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Research Report 2017-3

SMRI Research Report RR2017-3: Cyclic Thermal Loading Creep Tests

(This project was part of SMRI's ongoing research program on high frequency cycling of salt storage caverns.)

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CYCLIC THERMAL LOADING CREEP TESTS

SMRI Project Sponsor Summary

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Gas-storage caverns in rock salt have historically been operated on seasonal pressure cycles, but more recently, market requirements have driven a move toward rapid and frequent cycling and large pressure swings. Important recent examples of this trend are electrical utilities that are increasing their reliance on natural gas for “peak” power generation, commodity trading of gas on short-term markets, and compressed-air energy storage (CAES). Each of these types of storage project requires cycling between minimum and maximum inventory over time scales from hours to days.

Design and stability assessment of engineered salt caverns depend on characterizing of material properties of rock salt within ranges that are determined by lithostatic stress and geothermal temperature gradients in salt formations and the expected range, interaction of pressure, and temperature during storage and cycling. The levels and rates of change of these factors affect deviatoric stress development in the salt mass and the resulting strain and potential dilation of the salt. Traditional seasonal storage assessment has focused on rates of change in gas pressure and temperature appropriate for these projects. With rapid cycling, both the speed and magnitude of variation in deviatoric stress caused by rapid changes in gas pressure and temperature are receiving increased investigation along with the effects of temperature on strain and dilation properties.

In 2010, the Solution Mining Research Institute (SMRI) recognized the need for a laboratory research effort to address rock-mechanics concerns that are related to faster withdrawal and injection rates. A series of projects has been ongoing to study the effects of rapid cycling of stress and temperature on the creep behavior, dilation potential, and damage accumulation of salt. The goal of the research reported here was to assess the impact of rapid temperature cycling on the creep strain and dilational behaviors of salt.

RESEARCH PROJECT SUMMARY

Creep tests performed on salt from Avery Island were designed to focus on thermal effects by imposing reasonably severe temperature cycles while maintaining constant stresses. Parallel tests were performed by RESPEC in Rapid City, South Dakota, USA, and the Institut für Aufbereitung und Deponietechnik (Chair for Waste Disposal Technologies and Geomechanics) at the Clausthal University of Technology (TUC) in Clausthal-Zellerfeld, Lower Saxony, Germany. Temperatures were cycled over 2-day periods between 10 degrees Celsius (°C) and 50°C. This temperature change is consistent with calculated changes in temperature of the rock surfaces in CAES caverns.[1] Two levels of deviatoric stress were evaluated: one above and one below the threshold for dilation that had been measured in a previous study of this salt.

[1] **Bérest, P., P. Sicsic, and B. Brouard, 2016.** “Thermomechanical Effects of Depressurization in a CAES,” *Proceedings, 50th US Rock Mechanics/Geomechanics Symposium,* ARMA-2016-632, American Rock Mechanics Association, Houston, TX, June 26–29.

The test results differed significantly between the two laboratories because the method of imposing temperature changes for the TUC tests resulted in a larger (6°C and 8°C) temperature gradient across the test specimen at the upper and lower temperatures. Numerical modeling of the salt sample, where simulated temperature cycling represent conditions imposed by TUC test apparatus, verified that the larger temperature gradients were sufficient to induce tensile fracturing of the specimen during testing.

The results from the tests performed by RESPEC, where thermal gradients were relatively small, indicate that thermal cyclic loading by itself does not make salt more prone to the dilation caused by compressive shear loading. The conclusion is that material properties governing temperature-dependent creep and dilation threshold are not affected by cyclic thermal loading when internal temperature gradients are minimized.

In the case where thermal temperature gradients exist (TUC results), tensile stresses are able to induce damage. The combined results of the laboratory tests that were performed by RESPEC and TUC demonstrate distinctions that are important for both test methodology and in future assessment of cavern stability and include the following:

- Magnitudes of thermal diffusivity and thermal expansion coefficient for rock salt are such that laboratory procedures need to account for potentially interacting effects on the measured results of magnitude and rate of temperature change versus development of temperature gradients.
- While the thermal gradients during the TUC testing may be considered artifacts of the test apparatus, the temperature changes imposed during this study are of a magnitude that is comparable to those expected in rapid cycling storage. Thus, the TUC results conceptually validate the need to carefully assess thermally induced stresses in delimiting cavern operational limits.

Overall, the following main conclusion of this study in reference to the effect of temperature cycling on creep and dilational behavior can be drawn:

- When the effects of temperature cycling are isolated from the effects of differential thermal expansion and contraction because of temperature gradients, no measureable effect of temperature cycling on creep or dilational behavior was noted.

FUTURE RESEARCH POSSIBILITIES

The results of this study indicate that a logical and important extension of this work would be to investigate the thermal expansion coefficient and Young's modulus of damaged rock salt. The results of this work would provide a basis for assessing the magnitude of thermal-induced damage caused by temperature gradients and their significance for geomechanical design of CAES and high-performance, gas-storage caverns.

In March 2017, RESPEC and TUC submitted an unsolicited joint proposal to perform heated uniaxial and triaxial tests to evaluate the thermal expansion coefficient and elastic parameters of damaged and undamaged salt. This proposal was accepted at the Spring 2017 meeting in Albuquerque, New Mexico.