MW-Scale Prototype of the Fluidized Particles-in-Tube Solar Receiver. Design, Control and First Experiments at Themis Tower.

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1. Introduction

This paper presents the first experimental results of the fluidized particles-in-tube solar receiver 3 MW_{th} prototype. The industrial pilot-scale full loop (receiver/storage/heat exchanger/turbine) implemented at Themis tower (Targassonne – France) is the main achievement of the European project "Next-CSP", which aims to improve the reliability and performance of concentrated solar power plants using particles as heat transfer fluid and storage medium [1].
Particles used as heat transfer fluid in a central solar receiver is a promising solution to improve the efficiency of solar tower power plants. Actually, the use of particles as heat transfer fluid instead of molten salts, oil or vapour allows higher working temperatures and consequently higher efficiency thermodynamic cycles.
Several concept using particles are currently investigated in different cutting edge research centers all over the world. Among those technologies, there is the rotary kiln reactor of the DLR [2], the falling particle receiver developed at Sandia National lab. [3] and the fluidized particles in tube receiver patented by PROMES-CNRS laboratory [4].

2. Technology Concept and MW-scale design

The large-scale implementation at Themis tower is the result of several years of research from the laboratory scale to the pilot scale. The concept of the fluidized particles-in-tube solar receiver is based on upward circulation of a fluidized suspension of particles inside black coated stainless steel tubes. Olivine particles are first fluidized in a vessel (dispenser) inside which steel tubes are plunged. The bubbling fluidized bed has the properties equivalent to a fluid and by varying the freeboard pressure inside the dispenser, fluidized particles flows upward inside the tubes with a variable mass flow rate. Then tubes are exposed to concentrated solar radiations to heat up particles during their ascent. Afterwards, particles could either flow to the heat exchanger to run a high temperature thermodynamic cycle or fill a hot storage insulated tank to postpone the electricity production during electricity demand peaks. Smaller pilots or experimental setups have been developed since the concept coming up and permit to collect a lot of useful data about heat transfer and particle flow in tube leading to the MW-scale design and building [5,6,7].
The loop is composed of five main components: the receiver, the particle storage unit (cold & hot), the heat exchanger, the turbine and a particles conveying element (see Figure 1).

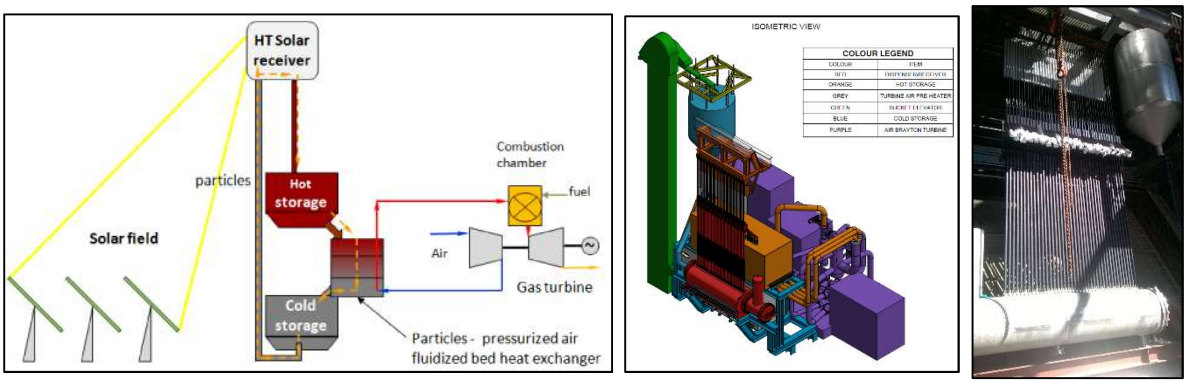

Figure 1. Loop concept (left), isometric view of the overall installation (center) and picture of the receiver (right).

3. Instrumentation and Loop control

The loop has been widely equipped with pressure sensors (43 Sitrans P250 differential pressure transmitters, 7 Sitrans P200 pressure transmitters), thermocouples (128 K-type), flowmeters (9) and gauges (2 Sitrans LVL200 level switches) to have a complete knowledge of physical parameters. The filling level of each element is control through the pressure drop of the fluidized beds. Suspension density inside tubes is calculated from differential pressure measured between the bottom and the top of each of the 40 tubes. The particle circulation velocity in the receiver is controlled by the freeboard pressure in the dispenser (via a leak valve). At the outlet of the receiver particles directly fall by gravity in the hot storage tank. The particles have to circulate through the overall loop to maintain the particle feeding of the dispenser and to avoid any emptying. To achieve this circulation, two L-valves [8] were installed. The first one between the cold storage tank and the dispenser and the second one between the hot storage tank and the heat exchanger. To close the loop, cold particles exiting the heat exchanger go back to the cold storage tank using a bucket elevator.

A control/command software has been developed to control the loop during experiments and to record all parameters necessary for establishing the performance. Key parameters to drive the loop are identified (freeboard pressure, filling level of the dispenser, particle temperature, receiver's front surface temperature) and the automation of the power plant has been elaborated.

An innovative approach for hot spot detection, which could damage the solar receiver tubes, on the receiver front surface has been developed. The use of a drone (UAV) equipped with an infrared camera provides a direct visualization of the irradiated receiver surface temperature distribution [7]. A security procedure of heliostat defocusing can be started in case of overheating.

4. First experimental results at MW scale

A cold test plan has been followed first to calibrate L-valves particle flowrates and to correlate the particle circulation flowrate through the receiver with the freeboard pressure of the dispenser.
Afterwards, preliminary on-sun tests were realized by increasing step by step the solar flux until the nominal power input. First thermal performance calculation are detailed in this paper.

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