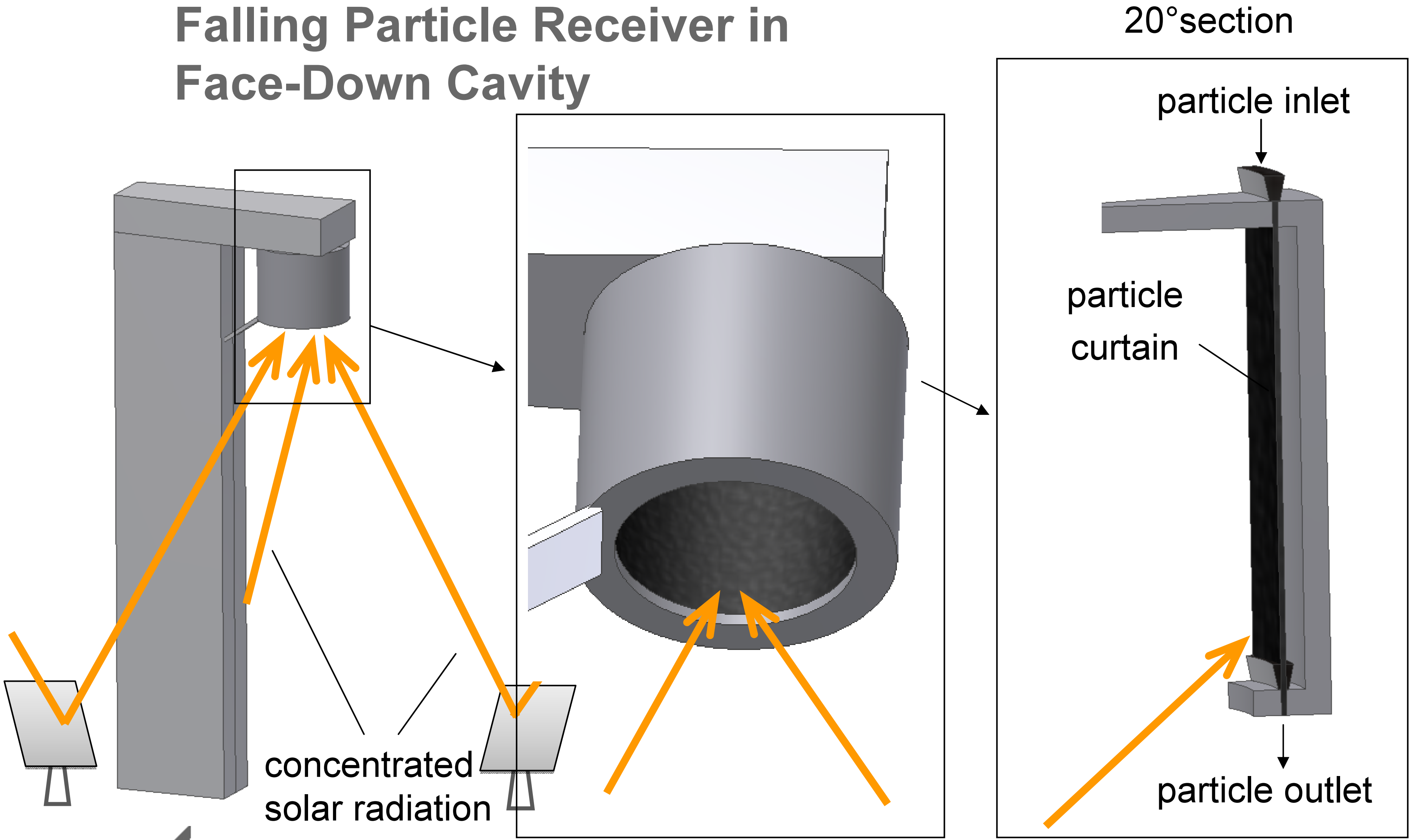
Particle Receiver

- Electricity generation (about 10..50 MWel, resp. 50..350 MWth)
- Solid ceramic particles as absorber, transport and storage material

- Direct absorption
- No freezing
- No decomposition
- High temperatures
- Inherent Storage

- Low Levelized Electricity Costs (LEC)

Falling Particle Receiver in Face-Down Cavity



Modeling

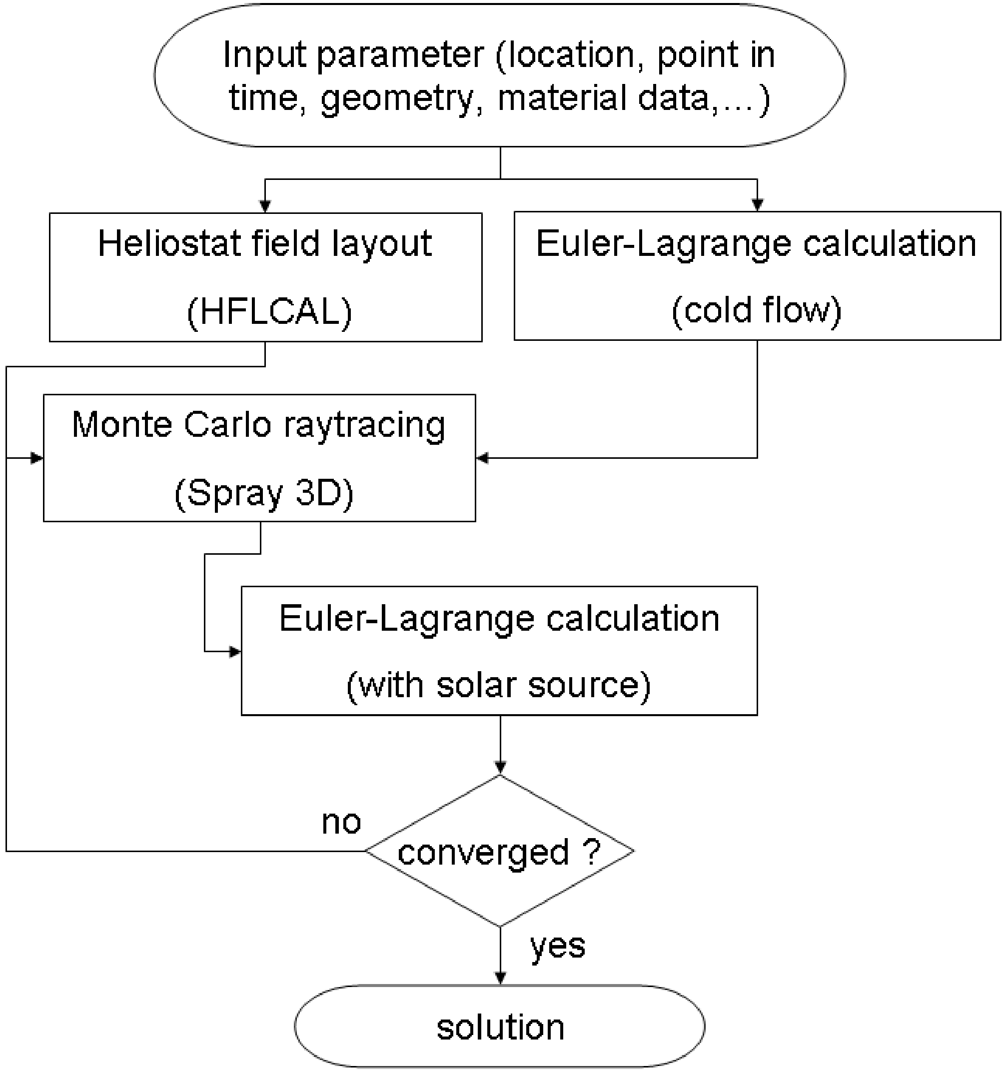
Workflow

CFD calculation
-air: continuous, Euler phase
-particles: discrete Lagrange phase

Monte Carlo raytracing
-solar radiation

CFD calculation
-Euler-Lagrange
-heat transfer
-diffuse radiation: discrete ordinate model

-sequentially solving of equations



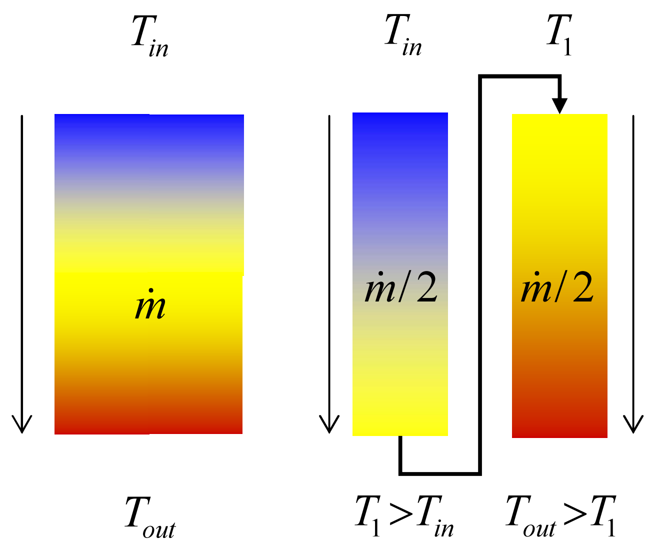
Reference Case
Model Parameters

- Reference case Matlab-model presented by Röger et al. (Solar PACES, 2010, J. Sol. Energy Eng. 2011):

- particles: sintered bauxite (main constituent $Al_2 0_3$)
- averaged particle diameter: 0.7 mm
- absorptivity of particles: 0.93

- solar input power: 394 MW
- aperture: 22.1 m diameter
- cavity height: 21.5 m
- absorptivity of walls: solar 0.25 / thermal 0.7

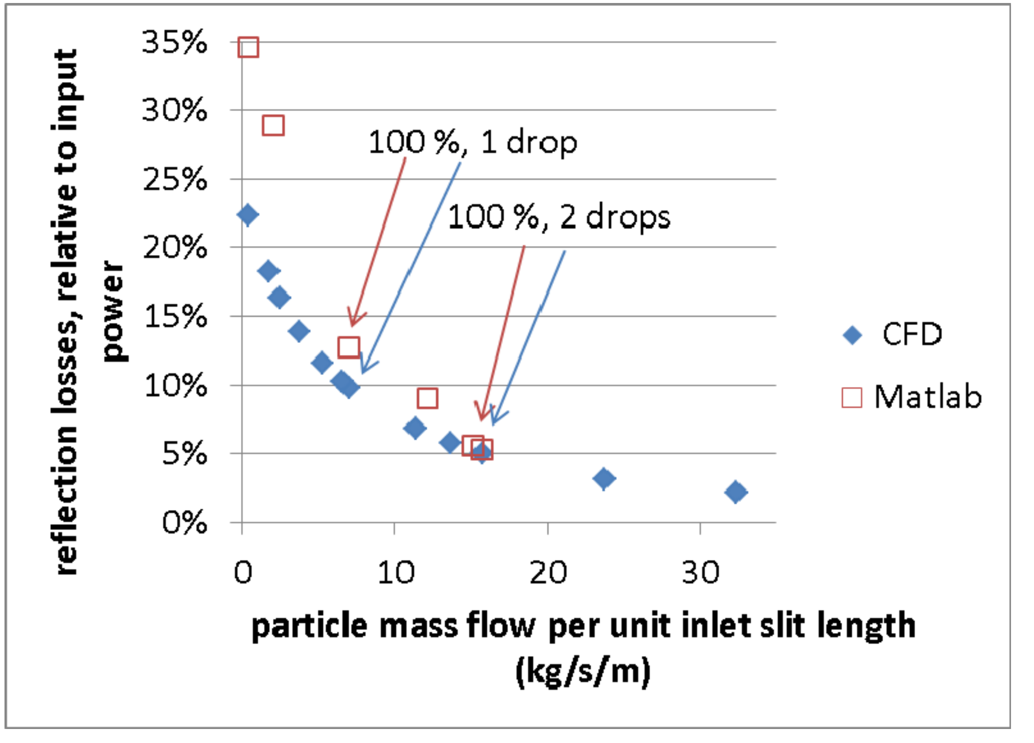
- temperature increase from 300 °C to 800 °C
- different operation strategies, recirculation



Results

Reflection losses

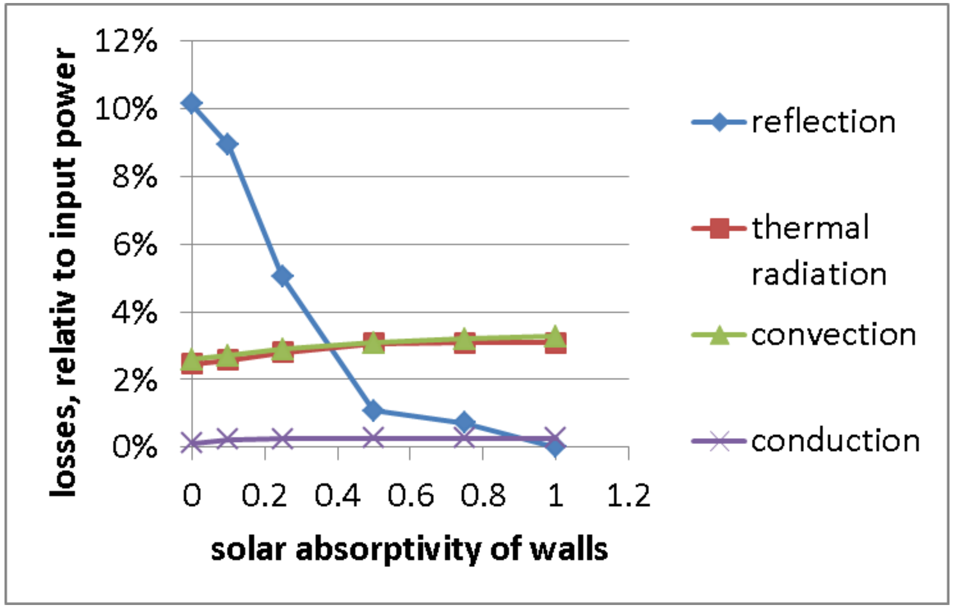
- Both models predict significant decrease of reflection losses (relative to input power) with increasing mass flow rate per unit inlet slit length.
- Good agreement at high particle mass flow rates, but difference at low mass flow rates, due to different calculation of air entrainment.

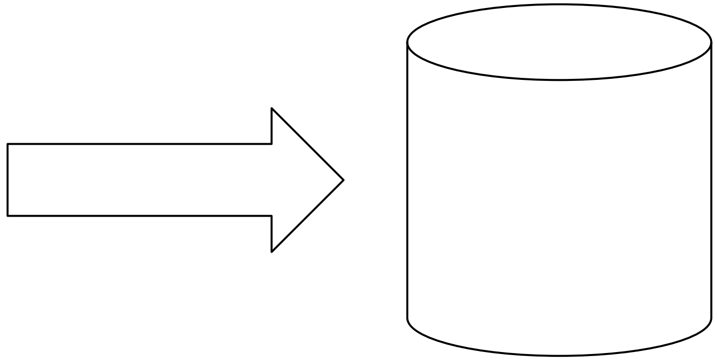


- Receiver walls with low solar absorptivity cause reflection losses in excess of 20 % during part load operation with low particle mass flows.
- Recirculation can reduce reflection losses to 2 % !

Solar Absorptivity of The Walls

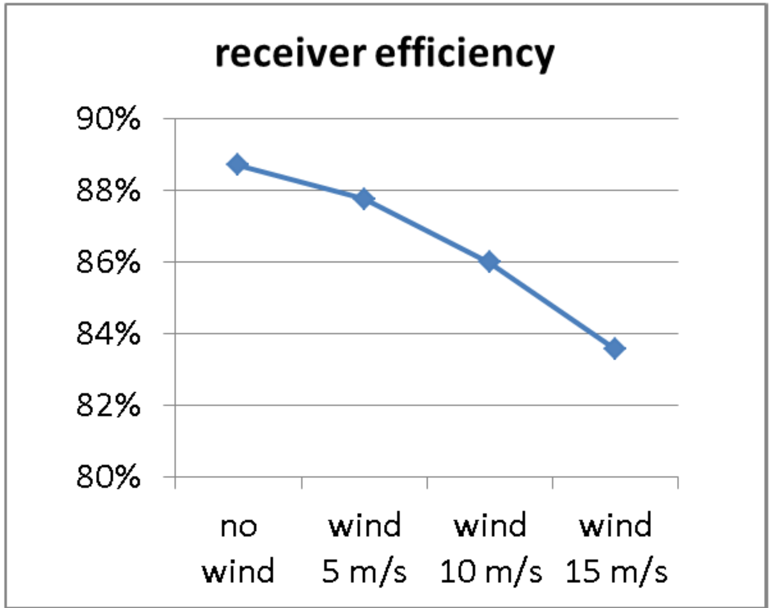
- Variation of solar absorptivity of the wall, test case 100 % load, 2 drops
- Realistic values: ceramic insulation 0.25, high temperature paint 0.95
- Decrease of reflection losses from 5 % (solar absorptivity of 0.25) to less than 1 % (solar absorptivity of 0.95).
- Convection, thermal radiation, and conduction losses increase due to slight higher temperatures, but all together less than 1.5 %-point.
- Black walls recommended.

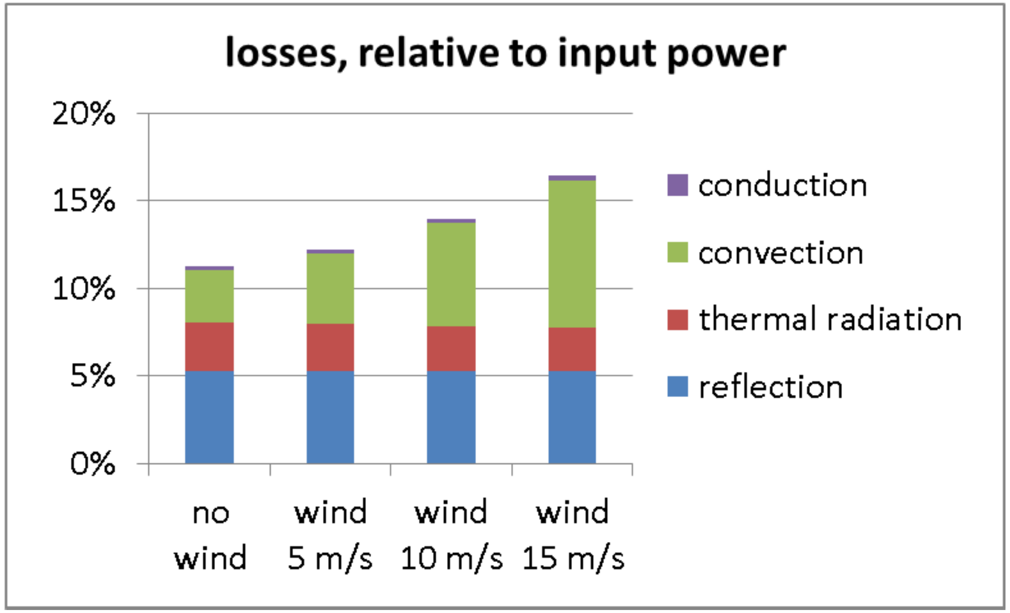




Wind Effects
Quantitative Results

- Horizontal side wind, different wind speeds
- Efficiency decreases with wind speed from 89 % to 84 %
- Major effect is the increase of convection losses (5.4%-points)
- The thermal radiation and conduction losses decrease slightly due to convective cooling (0.3%-points)





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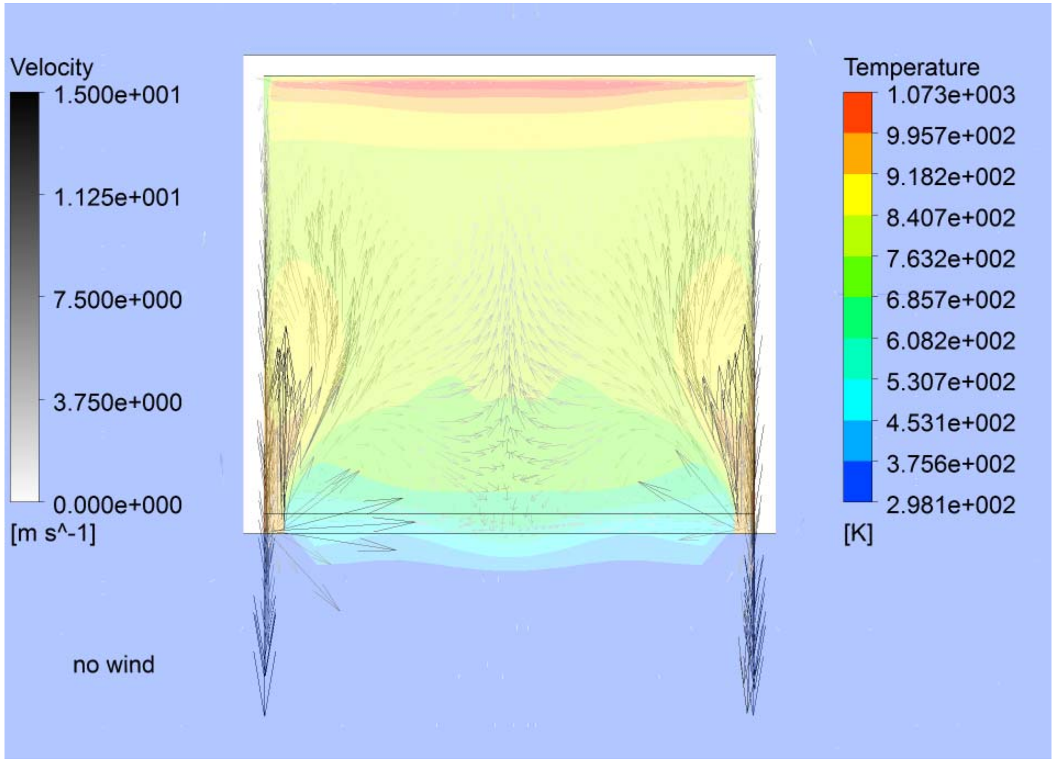
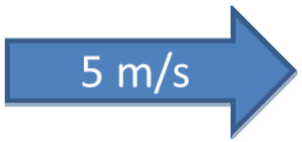
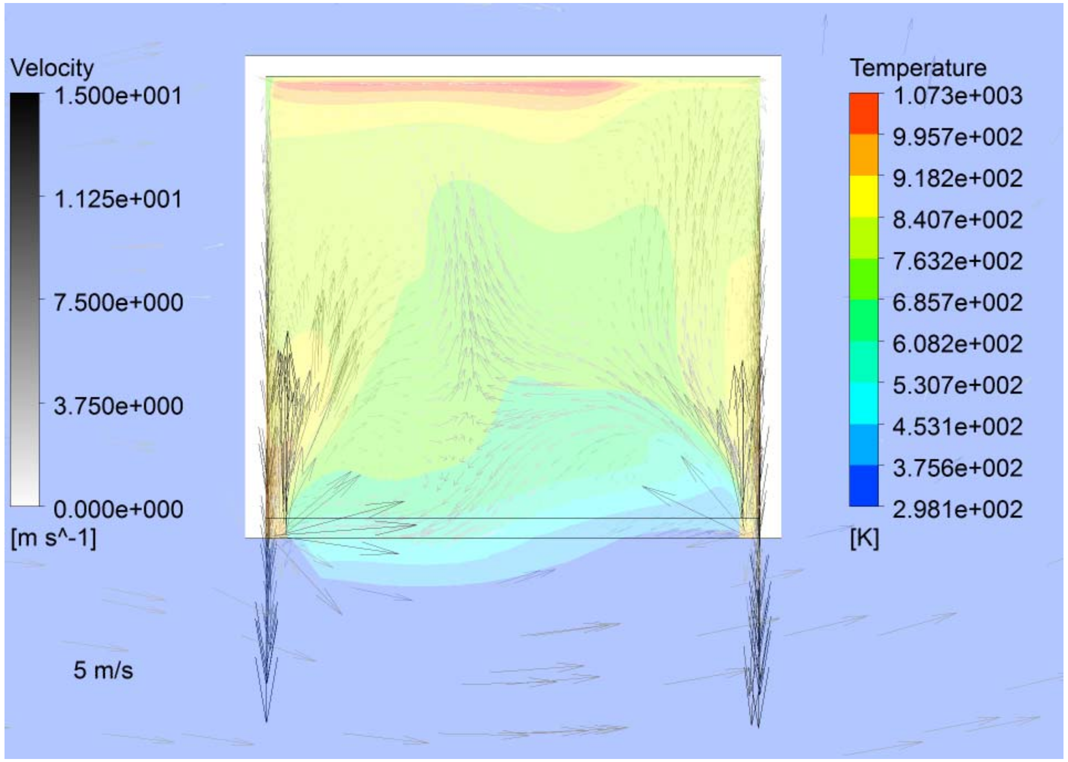
Wind Effects
Qualitative Results



velocity and temperature field in mid plane

Wind Effects
Qualitative Results

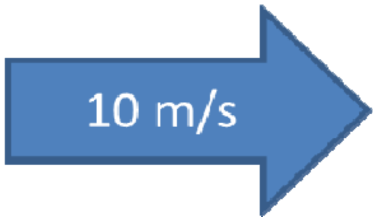


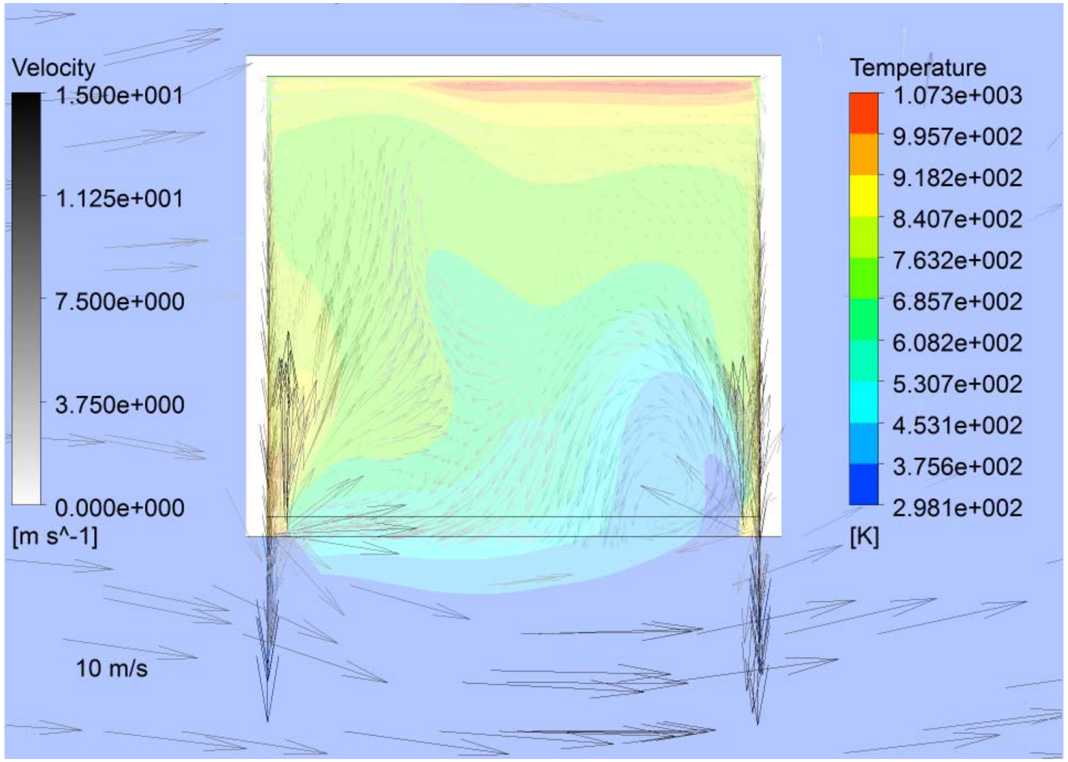


velocity and temperature field in mid plane

Wind Effects
Qualitative Results

- increasing vortex with increasing wind speed



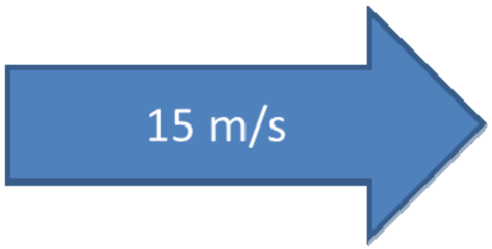


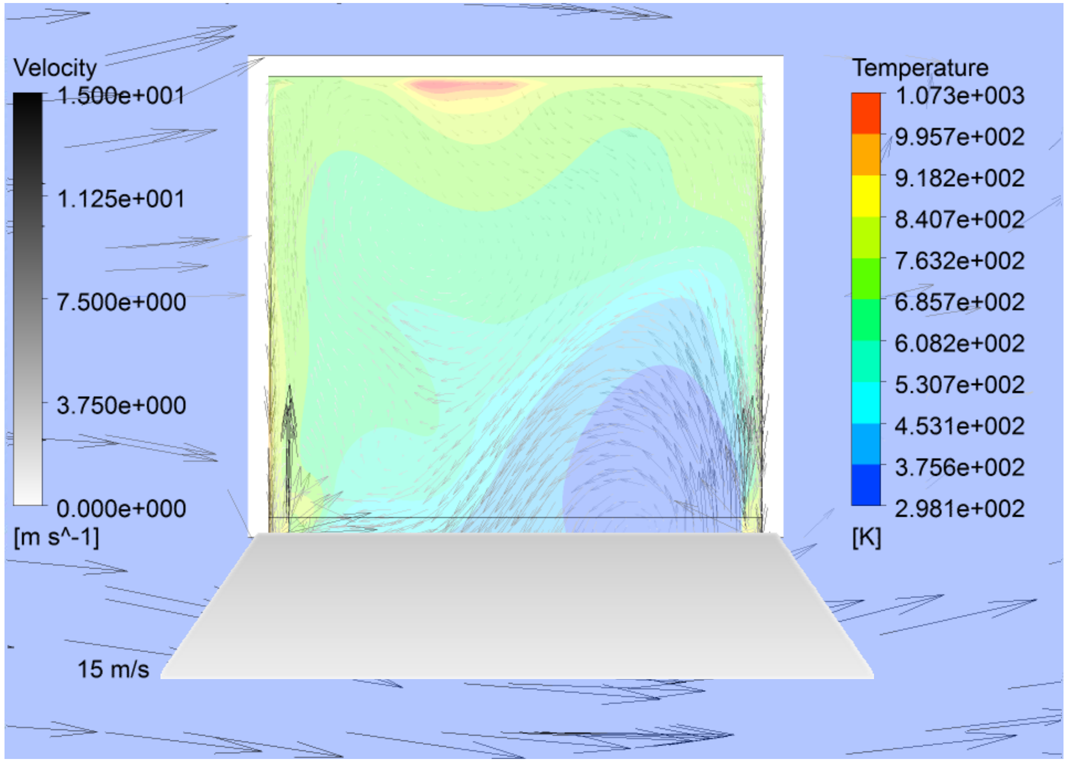
velocity and temperature field in mid plane

Wind Effects
Qualitative Results

- increasing vortex with increasing wind speed

- further work: design optimization to reduce losses, wind shielding





velocity and temperature field in mid plane

Summary and Conclusions

- Particle receiver power plant has advantages for large scale electricity generation (direct absorption, inherent storage and high temperatures).
- Promising receiver concept: falling particle in face-down cavity.

- Receiver model was developed which includes movement of air and particles, solar radiation, convective and radiative heat transfer.

- For receiver with high solar absorptivity of the walls an increasing particle mass flow decreases reflection losses from 22 % to 2 % → recirculation.
- The use of black walls is an other possibility to lower the reflection losses.

- Wind increases convection losses 5 %-points → design optimization.

Main issues for further work:
- Assessment of different parameters for layout and optimization.
- Further experiments for validation of partial models.
- Build a prototype receiver for demonstration and model validation.

Thank you for your attention!

Birgit.Gobereit@dlr.de