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The Swiss AA-CAES pilot plant: CFD modeling and validation of the TES system.

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Introduction

A valid alternative to pumped hydroelectric energy storage (PHES) is represented by compressed-air energy storage (CAES). Two industrial-scale CAES plants are nowadays successfully in operation: the 321 MW Huntorf plant (Germany) and the 110 MW McIntosh plant (USA). Their round-trip efficiencies, 42% and 54% respectively, are limited by the dissipation of the thermal energy produced during compression. Therefore fossil fuels are required to heat up the pressurized air before its expansion in the turbine [1].

Advanced adiabatic compressed air energy storage (AA-CAES)

To overcome the limitation of conventional CAES plants, the concept of AA-CAES was proposed (see Fig. 1). In this technology, a thermal energy storage (TES) is exploited to store the thermal energy produced during compression to be recovered before the expansion. Although AA-CAES concept is still in the research and development stage, the expected round-trip efficiency is in the order of 70%, comparable to PHES [2]. Other advantages of AA-CAES, such as limited environmental impact and lower estimated capital costs, make this technology attractive as a potential alternative to PHES for achieving the long-term energy policy developed by the Swiss Federal Council (Energy strategy 2050).

Pollegio AA-CAES pilot plant and experimental campaign

To evaluate the feasibility and applicability of the AA-CAES technology, a pilot plant was built, in a collaboration between ALACAES and ETHZ, in Pollegio (Ticino, Switzerland). A segment of a tunnel located north of Biasca, previously used by the AlpTransit project, was exploited as high-pressure air reservoir. The latter was enclosed by building two 5 m thick concrete plugs at the two ends of a 120 m long section (l.h.s. of Fig. 2). The pilot plant was designed to operate at pressures and temperatures up to 33 bar and 550°C respectively. A single-tank TES, based on a packed bed of natural rocks, was installed inside the pressure chamber. The volume of the packed bed is 44 m^3 with average particles diameter and void-fraction of 20 mm and 0.342 respectively.

An extensive experimental campaign was carried out on the pilot plant. The experimental data gathered in Pollegio were exploited also to evaluate the accuracy of the numerical models developed to simulate the real TES system behaviour.

CFD numerical validation and conclusions

Since the TES can be considered the key component of AA-CAES technology, a CFD model has been developed, to evaluate its thermo-fluid dynamics behavior, and experimentally validated. A schematic of the TES unit under investigation is reported in the r.h.s of Fig. 2.

The reference experimental campaign was characterized by a 42 h pre-charging, followed by five consecutive charge/discharge cycles. Figure 3 shows the comparison between simulation results and experimental data gathered from some thermocouples located, at different heights, into the packed bed. A fairly good agreement between simulation results and experimental temperatures can be observed demonstrating the effectiveness of the CFD model developed in replicating the thermo-fluid dynamics behavior of the experimental TES unit.

Figure 4 depicts the temperature contours of the TES unit at different time intervals. Concerning the experiments, although the maximum pressure reached was limited to 6 bars, the TES system and the cavern performed properly. The estimated efficiency of the pilot plant was in the range of 0.65-0.79 while the thermal efficiency of the TES was between 0.75-0.89.

Acknowledgments

The financial support of the Swiss Commission for Technology and Innovation through the Swiss Competence Center in Energy Research (SCCER HaE - Heat and Electricity Storage) and SNF through NRP 70 (Grant N. 407040_154017) is gratefully acknowledged.

References

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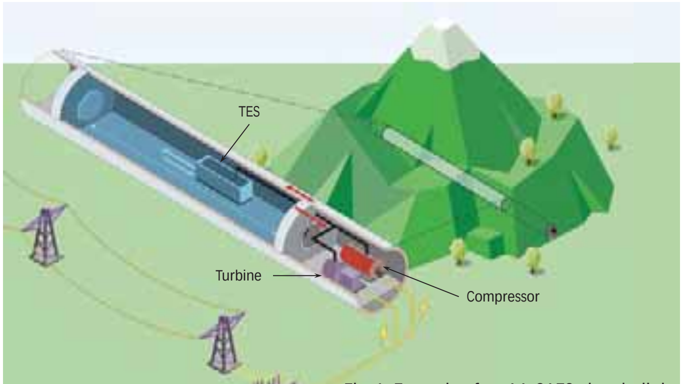

Fig. 1: Example of an AA-CAES plant built in a lined tunnel. Image adapted from [3].

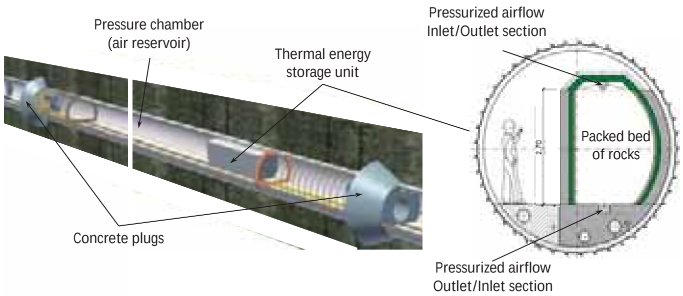

Fig. 2: AA-CAES pilot plant layout (l.h.s.) and tunnel cross-section (r.h.s.). Courtesy of ALACAES SA.

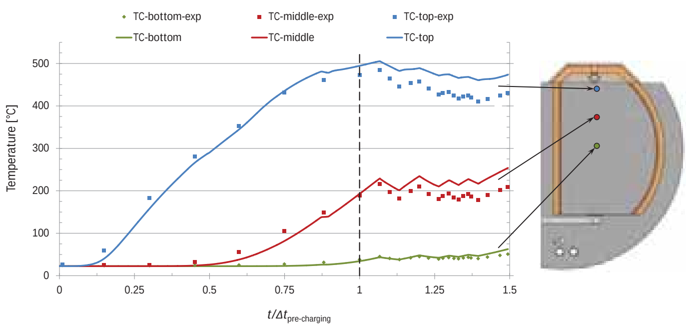

Fig. 3: Comparison between CFD simulation results (solid lines) and experimental data (markers).

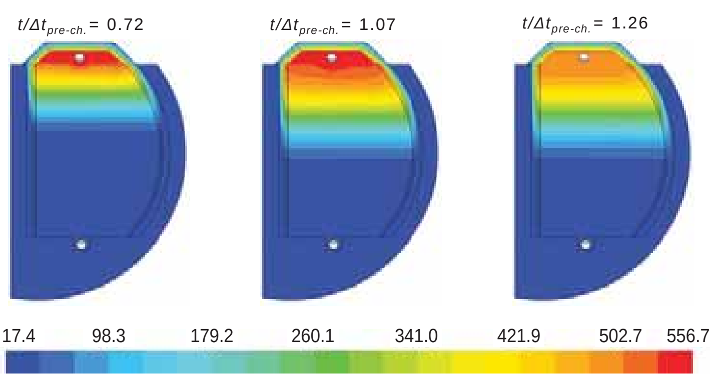

Fig. 4: Contours of static temperature. Temperature values are in [°C].

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