Heat and Electricity Storage – 5° Symposium

CFD modeling and experimental validation of the TES system exploited in the Pollegio AA-CAES pilot plant

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Abstract

In the present study, a computational fluid dynamics (CFD) approach has been developed with the aim of replicating the thermo-fluid dynamics behavior of the thermal energy storage (TES) system integrated in the advance adiabatic compressed-air energy storage (AA-CAES) pilot plant built in Pollegio (Switzerland). The TES system, exploited to store and release the thermal energy produced during compression, is based on a packed bed of natural rocks. An extensive experimental campaign has been carried out on the pilot plant demonstrating the applicability of AA-CAES technology. Furthermore, the experimental data were also exploited to evaluate the accuracy of the numerical model developed in replicating the behavior of the real TES system.

Introduction

In the field of large-scale electric energy storage, a valid alternative to pumped hydroelectric energy storage (PHES) is represented by compressed-air energy storage (CAES). As of today, two industrial-scale CAES plants are successfully in operation: the 321 MW Huntorf plant (Germany) and the 110 MW McIntosh plant (USA). The round-trip efficiency of these CAES plants, 42% and 54% for the former and the latter respectively, is limited by the fact that the thermal energy produced during compression is wasted and therefore they need to burn fuel to increase the enthalpy of the compressed air prior to expansion.

Advanced adiabatic compressed air energy storage (AA-CAES)

To overcome the limitation of conventional CAES plants, the concept of advanced adiabatic compressed air energy storage (AA-CAES) has been proposed. In this technology, a TES is exploited to store the thermal energy produced during compression to be recovered prior to 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. 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).

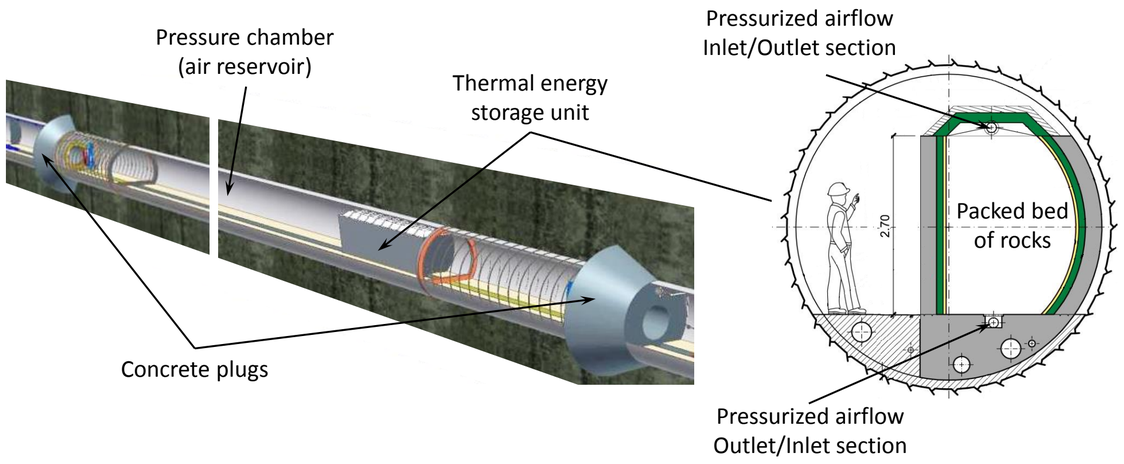

Fig. 1: AA-CAES pilot plant layout (l.h.s.) and tunnel cross-section (r.h.s.). Courtesy of ALACAES SA.

Pollegio AA-CAES pilot plant

To evaluate the feasibility and applicability of the AA-CAES concept, a pilot plant was built, in collaboration with ALACAES and ETHZ, in Pollegio. The pilot plant is designed to operate at pressures and temperatures up to 33 bar and 550°C respectively. A 120 m long section of a tunnel located north of Biasca (TI), 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 (l.h.s. of Fig. 1). A single-tank TES, based on a packed bed of natural rocks, was installed into 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.

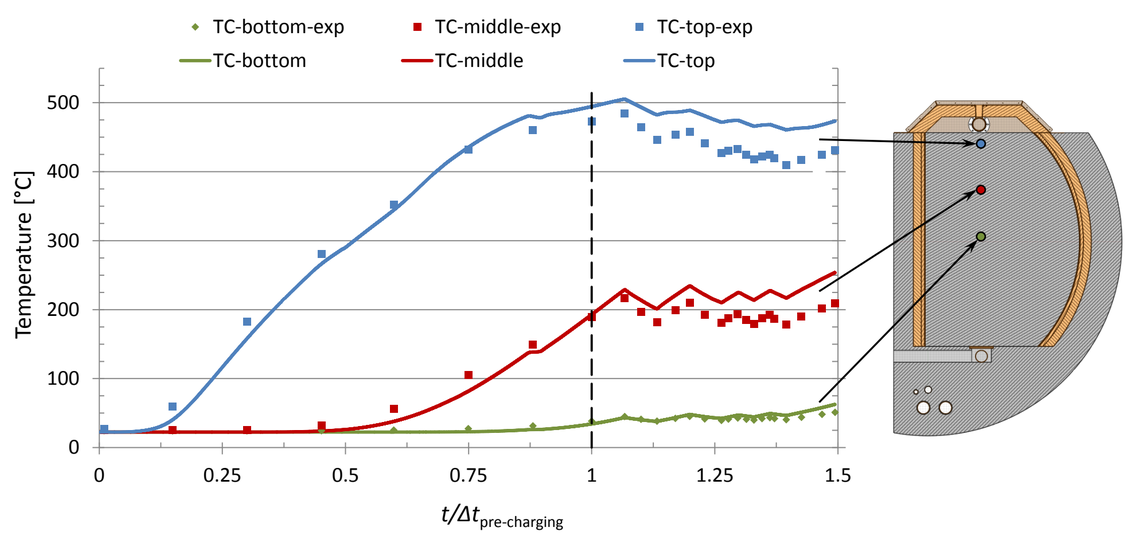

Fig. 2: Comparison between CFD simulation results (solid lines) and experimental data (markers).

Experimental campaign, 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. 1. The reference experimental campaign was characterized by a 42 h pre-charging, followed by five consecutive charge/discharge cycles. Figure 2 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 data can be observed demonstrating the accuracy of the CFD model developed in replicating the thermo-fluid dynamics behavior of the experimental TES unit. Figure 3 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 measured efficiency of the pilot plant was in the range of 0.65-0.79 and the thermal efficiency of the TES was between 0.75-0.89.

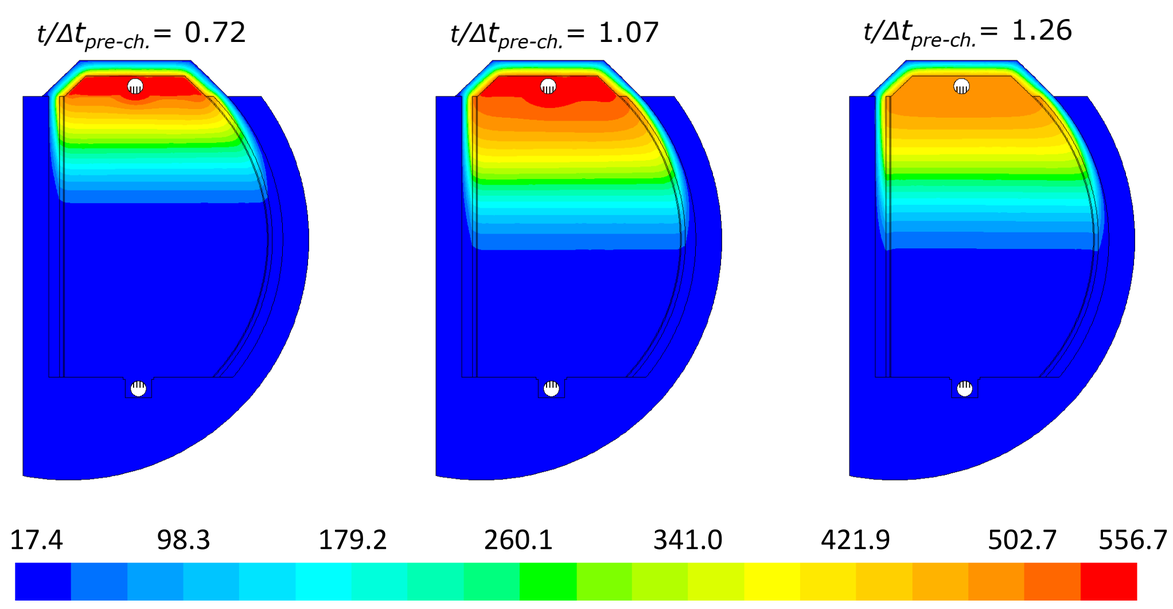

Fig. 3: Contours of static temperature. Temperature values are in [°C].

Acknowledgments

The financial support of the Swiss Commission for Technology and Innovation through the Swiss Competence Center in Energy Research (SCCER 3 - Energy Storage) and SNF through NRP 70 (407040_154017) is gratefully acknowledged.

Project partners: SUPSI, ETHZ and ALACAES SA.

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