MW-scale prototype of the fluidized particles-in-tube solar receiver.

Implementation, Design and Control of the setup at Themis tower.
- Presentation of the Next-CSP project
- Technology concept
- MW-scale design
- Human Machine Interface
- Loop control
10 partners, one objective:

Improving the reliability and performance of concentrated solar power plants through the development and integration of a new technology based on the use of fluidized particles in tube as heat transfer fluid and storage medium. (TRL 5)
Themis solar facility - Targassonne

1MW Solar furnace - Odeillo
Upward flowing dense particle suspension solar receiver:

Collector (connected to hot storage or heat exchanger)

Absorber tubes
Differential pressure between the dispenser and the collector drives the particle mass flow rate

Fluidized bed dispenser

Low particle velocity inside tubes (<10 cm/s)

No erosion

Exhaust Air (to dedusting unit)

Pressure control valve

Secondary air injection (Aeration)

Fluidized bed air feeding

Particles outlet (to hot storage tank)

Advantages of this concept:
- Possibility to reach higher temperature than conventional heat transfer fluids (temperature up to 750°C could considerably improve the thermodynamic cycle efficiency) → Combined cycle, supercritical CO₂ cycle
- Direct storage of heat through the heat transfer fluid
- No freezing problems
- Good scalability of the concept (multi-tubular solar receiver)

Drawback:
- Limited heat exchange between particles and the receiver wall surface

Olivine particles:

<table>
<thead>
<tr>
<th>Particle</th>
<th>Composition</th>
<th>Mean diameter ($d_{50}$) - μm</th>
<th>Sauter diameter ($d_{32}$) - μm</th>
<th>Density - kg/m$^3$</th>
<th>Bulk conductivity at 800°C – W/mK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olivine</td>
<td>MgO 49.5%, SiO$_2$ 42%, Fe$_2$O$_3$ 7.5%</td>
<td>59</td>
<td>30</td>
<td>3300</td>
<td>0.56</td>
</tr>
</tbody>
</table>

- Selected Olivine particles are part of the group A in the Geldart classification.

- The minimum air velocity to fluidized the particles is $U_{mf}$ = 0.40 cm/s

REF: Kang Q. et al., Particles in a circulation loop for solar energy capture and storage, Particuology, 43:149-156, 2019
MW-scale design

- A 3 MW\textsubscript{th} solar receiver has been assembled at the top of the THEMIS solar tower to demonstrate this technology in a relevant environment.
- A storage system composed of a cold and a hot tank
- A multi-stage heat exchanger
- An innovative 1.2 MW\textsubscript{el} hybrid turbine (OPRA turbine – Solar/gasoil)
- A 10 meters high bucket elevator
- A dispenser to fluidize particles
  *With homogeneous air injection through drilled tubes, (low air velocity $U_{mf} = 0.4\text{cm/s} \rightarrow \text{low air flow})$*
- 40 tubes with 8 fins to favour heat transfer (*316 SS, 3-meters high*)
- A refractive cavity to improve the receiver’s thermal efficiency

- Fully equipped with 100 thermocouples
  *(front/back surface, inside tubes & dispenser)*
- Differential pressure sensors to measure the pressure drop inside tubes inside dispenser.
Heat storage

- **A cold storage tank**
  - Particle filling through a 10 meters high bucket elevator
  - Level sensors to check the filling of the tank
  - A L-valve to empty the cold tank

- **A hot storage insulated tank**
  - Low airflow to fluidize particle inside tank to allow particle transfer to heat exchanger (via a L-valve)
  - Half an hour of storage capacity (~20 tons of particles)
**Fluidized particle/Air** heat exchanger
- Hot particles from hot storage tank
- Compressed air from turbine compressor
- 6 stages
- 1200 tubes
- At the outlet particles are recovered by the bucket elevator
- 1.2 MWel hybrid turbine

- Solar/Gasoil (first of its kind) - *OPRA development*

- Connected to the heat exchanger with a fully automated control of the combusted gasoil flow in function of air temperature at the outlet of the heat exchanger
- Control/Command by using a Labview HMI

- What to control:
  - $T_{\text{max}}$ receiver
  - $T_{\text{particles}}$
  - $P_{\text{sky dispenser}}$
  - $\Delta P_{\text{dispenser}}$, $\Delta P_{\text{hot storage}}$, $\Delta P_{\text{heat exchanger}}$
  - $\Delta P_{\text{tubes}}$

- What to operate:
  - Fluidization air flowrates
  - Dispenser freeboard pressure
  - L-valves air injection
Loop control

How to measure particle flowrate?

-1- Calibrate L-valves particle flowrates

- for several $Q_{\text{air}}$ L-valve, plot $\Delta P_{\text{dispenser}} = f(t)$ (follow the filling of the dispenser in function of time)

(the height of the fluidized bed is directly correlated to the pressure drop of the bed)

=Gives data about particle flowrate in function of $Q_{\text{air}}$ L-valve

-2- Establish a correlation between the particle flowrate and $P_{\text{sky}}$ dispenser

- Test plan of particles circulation through the receiver’s tubes for different dispenser freeboard pressure ($P_{\text{sky}}$).

- Set $Q_{\text{air}}$ L-valve to keep $\Delta P_{\text{dispenser}}$ constant (No emptying of the fluidized bed)

- Plot $\dot{m}_{\text{particle}} = f(P_{\text{sky}})$

-3- Establish a correlation between $Q_{\text{air}}$ L-valves and $P_{\text{sky}}$ dispenser to maintain the dispenser filling stable

Program the control (enslavement) of $Q_{\text{air}}$ L-valve in function of $P_{\text{sky}}$
- This project has received funding from the European Union’s Horizon H2020 research and innovation programme under grant agreement No 727762, Next-CSP project.

- The French “Investments for the future” program managed by the National Agency for Research under contracts ANR-10-EQPX-49 (SOCRATE) supported the facility.

- The Occitanie French region funded the cold mockup.
Questions