Sizing of a Supercritical CO_2 Brayton power cycle as energy conversion system for Gen3 CSP

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1. Introduction

Brayton supercritical CO_2 power cycles (S-CO2) are a promising technology to fulfill some of the objectives of Solar Power Gen3 Demonstration Roadmap from the National Renewable Energies Laboratory (NREL) [1], especially those regarding to efficiency and cost [2]. To that aim, the concentrating solar technology proposed is the central receiver (CR), working with ternary chloride molten salts (MS) at 700 °C. However, potential challenges arise associated to the molten salt clogging inside the narrow channels of printed circuit heat exchangers (PCHEs), which are usually used in S-CO2 cycles. A novel S-CO2 has been proposed to overcome such issue, transferring the heat power from the salts to the CO_2 in the low-pressure stream, so shell and tube heat exchangers (STHEs) can be used instead of PCHEs [2]. Shell and tube heat exchangers allow higher pass area for the salt circulating in the shell side, so avoiding the clogging issues. Figure 1 compares a conventional recompression S-CO2 with the new proposed layout.

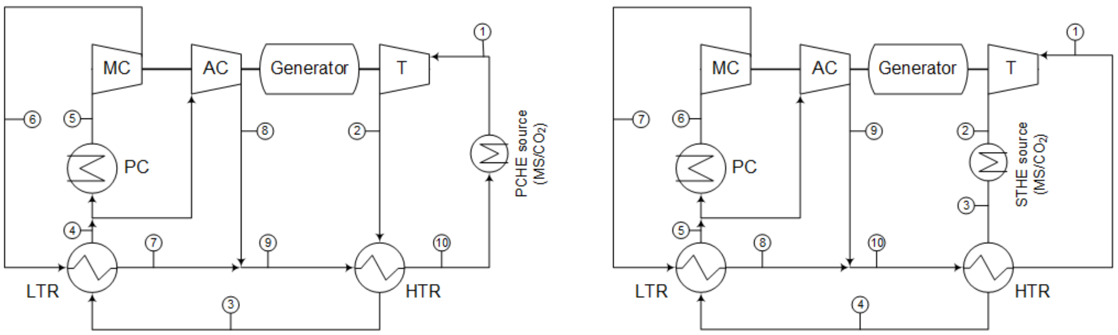

Fig. 1: Conventional recompression S-CO2 (left) and proposed layout (right).

In a previous study [2], the performance and investment of different layouts with the heat supply downstream the turbine have been investigated. In the current paper, two analyses have been carried out. On one hand, the performance maps of these layouts have been obtained, being compared to conventional S-CO2 layouts; on the other hand, complete sizing and CAD allocation model for the best solution have been performed. Such information will allow to carry out accurate dynamic studies in the future.

2. Methodology

Cycles modelling has been implemented in Engineering Equation solver (EES), which integrates the thermophysical properties of CO_2 and water. Properties of chloride ternary salt (24.5% NaCl – 20.5% KCl – 55.0% $McCl_2$) have been included through fitting functions. Printed circuits heat exchangers have been modelled assuming their size restrictions prescribed by the manufacturer and discretizing them to take into account the variation of CO_2 properties. Shell and tube heat exchangers have been designed as "E" type, according with TEMA standards. Air coolers employ a core sCF-734 [2]. Pipes have been sized according to Norsok Standards [3] and turbomachines have been selected following the Baljé performance chart [4]. A tubular cavity-type configuration has been selected for the receiver and both the solar field and the tower have been sized using the SolarPilot software [2]. An investment estimation has been carried out taking into account data from Sandia National Laboratory (SNL) for the S-CO2 and NREL for the solar facility [2].

3. Results

Figure 2 shows the performance maps for different layouts of the proposed cycle. Efficiency is plotted against the temperature increment of CO_2 in the main MS-to-CO_2 heat exchanger. The CO_2 temperature difference determines the molten salt temperature difference in this heat exchanger and, therefore, the volume of salt required in the thermal energy storage system. This temperature increment is reduced when reheating is employed and, as a consequence, an efficiency increase can be observed. As expected, higher efficiencies are obtained with wet cooling.

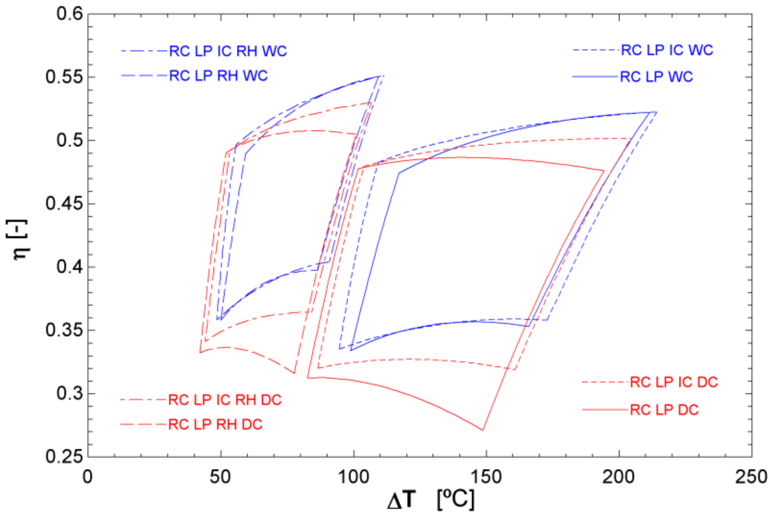

Fig. 2: Performance maps of different layouts of the proposed cycle (LP). All of them are based on a recompressed architecture, being simple (RC), including intercooling (RC IC), reheating (RC RH) and intercooling and reheating (RC IC RH). In blue lines, wet cooling is assumed (WC) whereas dry cooling (DC) is assumed in red lines.

Intercooling with reheating in dry cooling has been chosen for complete sizing. Gross electrical power of 50 MW has been assumed, according to Spanish regulations. Turbines have been selected as axial, with diameters around 425 mm. Regarding the compressors, there are three of them in the cycle: two have been selected as radial and one as axial, with diameters around 250 mm. All the turbomachines are attached to the same shaft, so they rotate at the same speed, estimated in this predesign at 17,000 rpm. Regarding the piping, the diameter of the CO_2 pipes ranges from DN300 to DN750, with schedules from 20 to 100. Due to the high pressure and temperature, the material selected for these pipes is Inconel 740-H, a Ni-Cr-Co alloy. Three hours of storage have been assumed (solar multiple of 1.5). Investment required is 437.1 M$ (8,742 $/kWe), in agreement with the projections of Gen3.

References

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