ADAPTED H2 STORAGE MODELS – PUBLIC SUMMARY

HYPSTER PROJECT

Deliverable 2.1b

Authors: P. Berest (Armines), B. Brouard (Brouard Consulting), M. Schlichtenmayer and M. Glöckner (ESK)

Project acronym:	**HyPSTER**
Project full title:	Hydrogen Pilot Storage for large Ecosystem Replication
Grant Agreement No. :	101006751
Duration :	36 months
Start date :	1st January 2021
2020 AWP topic addressed:	Topic 2.7 – Cyclic testing of renewable hydrogen storage in a small salt cavern
Coordinator's contact details:	Germain Hurtado - germain.hurtado@storengy.com

Version #	Implemented by	Revision date	Changes
V1	M. Schlichtenmayer	08.10.2021	Consolidation of partners chapters
V2	B. Brouard	18.10.2021	Update of results and comparison
V3	M. Schlichtenmayer	29.10.2021	Update of results and comparison, draft summary
V4	P. Bérest	03.11.2021	Review
V5	M. Schlichtenmayer	07.11.2021	Incorporation of reviewers comments
V6	B.Brouard	11.11.2001	Review of the public summary

Submission date: 11.11.2021
Status: Final
Confidential level: Public

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under Grant Agreement No 101006751. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

1. PUBLIC SUMMARY

HyPSTER is the first EU-supported project aiming for large scale green hydrogen underground storage in salt caverns. The demonstration facility will be built at Etrez in France. The WP2.1 of Hypster project aims at proving the suitability of models to simulate the complex behaviour of hydrogen-filled salt caverns. The deliverable D2.1 describes the results of numerical computations performed using the LOCAS software developed by Brouard Consulting and the software KAVPOOL developed by ESK in combination with the software FLAC3D. All these softwares are commercialy available. In a first part of this report, the physical gas property calculating using both software tools have been compared, which showed a reasonably good agreement of the respective models. The current part of the report focuses on the actual cavern modeling with respect to the thermodynamical and geomechanical effects in the cavern, the well and the surrounding rock. A comparison of the results of both model is carried out leading to a conclusion on the general suitability of the models for further use for the modeling of real hydrogen storage caverns.

In total 19 benchmarking cases have been considered with variations of the following parameters :

- Hydrogen injection temperature
- Creep model (Norton-Hoff vs. Munson-Dawson, normal/fast creep)
- Cavern depth
- Cavern geometry (volume, shape)
- Heat transfer coefficient
- Well parameters (tubing diameter, tubing roughness)

In general, it can be concluded that LOCAS and KAVPOOL/FLAC3D agree quite well with each other for the modeling of the hydrogen benchmarking cases in the relevant operational range. Some divergence of the model results could be observed at operating conditions beyond this range, e.g. at flow velocities above 100 m/s or for deep caverns in fast creeping rock salt. Furthermore, some minor model divergence was related to thermal effects in the well, which should be calibrated, whenever possible, using the measurement results from the upcoming tests at EZ53.

For all the computations cases, hydrogen mass balance and initial wellhead pressure were imposed to the models. Five yearly cycles were considered. For the cases that imply calculation of cavern creep closure, the 2-D Finite Element version of LOCAS was used. For the other cases, a borehole model has been especially developed in LOCAS. Implicit and explicit computation schemes have been programmed to assess the validity of the model. These models were developed both for the case of a spherical and a cylindrical cavern. A comparison between spherical and cylindrical model is given in Section 10. The computations results provided in this report were performed considering only the cylindrical model that is more representative of the cavern shape considered for the benchmark (**Erreur ! Source du renvoi introuvable.**).

For the simulations performed with LOCAS using a 2-D axisymetrical model (Figure 4), a stability stability analysis has been performed for all cases, looking for the possible onset of tensile effective stresses at the maximum pressure and possible onset of rock-salt dilation at the minimum pressure during the cycling. For the considered loading scenarios, some large effective tensile stresses and dilatant zones were found in some cases.

The software KAVPOOL is focused on the modeling of thermodynamical effects in the cavern, the well and the surrounding rock and the coupled operation of multiple caverns in a pool storage. It includes a cavern convergency module that is coupled with the software FLAC3D to allow detailed geomechanical modeling. Both software tool are widely applied in the industry and have proven to match well with

operational data from numerous sites for several decades. In the course of the HyPSTER project specific improvements on the KAVPOOL code had to be made to enable the modeling of infinite heat transfer from the storage inventory to the salt rock to allow a direct comparison with common LOCAS model implementations.

LOCAS is a huge software suite that has been developed continuously for 20+ years, especially for the purpose of analyzing salt caverns. LOCAS suite includes several softwares dedicated to several aspects of salt caverns behavior starting from analysis of creep tests performed at the lab to the full modeling of salt-caverns facilities. LOCAS includes 2-D and 3-D modules and is able to fully couple cavern thermodynamics and rock-salt complex geomechanics, see Appendix C for more details. A full coupling between cavern thermodynamics and rock-salt mechanics is of upmost importance for problems such as gas-storage management, caverns stability analysis, subsidence calculation, or cavern-abandonment.

Some comparisons between LOCAS and KAVPOOL are given in Section 11. As a main result, it could be concluded that both models show good agreement regarding the cavern pressure with differences smaller than 2 bar (see Figure 1). Nevertheless, some differences appear between the results of LOCAS and KAVPOOL. In particular, the amplitude of hydrogen-temperature variations in the cavern is slightly larger using KAVPOOL (Figure 2). However, the observed differences can still be regarded as small with respect to the common uncertainties of the cavern temperature, which are caused by the technical difficulties to measure the in-situ temperatures directly during storage operations.

Furthermore, the LOCAS results show a stronger thermal coupling of the gas in the well to the surrounding rock than obtained with KAVPOOL. It can be expected that withdrawal tests with hydrogen should give more insight, which wellbore module is more appropriate for real hydrogen caverns.

It should also be noted that, during the fast cycling phases of the benchmarking cases, very high flow velocities in the well have been obtained with both LOCAS and KAVPOOL, which exceed the commonly applied operational limit of 20 m/s. Consequently, such operational modes would probably not be realized with a real cavern. Significant differences between the models have been identified for velocities exceeding 100 m/s, which have not been resolved due to their minor operational relevance.

The loss of cavity volume due to salt creep can be compared for Benchmark #03 - #06. Except for Benchmark #06, in all other cases the difference between the volume evolution is less then 1% of the total cavity volume, which is a very good value and better than the accuracy, that is typically achieved with sonar measurements of the cavity volume. For Benchmark #06 very high convergency rates have been obtained with both models, which do not coincide well. Even though the model agreement is low in this case, it becomes clear from the results of each model, that cavern operation would not be feasible under such local conditions.

Regarding the geomechanical modeling the results agree qualitatively with each other. For all cases tensile stresses only have minimal impact to the surrounding rock, while dilation zones can extend for several meters into the rock around the cavern.

Based on the calculations performed and the comparative analysis of the calculation results generated, it can be concluded that the calculation models investigated appear suitable for future applications in association with the storage of hydrogen in solution-mined salt caverns.

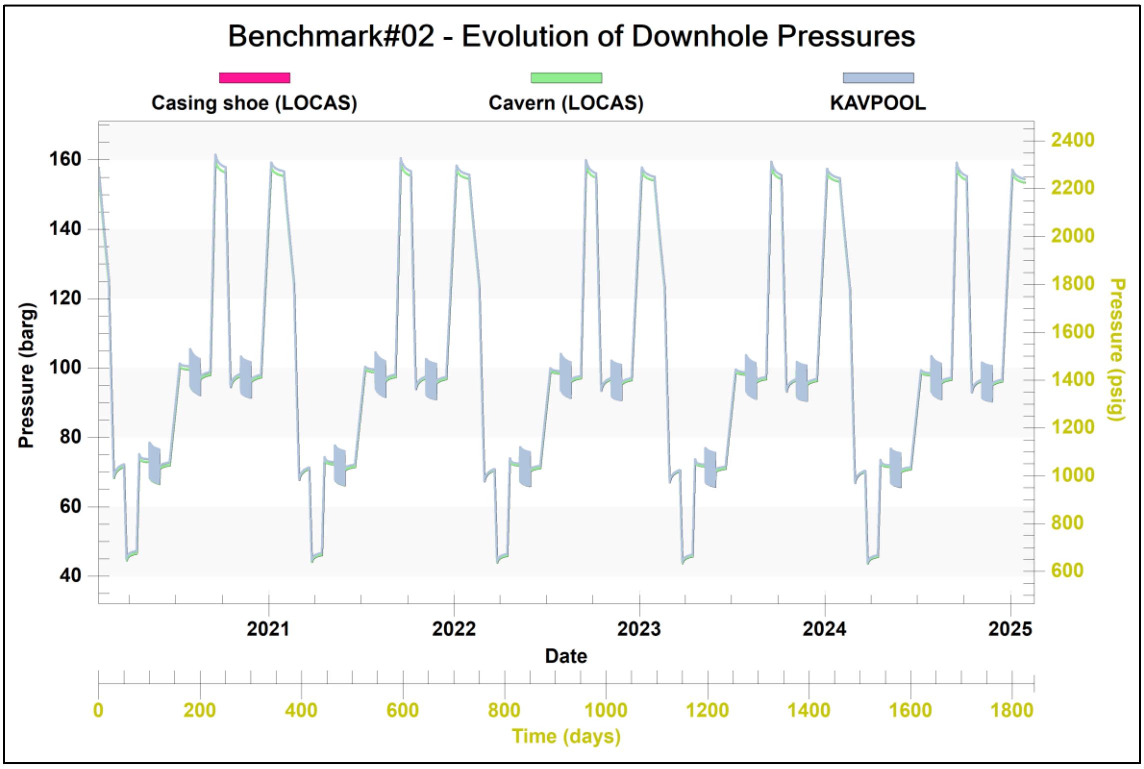

Figure 1. Comparison of the cavern pressure modeled with LOCAS and KAVPOOL for Benchmark #02.

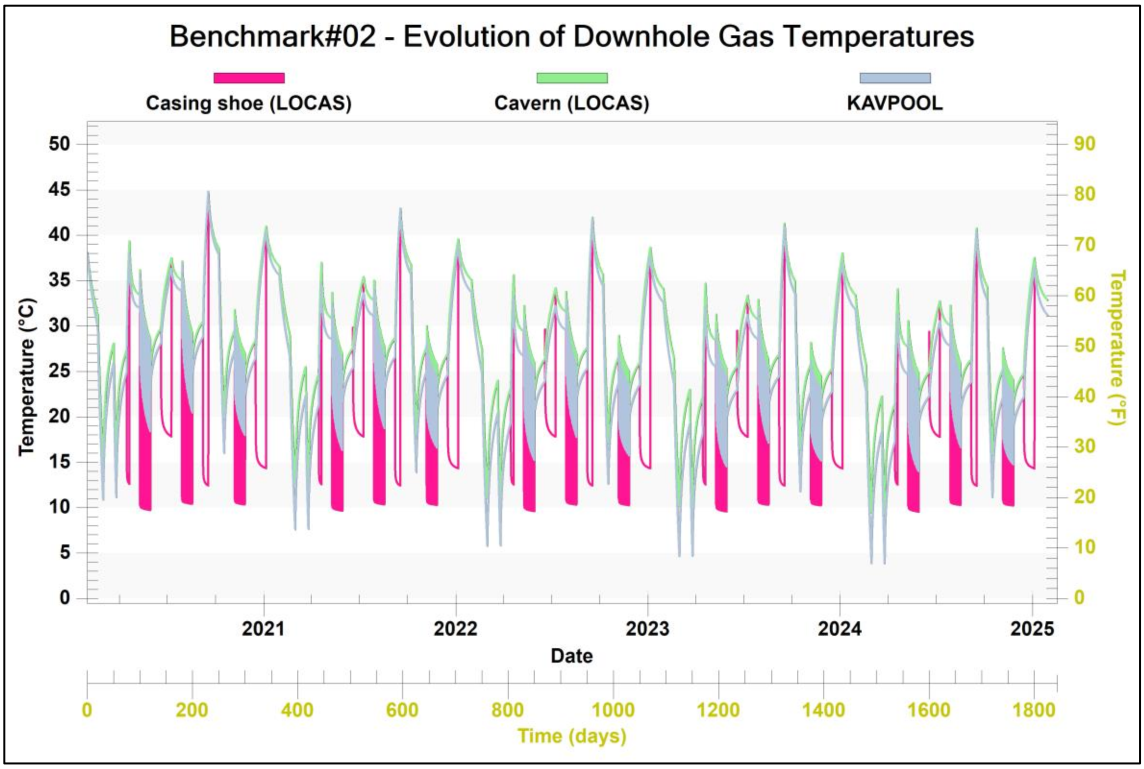

Figure 2. Comparison of the downhole temperatures modeled with LOCAS and KAVPOOL for Benchmark #02.

- ACKNOWLEDGEMENT -

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under Grant Agreement No 101006751. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.