SOLUTION MINING RESEARCH INSTITUTE
105 Apple Valley Circle
Clarks Summit, PA 18411, USA

Telephone: +1 570-585-8092
www.solutionmining.org

Research Report 2016-1

SMRI Research Report RR2016-1:

Perform a Thermo-mechanical Test in a Salt Mine,

as part of SMRI's Research Program on High Frequency Cycling of Salt Storage Caverns

Grégoire Hévin and Yvan Charnavel, Storengy, Paris, France
Cyrille Balland and Pascal Bigarré, INERIS, Nancy, France
Joel Billiotte, Faouzi Hadj-Hassen, BrunoTessier, Ahmed Rouabhi,
Frederic Pellet, Laura Blanco-Martin, Chloe Bonnard,
Mines ParisTech / ARMINES, Fontainebleau, France
Nicolas Thelier, Emmanuel Hertz and Daniel Tribout,
CSME / Salins,Varangeville, France
Kurt Staudtmeister, Bastian Leuger, and Dirk Zapf,
IUB / Leibniz Universität Hannover, Hannover, Germany

December 2016

"High Frequency Cycling of Salt Storage Caverns Research Program"
PERFORM A THERMO-MECHANICAL TEST IN A SALT MINE

SMRI Project Sponsor's Summary
Dieter Brückner

Innovative uses of salt storage caverns in recent years include "High Performance Natural Gas Storage" (HPNGS) and "Compressed Air Energy Storage" (CAES). Compared to seasonal storage caverns, operating pressure conditions are here characterized by:

(1) higher injection/production rates and subsequently higher pressure variation rates, and
(2) more intensive cycling i.e. essentially more cycles over the anticipated operating lifetime.

The SMRI recognizes that the industry requires additional research to improve its understanding of the effects of these relatively more frequently cycling pressure scenarios. Investigations regarding the temperature influence to the salt body caused by thermodynamics during high cyclic operation become necessary to understand those processes relevant for cavern stability, integrity and tightness. More specifically, a better assessment is required of the phenomena subsequent to the cooling of rock salt after rapid pressure drops in a gas-filled salt cavern.

A Research Team under the leadership of Storengy guided by Grégoire Hévin was commissioned to perform a thermo-mechanical test in a salt mine.

The presented report is describing in detail the test side, the test preparation, how the tests were carried out, their outcome, the physical interpretation, finally the conclusions and the impact to cyclic operated caverns. Remarkable are the results of the ultrasonic (AE) and strain measurements regarding the extent and distribution of tensile crack at the bottom of the test chamber. It is important to see that most of the cracks and the largest one occur during the first cooling phase, while during later cycles the number and the dimensions of the cracks are limited to values smaller than in the first cooling phase. Surprisingly, the interpretation of AE-events leads to the conclusion that the main deformation mechanism during the cooling phase change from tensile to shear.

The report also summarizes the results of two independent numerical models. The general constitutive approaches used for the modeling result from salt creep. It could be shown that each model calculates the stress state of the rock salt taking into account the thermal variations. Although the continuum mechanical models cannot simulate cracks, there is strong correlation between tensile stress distribution in the salt and the location of the cracks, the orientation of these cracks and their maximal penetration depth.

The first step is done to understand the thermodynamic aspect of high frequency cycling during storage operation in salt caverns. The thermo-mechanical test in a salt mine is very

helpful to identify critical, temperature induced processes cause by the storage operation mode.

In this context, it could be clarified by the report:

- how the observed partial closing of tensile crack works,
- that the extension of tensile stress influenced zone is limited in their extent and also in the pressure cycle,
- that the tensile stress state occur during all cycles, and
- how the high cyclic operation mode of a cavern can be adapted to prevent tensile stresses.

The limits of the performed modelling are demonstrated as well, which implies that more complex approaches are necessary for a further description of the processes occurring during high cyclic cavern operation. Advanced rock mechanical approaches implemented in extended numerical models may be verifying the development of tensile cracks during repeated load cycles.