Particle flow and heat transfer in fluidized bed-in-tube solar receivers

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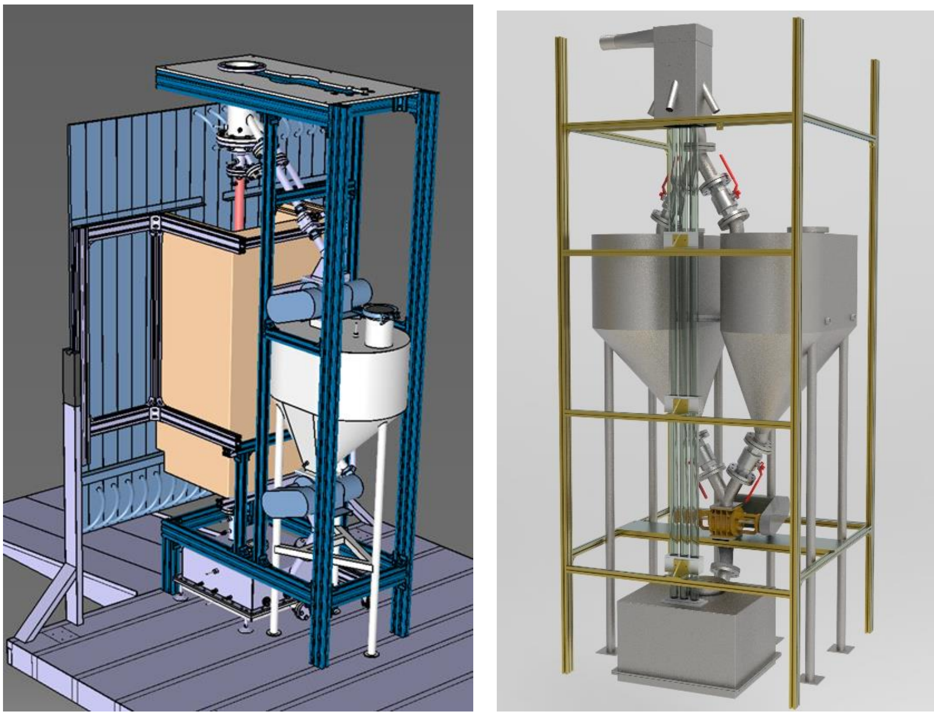
1. Introduction

This work is part of the European project "Next-CSP" which aims to develop a next generation of concentrated solar power plants through the fluidized particle-in-tube technology working at high temperature (>700°C). A 3MWth pilot unit including a solar receiver, storage tanks, a heat exchanger and a gas turbine implementation is under assembly at the top of a solar tower (Themis-France) to demonstrate this technology. The unit will use the fluidized bed-in-tube solar receiver concept [1]. The scaling up of this concept needs researches on the gas-particle flow structure evolution along the tube and on wall-to-fluidized particles heat transfer.

Therefore, several experimental set-ups were implemented to study the particle flow and heat exchanges in order to define the best operational conditions for the full-scale 3MW test unit. The first one (figure 1.a) is an on-sun experiment equipped with a one meter-long finned tube to collect data on the distribution of wall surface and particles temperature, thermal exchange and thermal performance useful for further modelling and up scaling. The second one (figure 1.b) is a cold experiment with three 3m-long transparent tubes implemented to study dense particle suspension (DPS) flow in tube and the distribution between the different tubes. 3m is the length of the solar receiver tubes.



a b

Figure 1. 3D view of experimental set-ups developed for heat transfer and particle flow analysis. a. On-sun experiment with a 1 meter long finned tube b. Cold experiment with three 3 meters long transparent tubes.

After the presentation of particles characteristics and the complete description of both setups, the operating parameters of experimental campaigns are detailed (solar flux density, particles flow rate, fluidization air flow rate,…). Then the experimental results are presented as well as their interpretation.

2. Heat transfer in tubular solar receiver

For a better understanding of thermal transfer between tube surface and DPS, a test plan has been followed to observe the influence of major parameters on heat exchange. The on-sun campaign was performed at the focus of the 1MW solar furnace of Odeillo. Several solar flux density were investigated to estimate the influence on thermal performances (from 236 kW/m² to 485 kW/m²). The particle mass flowrate inside the tube was studied from 25 kg/m².s to 110 kg/m².s. A secondary air injection was tested in the range 200 g/h to 700 g/h. Moreover, particles pre-heating was done at different temperature.
Wall temperature profiles were recorded for each conditions as well as particles temperature at the inlet and the outlet of the solar receiver. Particles at ambient temperature were heated up to 400°C and the temperature profile of the tube along the height and around the circumference gave useful information for the up-scaling.
The power extracted by particles and a global heat transfer coefficient were calculated in function of these major parameters. The power extracted by particles ranges between 17.8 kW and 32 kW under different conditions and the heat transfer coefficient reaches 1200±400 W/m².K.

3. Particle flow in tube

To study the particle flow, cold experiments (without solar heating) were performed with the second setup. The mock-up was equipped with pressure gauges to measure differential pressure drop at different heights in tubes and it fluctuation with time. The influence of the particle flowrate as well as a secondary air injection on fluidization behaviour of the upward bubbling dense suspension was studied. In particular, the influence of these parameters on the appearance of wall slugging was examined because it affects the heat transfer [2].
Experimental results dealt with fluidized particle volume fraction along the tube and gives information about the fluidization regimes.

4. Conclusion

Two experimental mock-ups were implemented to investigate heat transfer and particles flow in tubular solar receiver using upward bubbling dense particle suspension as heat transfer fluid. Experimental campaigns were performed to highlight the influence of major parameters on thermal performances. All these collected data are necessary for further modelling in order to improve the thermal performances of the solar receiver. They are also useful to define optimized operating parameters for further large-scale experimental tests.

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