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Solugas – Comprehensive analysis of the solar hybrid Brayton plant

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ABSTRACT

This article presents the first megawatt scale solar-hybrid plant with a solarized gas turbine. The works and improvements that made the Solugas project succeed during design, construction and long-term solar operation are described and explained.

More than 1000 operation hours and receiver outlet temperatures of 800 °C were achieved. The operation behaviour and performance of the key components – the solar pressurised air receiver and the gas turbine – are presented here as a proof of the high potential of the technology.

1. Introduction

Following the requirement to reduce CO_2 emissions from power generation, solar thermal electricity (STE) emerges as one of the most promising sustainable options. Different STE technologies and suitable heat transfer fluids (HTF) entered the market during the last years and proved the reliability of concepts and components. There are significant technical differences for example in availability, dispatchability, scalability and footprint. The most common technologies are parabolic trough and tower using different HTF, such as synthetic oil, steam or molten salt, to run the steam turbine of a Rankine cycle. A healthy competition among these technologies as well as with other renewables, especially PV and wind, is leading to continuous improvements in efficiency and cost. Thus, momentary it mainly depends on the local conditions, the requirements of the utility, maturity, the available subsidies and financing questions which incline to one or the other technology.

However, in order to achieve a leap forward in competitiveness to conventional power plants, combined with the more and more mandatory operation flexibility, a profound change of the STE technologies is required. Previous small scale tests on components, up to the range of a few hundred kW, have shown promising results. The time was ready to demonstrate in a large project, with a full operable prototype, the technical feasibility and potential for future solar tower generations: Solugas, a solar hybrid Brayton cycle, uses concentrated solar power to heat up pressurised air driving a gas turbine.

From end of 2008 until 2014, an international consortium of companies and research centres achieved with the support of the EC Framework Programme 7, the design, construction, operation and evaluation of the largest and most ambitious research project in the field of solar thermal electricity with a Brayton cycle. The consortium was comprised of the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR), Turbomach, Kelvion Sp. z o.o. (former GEA Technika Cieplna Sp. z o.o.), New Energy for Algeria (NEAL) and led by Abengoa.

Thanks to the power cycle and the possibility to combine solar energy together with the heat produced from other energy sources, the technology presents clear advantages compared with the electricity generation from other renewable and conventional plants (Schwarzbözl et al., 2006; Teske et al., 2016):

- Full dispatchability and grid stability through flexibility and instant regulation of the additional fuel flow.
- Fast start up of the gas turbine.
- Easy operability compared with other solar technologies.
- Low to zero water consumption.
- Air as cheap and “harmless” heat transfer fluid (no freezing, no overheating).

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- A wide range of plant concepts, adapting to the requirements of the country and region, are feasible: independent recuperated Brayton cycle, peaking plants and especially combined cycle with or without thermal energy storage.
- Cycle efficiencies of >50% in solarized combined cycle configuration possible.

Thus, it provides reliable power with variable solar share and if fuels from renewable sources are used, such as biogas (Cameretti et al., 2015) or solar fuels, it is also 100% sustainable.

For the solar hybrid Brayton cycle, the two key components to be developed are the solar receiver and the adapted gas turbine.

A large fraction of the thermal power required by the gas turbine should be provided by solar energy to achieve a reasonable solar share, ideally up to 100%. On the other hand, the efficiency of the Brayton cycle rises with higher operation temperatures and pressures. Consequently, to become viable the solar receiver developments need to focus on conditions with highly demanding material requirements to reach outlet temperatures of 800 °C and more. A modern molten salt solar plant for example operates at up to 580 °C. Furthermore, the low heat capacity and thermal conductivity of compressed air compared with other HTFs, as shown in Fig. 1, make it necessary to think of design concepts which still allow high thermal receiver efficiencies.

The gas turbines main challenges are the substantial changes to accept the externally heated gas flow from the solar receiver and the combustion chamber modifications. High requirements on air flow control are a consequence of the introduction of a solar receiver and a larger air volume in the ducting between compressor and turbine. The combustor needs to operate at significantly higher and varying air inlet temperatures and must react fast enough to ensure stable gas turbine operation during solar fluctuations.

Previous to Solugas, various solar Brayton research projects were developed. They mainly concentrated on the compressed air receiver development or small scale configurations for off-grid applications. Two important examples are the Solgate (Solgate, 2005) and Solhyco (Amsbeck et al., 2008) projects, co-financed by the EC FP5 and FP6 and tested on the PSA in Almería, Spain. During Solgate, three modular serial connected receivers (metallic tubular, volumetric with a metallic wire mesh absorber and volumetric using ceramic absorber) reached an outlet temperature of almost 1000 °C to feed a 250 kW gas turbine at experimental scale. Solhyco is the predecessor of the Solugas project: a tubular pressurised air receiver operating for more than 100 h was providing up to 800 °C and 200 kW of thermal energy. For hybridization the turbine could use different fuel types, including biofuel. The Solhyco receiver, with its conical configuration of the absorber tubes, and air distribution and collector rings, was an initial step towards the cylindrical Solugas receiver design.

2. Solugas design and description

The main project objective was the demonstration and validation of a fully operable pre-commercial scale solar hybrid gas turbine system. In order to achieve that, an entire solar plant, as shown in Fig. 2, had to be designed, constructed, operated and analysed.

Solugas is the first demonstration project at megawatt scale where the gas flow can be extracted from the gas turbine compressor at up to 9 bar gauge, preheated by a 3.2 MW_{th} solar receiver up to 800 °C and returned to the combustion chamber of the 4.6 MW Solar Turbines Mercury™ 50 gas turbine. The plant configuration shows some differences from a commercial plant approach. These were implemented to allow a high flexibility of the installation and to be able to operate the receiver, turbine and all high temperature components (insulation, sensors, etc.) at their maximum viable conditions.

Fig. 2. Solugas plant operating.

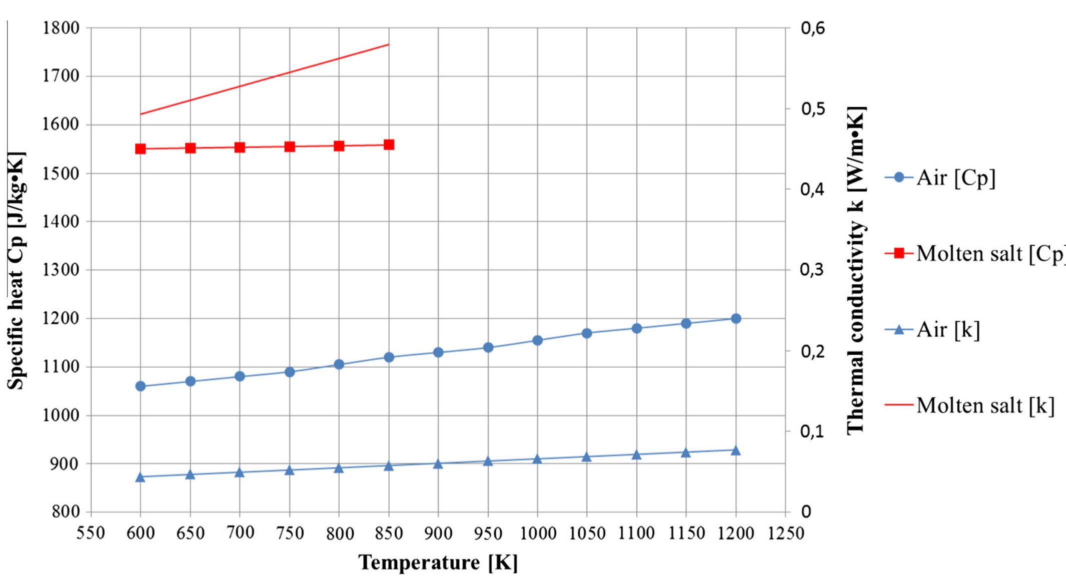

Fig. 1. Comparison of thermal properties of compressed air and molten salt (Bauer et al. 2012).