Simulation of the Next-CSP Solar Loop Including a Hybrid Gas Turbine

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1. Introduction

The Next-CSP project [1] aims at demonstrating at pilot-scale the concept of CSP particle technology using high temperature particles as heat transfer fluid and storage medium. The system has been installed at the Themis tower in Targasonne (France). The solar receiver is mainly a multi-tube absorber in which the fluidized particles flow upward in forty 3m-long tubes before flowing out in a hot storage tank. Then, the hot particles fall into a multi-staged fluidized bed heat exchanger to preheat the pressurized air coming from the compressor of a hybrid gas turbine. Figure 1 presents the layout of the Next-CSP facility.

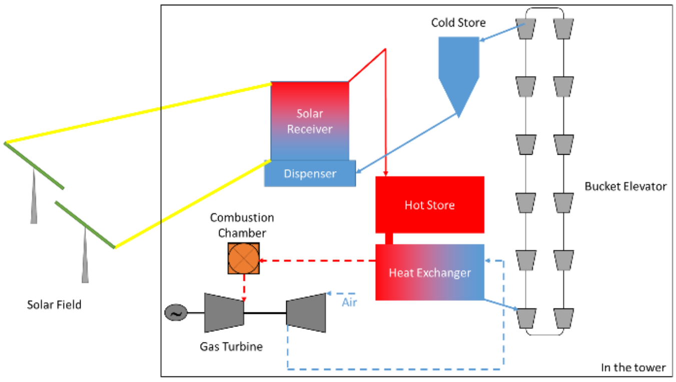


Fig. 1: Layout of the Next-CSP facility installed at the Themis tower – Particles in solid lines, Air in dotted lines

2. Simulation of the complete system

This section describes the method to simulate each component of the system: the solar field, the solar receiver, the heat exchanger and the gas turbine (GT). The complete system is not optimized. In particular, the gas GT is a commercial engine that was solarized to be adapted to the particle loop. As a result, the turbine inlet temperature (TIT), approximately 1000°C, is by far too high to reach high solar share. Consequently, the main objective of the project is to demonstrate the operation of the particle loop, particularly the solar receiver and the heat exchanger.

2.1. The solar field

The simulation of the solar field consists in an aiming point strategy (APS) in order to spread the flux on the forty tubes and avoid hot spots that would lead to receiver damage. The aiming point strategy is achieved using the TABU search associated with the convolution-projection model UNIZAR [2]. Results of APS are introduced into *Solstice*, a new open-source ray-tracing software developed by the CNRS-PROMES laboratory and Meso-Star SAS [3]. This simulation gives the flux distribution on each tube as well as on the cavity panels.

2.2. The solar receiver

The flux distributions on each tube computed by Solstice are post-processed and implemented in a simplified thermal model developed with the Matlab® software [4]. The thermal model is based on the Net Radiation Method, which makes the balance on heat flux and radiosity. The main output is the particle outlet temperature.

2.3. The heat exchanger (HEX)

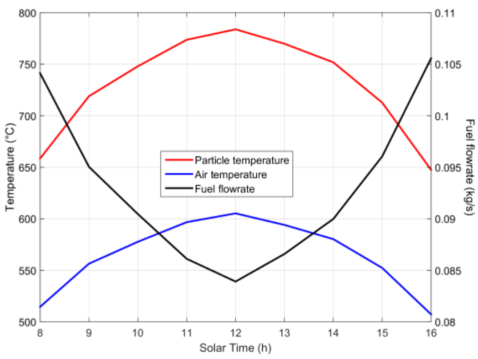
The particle temperature computed by the thermal model is introduced into the multi-stage tube/shell HEX model [5]. The compressed air coming from the Gas Turbine (GT) flows in the 1400 tubes in counter-current with the particles that are fluidized through six stages. An algorithm simulating the six stages of the HX gives the inlet/outlet air/particle temperature in each stage.

2.4. The gas turbine (GT)

Typical GT cycle consists of a compressor, a combustion chamber, and a turbine section. A practical technique, based on the performance maps of the turbine and compressor sections, is used to model the GT cycle. This approach enables to predict the turbine performance for part-load operations, based on similarity and dimensional analyses, and is widely used in turbomachinery [6]. In this hybrid gas turbine, the air entering the combustion chamber is at the temperature of the last HEX stage, tube side.

3. Results

Combining the different components model presented in the sections above results in determining all the required parameters to assess the performance of the system, such as the optical/thermal efficiency, the air and particle temperature in each component or the fuel consumption. Figure 2 shows some results computed by the global model. Simulations are carried out at Equinox.



During the day, the particle temperature at the outlet of the solar receiver varies from 650°C to 785°C, resulting in an air temperature at the outlet of the HEX from 507°C up to 605°C.

The fuel required to reach the TIT ranges between 84 g/s and 106 g/s.

Fig. 2: Air/Particle temperature at the outlet/inlet of the HX during the day

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References

[1]http://next-csp.eu/

[2]F.J. Collado et al., Journal of Solar Energy 37, 215-234 (1986)

[3]PROMES-CNRS, MESO-STAR SAS. SOLSTICE, SOLar Simulation Tool In ConcEntrating optics, version 0.7.1 (2017), France, https://www.meso-star.com/projects/solstice.html https://www.labex-solstice.fr/logiciel-solstice.html

[4]B. Grange & al., Journal of Solar Energy Engineering 133(3), 031004 (2011)

[5]F. Gomez-Garcia et al., Applied Energy 190, 510-523 (2017)

[6]Dixon S.L., Hall C.A. Fluid Mechanics and Thermodynamics of Turbomachinery. Sixth edition, Butterworth-Heinemann, 2014