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High solar flux heating of upflow bubbling fluidized bed circulating in opaque vertical tube - 3d numerical simulation

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3D Numerical Simulation of Upflow Bubbling Fluidized Bed in Opaque Tube under High Flux Solar Heating

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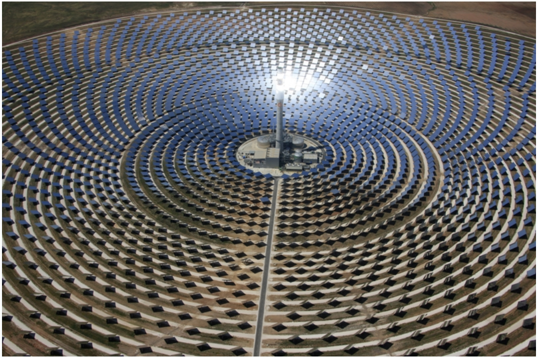
Outline

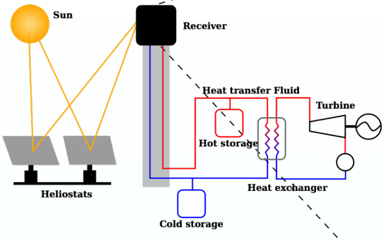
European project CSP2: Solar receiver



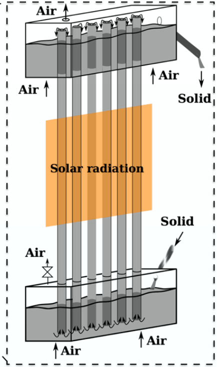
Main objectives:

- To propose an alternative to current Heat Transfer Fluid for concentrated solar power plants that can operate in a wide range of temperature (100°C-1,000°C) without freezing and decomposition.
- Geldart's group A particle of silicon carbide, easily fluidizable.

European project CSP2: Solar receiver



Power tower process diagram



Solar receiver

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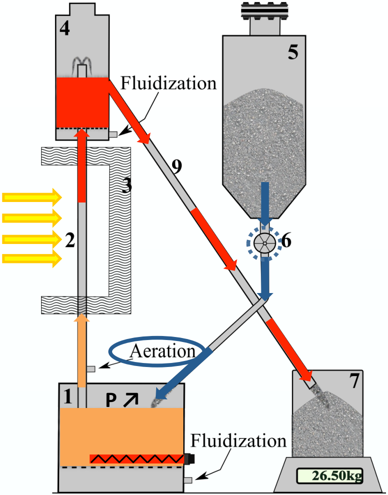
Outline

Experimental Pilot Rig

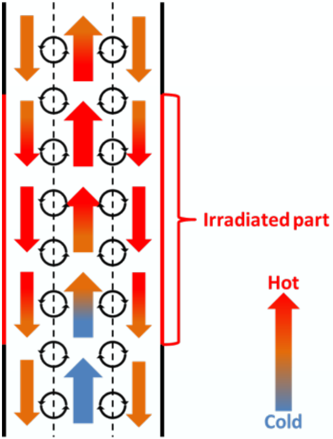
Side photograph of the setup set at the CNRS solar furnace focus.

Experimental Pilot Rig



Schematic cross-sectional view of the lab-scale solar rig.

Particle recirculation



- $T_{cavity,inlet} > T_{DiFB}$
- Cavity inlet: $T_{close-to-wall} > T_{center}$.
- Cavity outlet: $T_{close-to-wall} < T_{center}$.

Recirculation confirmed by:

- 3D numerical simulations.
- Positron Emission Particle Tracking (PEPT) (University of Surrey).

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Experimental results

- Dense Particle Suspension can work as HTF.
- Suspension temperature up to 750 $^\circ$C.
  $\Rightarrow$ high efficiency thermodynamic cycles.
- Heat transfer coefficients up to 1100 $\mathrm{W/m^2.K}$.
- 150 kWth 16-tube pilot successfully tested (multi-tube concept validated).

Reproduce process by numerical simulations:

- To obtain additional informations on the flow behavior.
- To develop a numerical simulation tool coupling hydrodynamics and heat transfer for the design and the optimization of a multi-megawatt particle solar receiver.

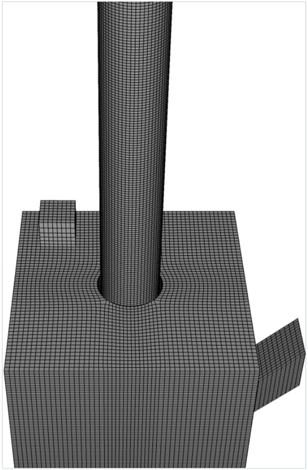
Outline

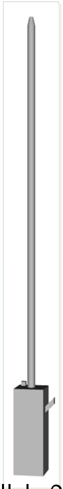
Mathematical model

Eulerian n-fluid modeling approach for turbulent and polydispersed fluid-particle is implemented in NEPTUNE_CFD, unstructured parallelized CFD multiphase flow code.

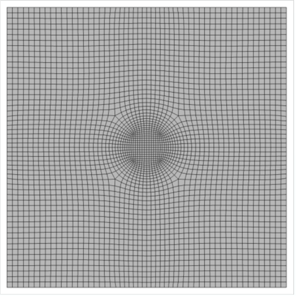
- Fluid turbulence modeling:
  no model.
- Particle stress modeling based on granular kinetic theory
  $q_p^2 - q_{fp}$.
- Convective/diffusive heat transfer between the gas and dispersed phase and inter-particle radiative transfer (Rosseland)

Numerical parameters





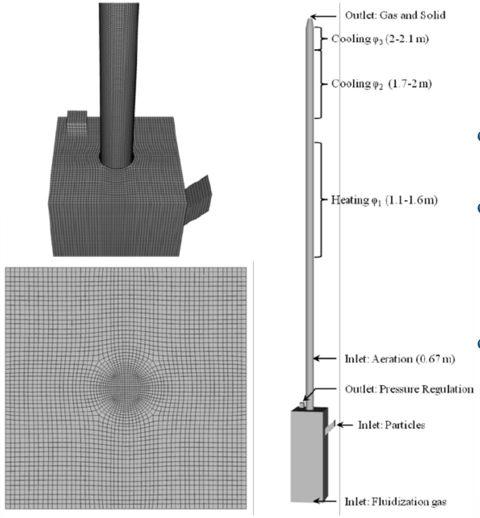
3D mesh: 1,650,000 hexahedra



Computations run on 140 cores in parallel. 2 steps (more than 1 month):

1. Transitory $\frac{dm_{solids}}{dt} \neq 0$, $T_{predicted,outlet} \neq T_{measured,outlet}$.
2. Statistics for comparisons during 150 secondes

Numerical parameters



- Imposed solid mass flow rate (DiFB inlet).
- Uniform heat flux density at the wall → right T at the tube center at the cavity outlet.
- T dependent phases' properties.

Solar receiver hydrodynamics

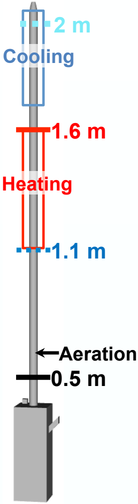
Outline

Comparisons with experiments

- Problem: Recirculation overestimated.

  ⇓

- Temperature overestimated at cavity inlet.
- Temperature underestimated at cavity outlet.

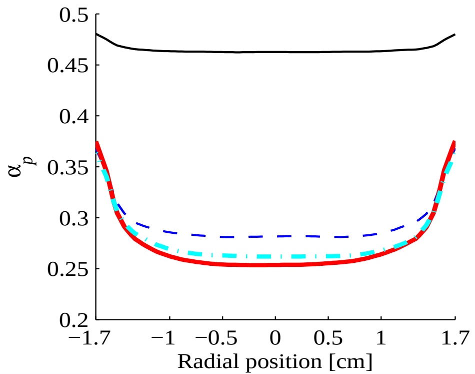


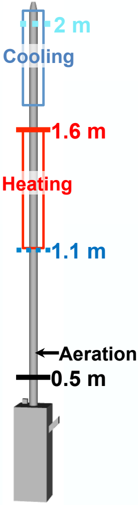
General comparisons

Parameter	Medium solid flux	High solid flux
gas pressure drop	−4.6%	+2.6%
T_p cavity inlet	+26%	+9%
T_p cavity outlet	−2.7%	+0.2%

- The errors decrease when the solid mass flux increases (decrease on downward solid mass flow).

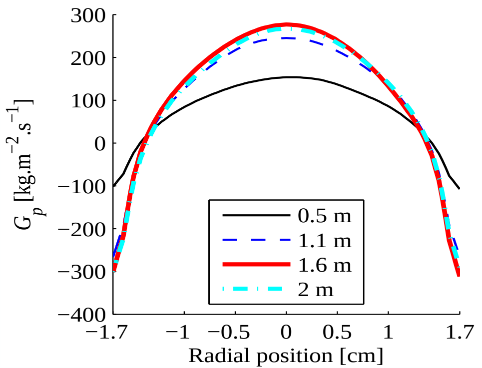
Solid volume fraction

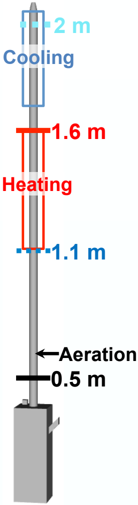




- α_p wall > α_p center.
- Aeration → α_p decrease (bubbles).
- T increase → α_p decrease (air expansion).

Vertical net solid mass flux





- Gp wall < 0 and Gp center > 0 ⇔ recirculation.
- Aeration ⇒ recirculation increases (air velocity increases).
- T increases ⇒ recirculation increases.

Outline

Conclusions

- Dense Particle Suspension upward flow in tube simulated with NEPTUNE_CFD.
- Particle recirculation reproduced but overestimated.
- Accurate linear pressure drop.
- Influence of aeration and temperature on the vertical and horizontal solid velocities and on the time variance of the solids velocities (not presented).
- Heat transfer from the wall to the center governed by particles' collective movement.

Perspectives:

- Better account for the particle-particle friction, for the particle size distribution and highly irregular shape.
- Simulate non-uniform heat flux.
- Effect of higher tube and greater temperature increase.