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Performance Study of a Dry-Cooled supercritical CO_2 Cycle Integrated with Solar Tower

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In the past few decades, renewable and sustainable energy development received noteworthy consideration by scholars and government agencies due to the energy crisis and alarming global pollution. The concentrated solar power (CSP) is a prominent area of research in the renewable and sustainable energy sectors. The capital cost of a CSP plant can be considerably reduced by coupling it with the supercritical CO_2 (sCO_2) cycle due to its attributes of lower cost, higher thermal efficiency, and compactness in heat exchanger design [1]. Zhu et al. Investigated the thermodynamic analysis of various configuration (recuperated, recompression, precompression, partial cooling and intercooling) of sCO_2 cycle layouts coupled with a solar tower where the sCO_2 directly heated in the central receiver and used as both heat transfer and cycle fluid [2]. Recently, Wang et al. also assessed the CSP plant performance equipped with thermal energy storage of different sCO_2 cycles with multivariable optimization [3].

In arid areas, dry cooling technology is a preferable alternate of wet cooling mainly due to the scarcity of abundant water supply. However, the supercritical power cycle still offers considerable thermal performance even at higher ambient temperature. In our previous study, a natural draft dry cooling tower (NDDCT) model was developed using MATLAB to compare the cycle cooling performance with the direct and indirect cooling circuit [4, 5]. Later, the cooling tower was coupled with sCO_2 recompression cycle to investigate the effect of cooling tower design on the cycle performance under the variation of cycle fluid entrance temperature inside the NDDCT and air temperature [6]. In the present work, a comprehensive thermal performance study of a dry cooled sCO_2 cycle is investigated in CSP application, as demonstrated in Figure 1. The recompression power cycle is coupled with a dry cooling tower.

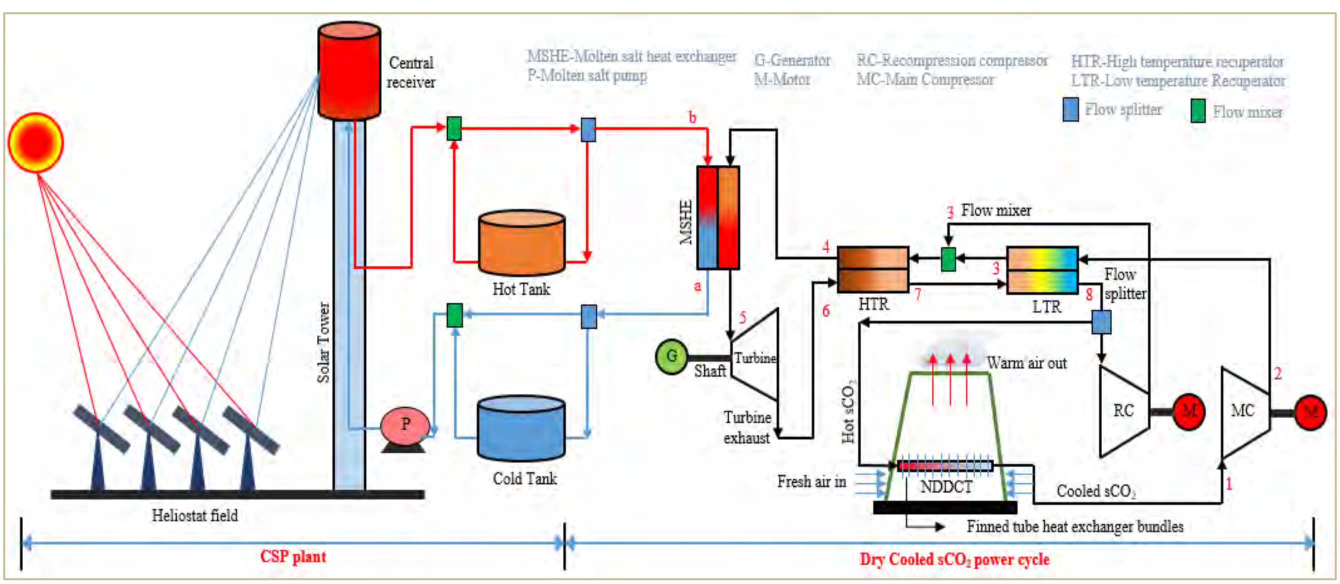

Figure 1. The dry-cooled sCO_2 recompression cycle coupled with CSP.

The plant dynamic performance is studied under the intermittent nature of solar irradiance and fluctuating air temperature throughout the year. The selected location is Alice Springs, Australia a potential site for future sCO_2 CSP plant for commercialization. The system is equipped with molten salt thermal energy storage (TES) to supplement uninterrupted power generation when no solar insolation is available. Prior to the design of the NDDCT, two sets of air temperature are selected based on the historical annual temperature data. This requires the rectification of another two sets of design point main compressor inlet temperature (MCIT)/tower exit temperature for cooling system design parameters. The cycle pressure ratio for both scenarios are optimized and the maximum cycle pressure is kept at 20 MPa. Various parameters in the solar system (molten salt mass flow rate, salt split ratio, and cold tank temperature) and the power block (cycle mass flow, split ratio, and turbine exhaust pressure) are optimized. The turbine and compressors (MC and RC) are modelled with their prescribed adiabatic efficiency. The power cycle validation with a good agreement is performed with the existing literature. All the thermodynamic processes attain steady-state condition. The heat exchangers are discretized for accurate prediction of sCO_2 local properties with change of bulk temperature in the cooling tower as well as in the recuperators. Kroger's detailed dry cooling tower model is implemented while designing the NDDCT. The required size of the heliostat field, tank capacity of TES, and detailed specification (tower outlet height, tower diameters, number of heat exchanger bundles, and number of tower supports) of the NDDCT are revealed at optimum MCIT condition. The year-round system dynamic behavior is observed in terms of tower exit temperature, heat rejection in the tower, air mass flow rate, and net power generation under the variant solar insolation and climate temperature. The contribution of TES during nighttime and the corresponding system dynamic response is also investigated in the present work. The work demonstrates the impact of cooling tower design parameters on the CSP plant and its off-design performance under various climatic conditions on the overall system performance.

References

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