Dense gas-particle suspension upward flow used as heat transfer fluid in solar receiver: PEPT experiments and 3D numerical simulations

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Outline

1. Concept
2. Description of PEPT Experiments
3. Descriptions of 3D numerical simulations
4. Comparisons
5. Conclusions
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 ($100^\circ$C-1,000$^\circ$C) without freezing and decomposition.

- To develop a numerical simulation tool coupling hydrodynamics and heat transfer for the design and the optimization of a multi-megawatt particle solar receiver.
Main objectives:

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To obtain sufficient experimental data it was necessary to make this rig operate in a continuous circulation mode so that sufficient passes of the radioactive tracer could be observed.

The rig is also equipped with a pressure control system.

Informations to be extracted: gas pressure drop, particle trajectory, solids flow pattern and solids velocities.
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Eulerian n-fluid modeling approach for turbulent and polydispersed fluid-particle is implemented in NEPTUNE_CFD, unstructured HPC CFD multiphase flow code.

- Fluid turbulence modeling:
  - no model.
- Particle stress modeling based on granular kinetic theory
  \[ q_p^2 - q_{fp} \]
- Gas-particle interphase momentum transfer:
  \[ C_d^* = \begin{cases} C_{d,WY} & \alpha_p < 0.3 \\ \min(C_{d,WY}, C_{d,Erg}) & \alpha_p > 0.3 \end{cases} \]
Numerical parameters

- $\rho_g = f(P)$.
- $\rho_p = 3210 \text{ kg/m}^3$ (silicon carbide)
- $d_p = 40 \mu m$
  Particles assumed as monodispersed and spherical.
Boundary conditions

\[ V_{gas} = V_f + V_{ae} = 9U_{mf} \]

Aeration
Pressure regulation valve
Solid injection
Dispenser fluidized bed
\[ V_f = 3U_{mf} \]
Numerical parameters

3D mesh: 1,650,000 hexahedra

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

1. Transitory $\frac{d m_{\text{solids}}}{d t} \neq 0$.
2. Statistics for comparisons during 400 seconds.
Solar receiver hydrodynamics
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Exp. vs NEPTUNE_CFD

Gas pressure drop:

<table>
<thead>
<tr>
<th></th>
<th>Exp. data</th>
<th>Numerical results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below the aeration</td>
<td>136 mbar/m</td>
<td>135 mbar/m</td>
</tr>
<tr>
<td>Above the aeration</td>
<td>115 mbar/m</td>
<td>117 mbar/m</td>
</tr>
</tbody>
</table>

- Good agreement.
- The code reproduces the aeration effect.
Solid volume fraction and vertical velocity

- Dense gas-particle suspension more concentrated near the wall.
- Positive vertical solids velocity at the center and negative close to the wall.
Upward flow at the centre of the transport tube due to rising bubbles with a backmixing flow near the wall.

Downward flow slightly overestimated by simulation.

The simulation well predicts the axial solid mixing.
Comparison is made close to the aeration point where the flow is not fully established.
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Conclusions

- 3D simulations are successful in predicting the axial gas pressure drop, in reproducing the radial evolution of the vertical and horizontal solid velocities and the time variance of the solids vertical velocity.

- Both numerical predictions and PEPT measurements describe an upward flow at the centre of the transport tube due to rising bubbles with a backmixing flow near the wall which will strongly influence the solar to particles heat transfer mechanism.

- Next step: coupling heat transfers and hydrodynamics to simulate at large scale receiver.