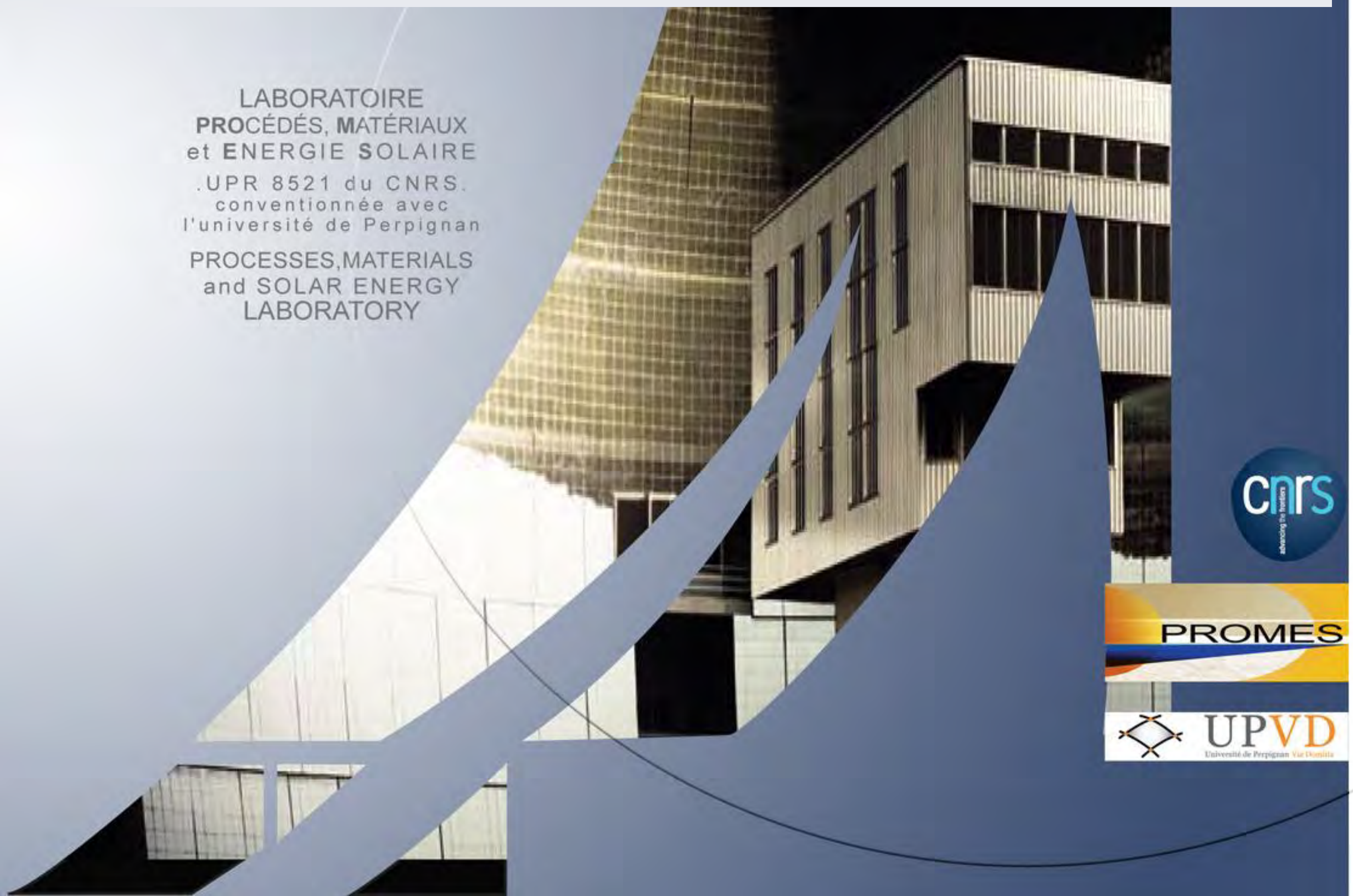
MW-scale prototype of the fluidized particles-in-tube solar receiver.

Implementation, Design and Control of the setup at Themis tower.



SolarPACES
Solar Power & Chemical Energy Systems

next-CSP

SolarPACES conference

September 30, 2020

On-line event

A. Le Gal*, B. Grange, G. Flamant*

PROMES-CNRS

cnrs

PROMES

UPVD

Overview

- 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)

Next-CSP project

Themis solar facility - Targassonne

1MW Solar furnace - Odeillo

PROMES

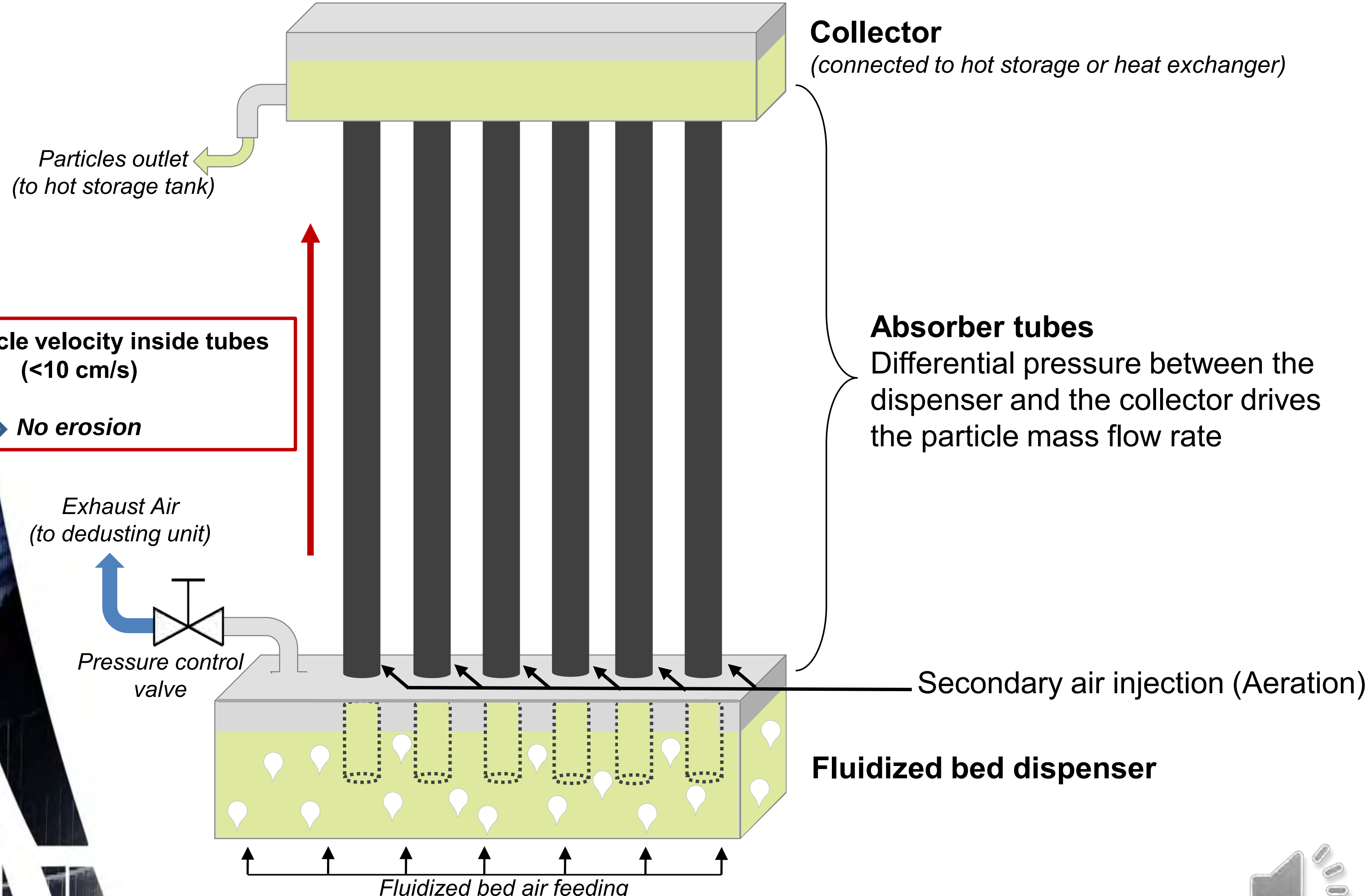
CNRS

Technology concept

Upward flowing dense particle suspension solar receiver :

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

No erosion



Patented concept : *Flamant G., Hemati H., Dispositif collecteur d'energie solaire (Device for collecting solar energy), French patent FR 1058565, 2010, PCT extension WO2012052661, 2012*

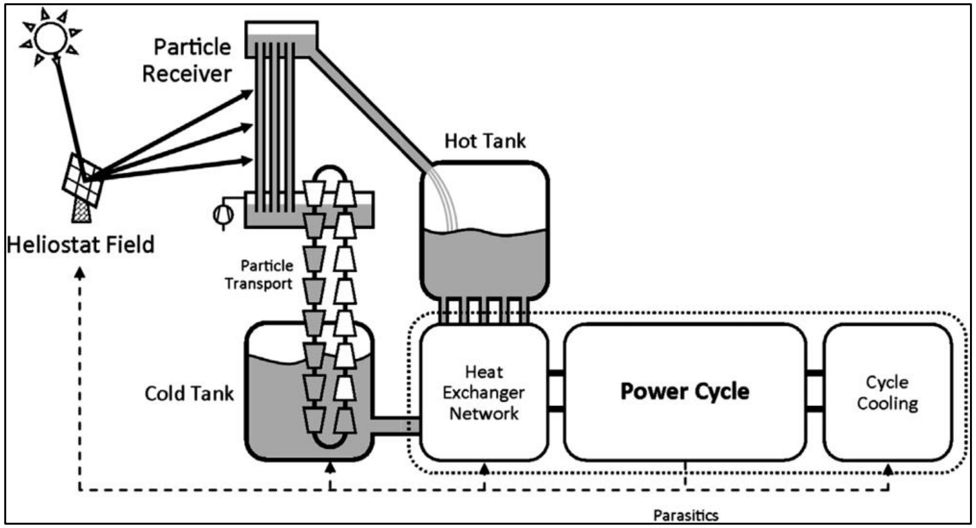
Technology concept

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 CO_2 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



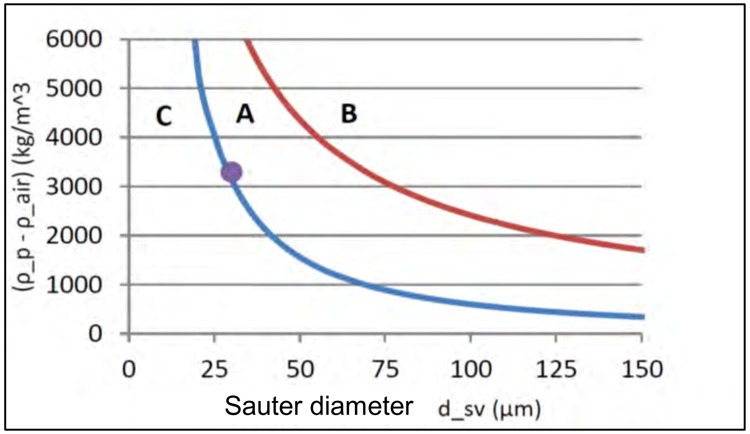
Generic layout of the dense particle suspension power plant. [1]

[1] M.A. Reyes-Belmonte et al., Energy, 112, p17-27, 2016

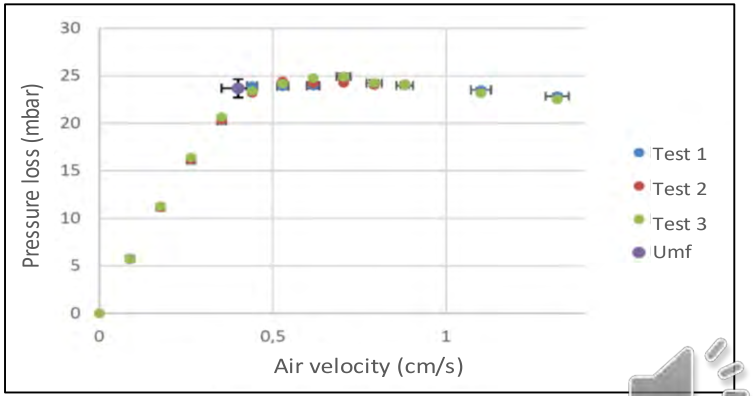
Technology concept

Olivine particles :

Particle	Composition	Mean diameter (d_{50}) - µm	Sauter diameter (d_{32}) - µm	Density - kg/m^3	Bulk conductivity at 800°C – W/mK
Olivine	MgO 49.5%, SiO_2 42%, Fe_2O_3 7.5%	59	30	3300	0.56



Geldart classification of the selected olivine particles



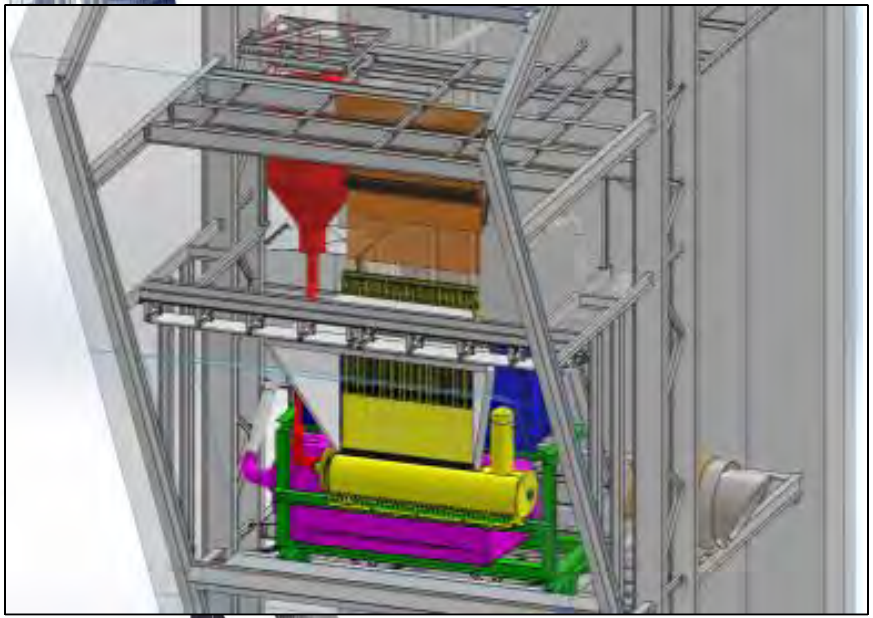
Determination of the olivine particles minimum fluidization velocity (U_{mf}).

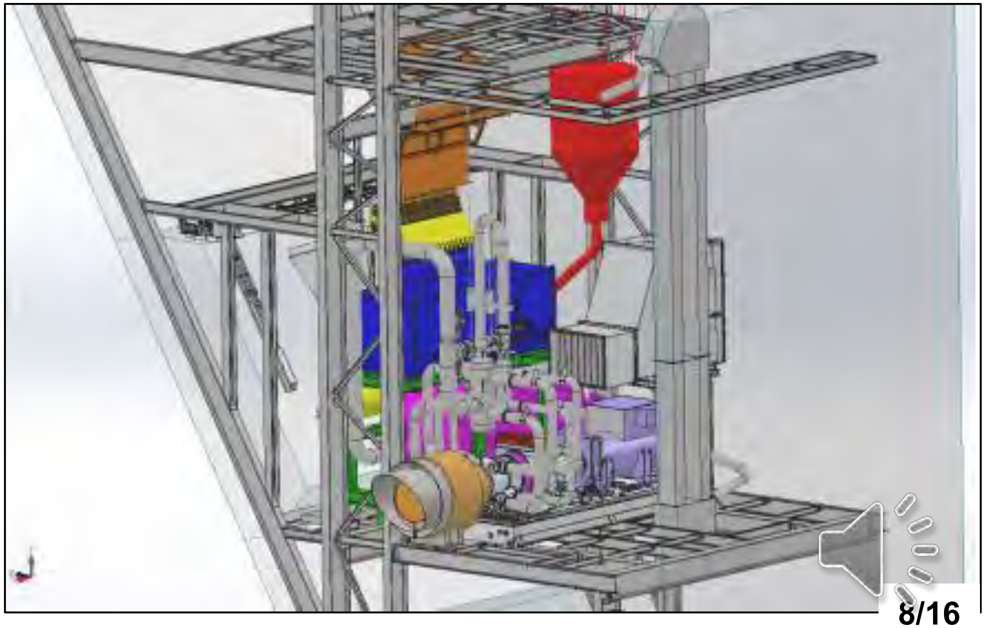
- Selected Olivine particles are part of the group A in the Geldart classification.
- The minimum air velocity to fluidized the particles is U_{mf}= 0.40 cm/s

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

MW-scale design

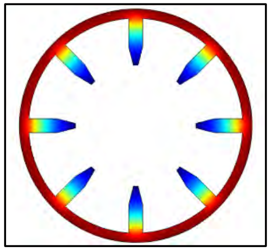
- A 3 MW_{th} solar receiver has been assembled at the top of the THEMIS solar tower to demonstrate this technology in a relevant environment.
- A storage system composed of a cold and a hot tank
- A multi-stage heat exchanger
- An innovative 1.2 MW_{el} hybrid turbine (*OPRA turbine – Solar/gasoil*)
- A 10 meters high bucket elevator

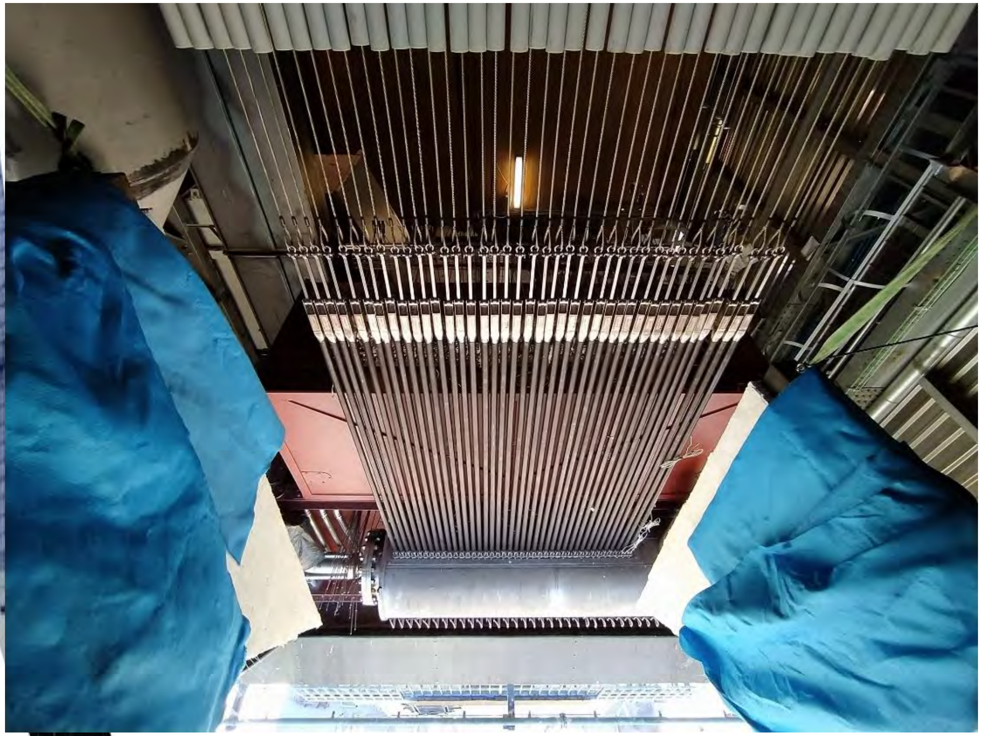


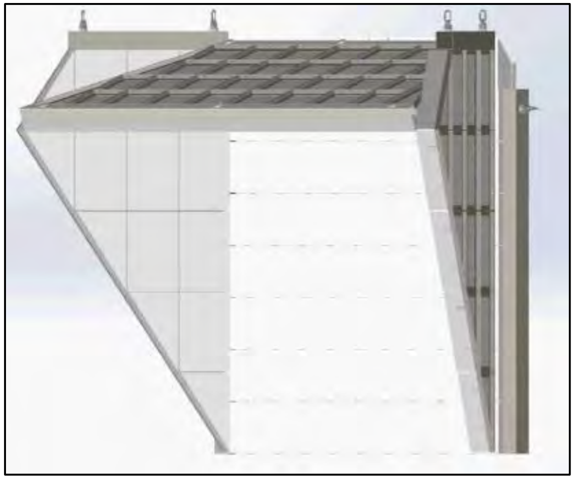


The solar receiver

- A dispenser to fluidize particles
  With homogeneous air injection through drilled tubes, (low air velocity U_{mf} = 0.4cm/s → 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





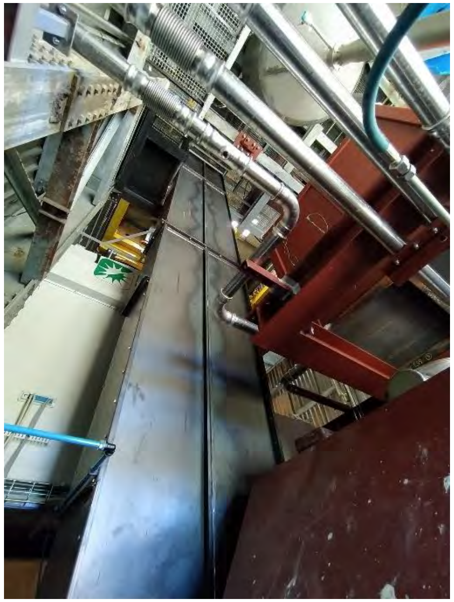


- Fully equipped with 100 thermocouples
  (front/back surface, inside tubes & dispenser)
- Differential pressure sensors to measure the pressure drop inside tubes, inside dispenser.

Heat storage

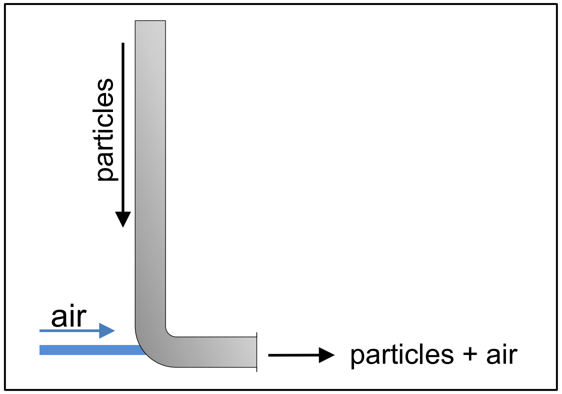
- **A cold storage tank**

Level sensors to check the filling of the tank



Particle filling through a 10 meters high bucket elevator

a L-valve to empty the cold tank



L-valve illustration

- **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)

Top view of the hot storage tank with receiver's tubes connexion

Heat exchanger

Fluidized particle/Air heat exchanger

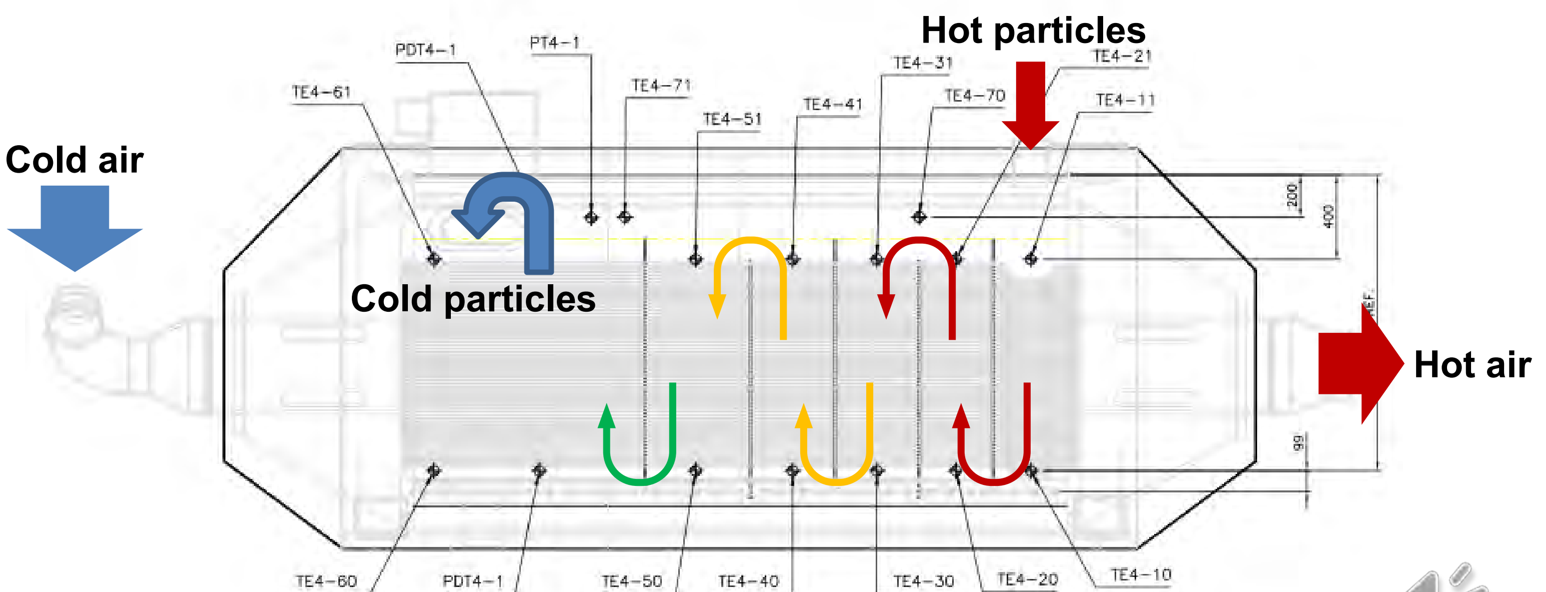
- Hot particles from hot storage tank

- Compressed air from turbine compressor

- 6 stages

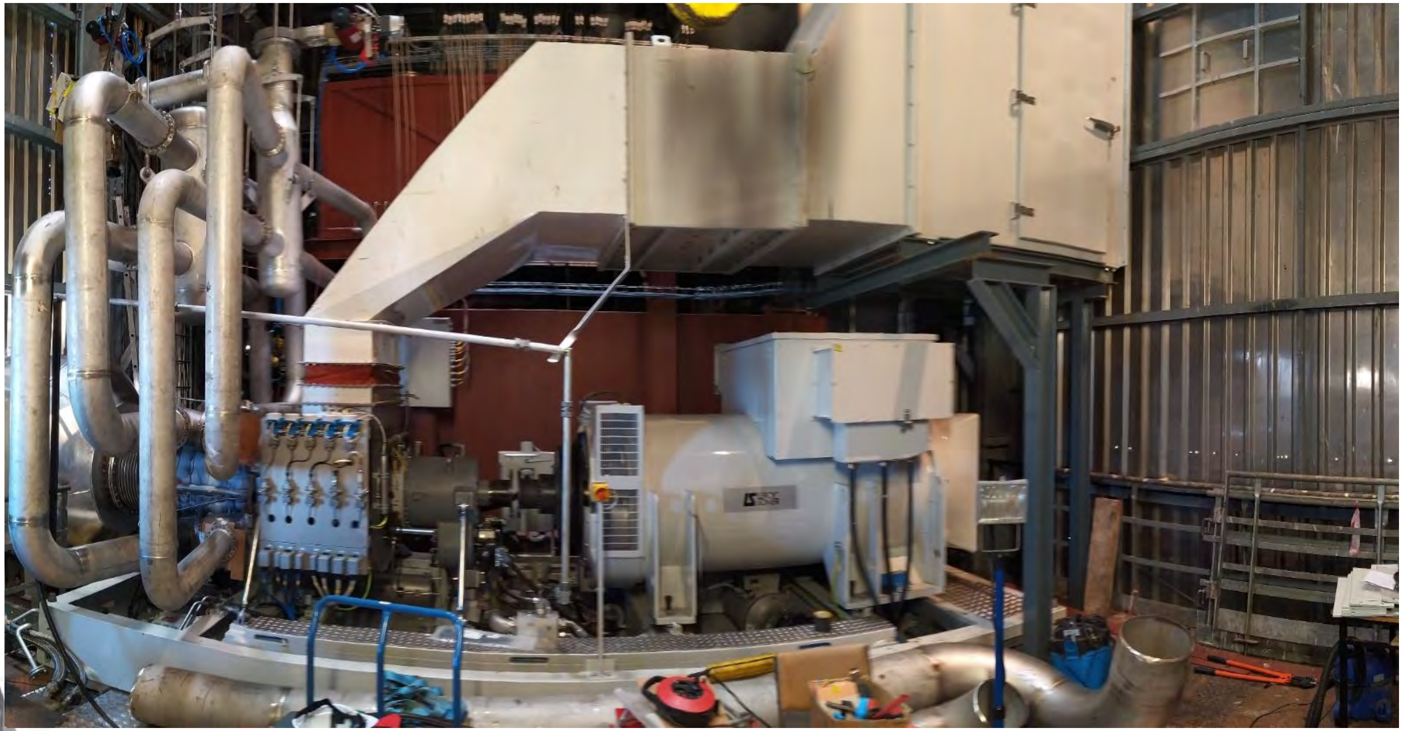
- 1200 tubes

- At the oultet particles are recovered by the bucket elevator

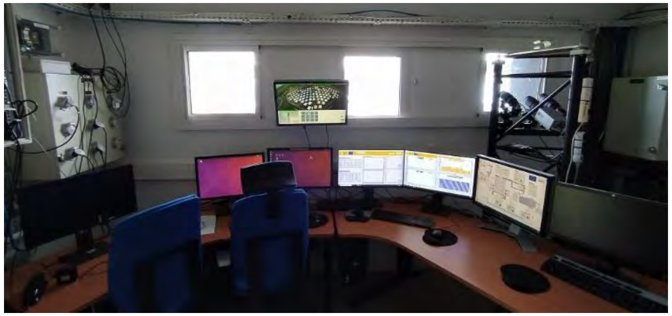


Hybrid turbine

- 1.2 MWel hybrid turbine
- Solar/Gasoil (first of it 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

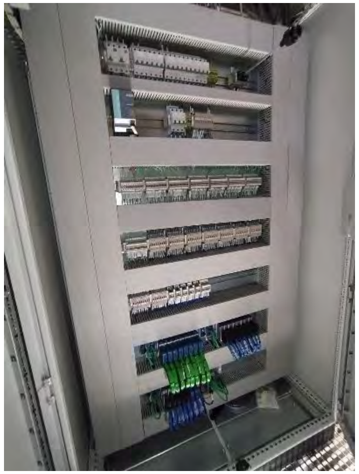


Control command



- Control/Command by using a Labview HMI

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



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

How to measure particle flowrate ?

-1- Calibrate L-valves particle flowrates

- *for several Q_{air} L-valve, plot $\Delta P_{dispenser} = f(t)$ (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_{air} L-valve*

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

- *Test plan of particles circulation through the receiver's tubes for different dispenser freeboard pressure (P_{sky}).*
- *Set Q_{air} L-valve to keep $\Delta P_{dispenser}$ constant (No emptying of the fluidized bed)*
- *Plot $\dot{m}_{particle} = f(P_{sky})$*

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

Program the control (enslavement) of Q_{air} L-valve in function of P_{sky}

Acknowledgements

- This project has received funding from the european Union's Horizon H2020 research and innovation programme under grant agreement No 727762, Next-CSP project

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- The Occitanie French region funded the cold mockup.

Questions ?