next-CSP

High Temperature concentrated solar thermal power plant with particle receiver and direct thermal storage

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Deliverable *D6.2*

WP6 – Assessment of the highly efficient thermodynamic cycles that can be combined with the high temperature solar loop

Deliverable D6.2 Report on the thermodynamic cycles that are best suited to the solar loop

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Foreword

This report (D6.2) describes the thermodynamic cycles that are best suited to the solar loop. High efficiency thermodynamic trends and cycles suitable to be coupled with solar power plant as proposed on subtask 6.2 have been reported.

The report has been prepared by IMDEA Energy (lead partner of WP6) in collaboration with EDF.

1 Introduction

The installation and use of renewable energy sources for electricity production is gaining in importance due to stringent environmental standards seeking to reduce pollutant emissions and fossil fuel dependence. In this context, concentrating solar thermal technologies (CST) are considered to be one of the most promising ways for electricity production in coming decades [1]. Concentrating solar power (CSP) has shown many advantages compared to other intermittent renewable electricity sources such as wind and photovoltaics. Amongst the main advantages; solar thermal electricity is reliable, flexible and when integrated with thermal energy storage (TES) systems is not limited to operating only when the sun is shining [2]. In addition, when coupled with dry-cooling, the water requirement of CSP technologies is limited [3]. However, cost reductions achieved by competing technologies (mainly PV) are forcing CSP developers to move a step further seeking for cost reductions due a highly competitive market and the lack of tariffs that correctly value the dispatchability of CSP [4].

Reaching higher temperatures is seen as key for future cost reductions of the CSP, as higher temperatures are leading to both higher power conversion efficiencies and increased storage densities [5]. Molten salts technology has been succesfully proved coupled to subcritical Rankine cycles [6,7] and has been consolidated in the CSP market. However, molten salt power plants are limited to operate typically below 565 °C, thus limiting conversion efficiency while direct steam towers can produce steam at 585 °C but do not allow efficient thermal storage that is key for CSP [8]. The use of novel heat transfer fluids on the solar receiver should allow reaching temperature limits far above 550 °C as well as facilitating massive thermal storage. The higher temperature will provide an opportunity to explore innovative power cycles for future CSP plants with higher conversion efficiency [9].

In that context, this report summarizes main findings and conclusions on power plant layout selection for a concentrated solar power application designed on the concept investigated in the H2020 research project next-CSP and previously on CSP2 project, i.e. using dense particle suspension (DPS) as novel heat transfer fluid [10]. High temperatures achievement at central receiver (above 750 °C [11]) coupled to the flexible solar layout platform isolating the solar loop from the power loop is allowing the study of several thermodynamic cycles for CSP applications. In particular, supercritical steam Rankine cycle, supercritical carbon dioxide (sCO_2) and Combined Cycle configuration will be optimized.

3 Conclusions

In this report, several power cycles have been screened and modelled for electricity production coupled to particles receiver. Studied cycles have in common their potential for reaching very high efficiencies at temperature levels compatible with particles solar application. Power cycles that have been studied in this deliverable are:

- Supercritical steam Rankine cycle
- Recompression supercritical CO_2 cycle
- Combined cycle

In all cases, power cycles working conditions have been determined for net efficiency maximizing using only solar thermal energy as thermal input.

Main conclusions for supercritical steam Rankine cycle are:

- Gross power cycle efficiency near 48% can be achieved
- Net power cycle efficiency above 45% can be achieved (as it was targeted) despite high parasitic losses (power consumption from the fan of the dry cooling system)

Main conclusions for recompression supercritical CO_2 cycle are:

- Very high efficiencies can be achieved (above 50% as targeted) for moderated TIT (680 ºC to 730 ºC). However, such high efficiencies cannot be achieved without wet cooling.
- Cycle efficiency is very sensitive to CIT (the closer the temperature to critical point the higher the efficiency)
- Net efficiency gaining (1%) of the power block that is obtained by increasing TIT from 680 ºC to 730 ºC will be lost by receiver thermal efficiency worsening (1%)

Main conclusions for Combined Cycle are:

- Among the cycles scanned, the recommended configuration for pure-solar cycles is a combined cycle gas turbine, with an uncooled, double-reheat Brayton cycle with a TIT of 780°C.
- The most efficient Brayton cycle has equal pressure ratios across all turbines. However, adjusting these pressure ratios for equal air temperatures at every DPS-HX inlet may simplify the DPS-HX particle-side layout.
- For now, the Brayton cycle's TET would be 600°C, with a 3P-RH Rankine cycle at 160-20-3 bars / 585-575°C. That TET may change once the design of the DPS-HX is known in more details, but should be between 555°C and 620°C, corresponding to an air pressure at the DPS-HX between 2.16 and 2.98 bars.
- The particles cannot be expected to enter the receiver at a temperature far below 600°C if the Brayton cycle is not intercooled. However, intercooling would heavily penalize the cycle efficiency.
- Best Combined Cycle layout is exhibiting net power cycle efficiency above 48% (48.6%). Targeted efficiency expectations of at least 50% for the ISCC (integrated solar combined cycle) were not achieved due to the very low TIT (780 ºC) compared to the working conditions of modern and very efficient combined cycle plants. In case of particles receiver would be re-designed allowing TIT above 800 ºC net cycle efficiency above 50% can be achieved.