Hybrid parabolic-type thermosolar gas-turbine power plants: working fluid analysis

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1. Introduction

This work provides an integrated design of a small-scale hybrid solar power plant aimed at distributed generation of electrical energy. This technology may be especially interesting for remote areas with no access to electricity and advantageous solar conditions. The inherent limitations of a solar-only power plant (seasonal and meteorological sun fluctuations, nights) may be overcome with a hybrid operation mode. These systems can work uninterruptedly with an approximately constant power output, since the pressurized gas (usually air) of the cycle is heated from the concentrated solar irradiance and, when necessary, from the combustion of a fossil fuel. Then, the transformation of thermal energy to mechanical one is carried out by means of a Brayton thermodynamic cycle and a system of alternators.

Several experimental prototypes have shown that this hybrid parabolic dishes technology is technically feasible [1]. However, research and development efforts need to be done in order to improve its commercial interest by lowering output power price. This can be achieved by increasing the power plant efficiency, which would lead to a larger power production with reduced fuel consumption.

The main purpose in this work is to optimize the performance of the system optimizing the overall pressure ratio for different working fluids, through a complete thermodynamic model based on a reduced number of parameters. This flexible model allows to simulate recuperative and non-recuperative plants and to compare between different plant operation modes (hybrid solar with gas-turbine and pure combustion modes). After optimizing both pressure ratio and mass flow rate for the four studied heat working fluids, a dynamic model is employed, in which the instant solar irradiance and ambient temperature is considered. The annual energy generated, and its associated fuel consumption is then calculated, for hybrid and combustion only operating modes for a real installation and current meteorological data in Salamanca (Spain).

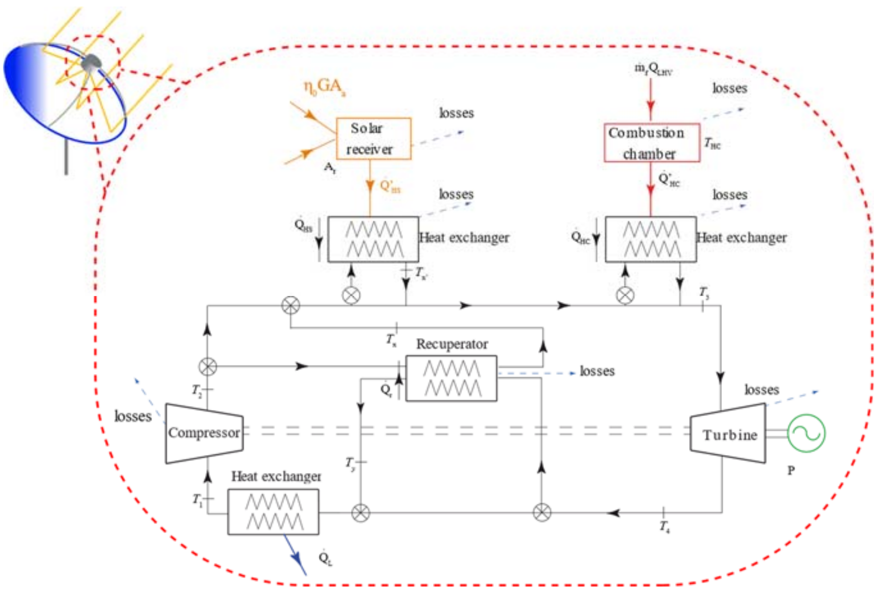

Fig. 1: Schematic representation of the hybrid plant composed of the parabolic dish collector and the Hybrid Solar Receiver Combustor.

2. Thermodynamic model

A thermodynamic model is developed in Mathematica® based on previous works of our group [2], and it incorporates the main irreversibilities taking place in all subsystems and heat exchangers of the hybrid plant.

The designed hybrid plant includes a parabolic dish that collects the sun radiation and heats a working gas flowing in a hybrid solar receiver combustor (HSRC) situated at the focal point. As sketched in Fig. 1, the HSRC includes a volumetric solar receiver, a combustion chamber and a micro-gas turbine (mGT) operating on a recuperative Brayton cycle. Independently of the solar conditions, the combustion chamber ensures the turbine inlet temperature (prefixed for system limitations to 1170 K), which provides a contant power output. This means that the produced electricity is predictable and independent of irradiation fluctuations, and therefore, storage systems are not required. According to the amount of solar irradiation *G* and ambient temperature, the integrated combustion chamber could release an energy flow to increase the fluid temperature up to the pre-fixed temperature.

The overall plant efficiency can be expressed in analytical terms as a combination of the efficiencies of the subsystems. This plant performance is compared by taking similar conditions for four working fluids: subcritical CO_2, helium, nitrogen and air. The mean values of pressure specific heat and adiabatic coefficient are calculated from a temperature varying specific heat fourth order polynomial. The coefficients of the fits for the different working fluids were taken from [3] at an average pressure of p =1.9 bar.

3. Analysis and results

The use of different working fluids in a hybrid parabolic dish power plant based on a closed Brayton cycle is presented in this work. The results for the different working fluids were first compared at the same pressure ratio and later, specific values of the pressure ratio leading to maximum overall plant efficiency were compared. In the case of air and nitrogen, the efficiency reaches its maximum value for pressure ratio in the interval 3-4, meanwhile for CO_2 the efficiency progressively increases with the pressure ratio, until its stabilization to an efficiency of 0.25 for pressure ratios above 10. Expected efficiencies at optimum pressure ratios can reach values about 0.25 for air, nitrogen and CO_2, and about 0.38 for helium.

The annual performance of the plant is estimated in Salamanca (Spain), with annual Direct Normal Irradiation (DNI) accumulated of 1834 $kWh \cdot m^{-2}$. Last year ambient temperature and DNI real data were employed in a dynamic thermodynamic simulation, which gives the total generated energy, fuel consumption and yearly average power output and thermal efficiency, for the four working fluids.

This study shows the potential of small-scale hybrid CSP plants to become attractive for off-grid applications in the distributed energy generation in regions with high solar radiation and low water resources and nowadays can compete against non-renewable diesel generators or photovoltaic technology.

4. Acknowledgements

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References

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