SOLUTION MINING RESEARCH INSTITUTE
679 Plank Road
Clifton Park, NY 12065, USA

Telephone: +1 518-348-6995
www.solutionmining.org

Research Report 2020-2

SMRI Research Report RR2020-2:

Determination of Thermal Expansion Coefficient by Stress-Controlled and Volume-Controlled Triaxial Tests to Address Thermal-Induced Stresses in Cyclic Storage Caverns

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

Stuart Buchholz, RESPEC, Rapid City, SD, USA
Evan Keffeler, RESPEC, Rapid City, SD, USA

Uwe Düsterloh, Clausthal University of Technology, Clausthal-Zellerfield, Germany

31 July 2020

Determination of Thermal Expansion Coefficient by Stress-Controlled and Volume-Controlled Triaxial Tests to Address Thermal-Induced Stresses in Cyclic Storage Caverns

SMRI Project Sponsor Summary

Peter W. Jordan
Lonquist & Co. LLC

In 2010, the Solution Mining Research Institute (SMRI) recognized the need for a laboratory-research effort to address rock-mechanics concerns related to rapid cycling of gas inventory in caverns that are driven by market requirements for electrical utilities that rely on natural gas for “peak” power generation, commodity trading of gas on short-term markets, and compressed-air energy storage (CAES). In response, SMRI funded a series of projects to study the effects of rapid cycling of mechanical stress and temperature on the creep behavior, dilation potential, and damage accumulation of salt.

These studies are intended to support design and stability assessments of engineered salt caverns, which depend on knowledge of the material properties of rock salt, how these properties vary with expected ranges of in situ lithostatic stress and temperature, and the expected range and rate of change in pressure and temperature that occurs with rapid cycling. The levels and rates of change of these factors affect deviatoric stress development in the cavern wall and deeper in the salt mass as well as the resulting strain and potential dilation of the salt.

The previous research project in this series (RR2017-3) focused on assessing the impact of rapid temperature cycling on the creep strain and dilational behaviors of salt. Thermal cycling, when isolated from the effects of differential thermal expansion and contraction because of temperature gradients, has no measurable effect on creep or dilational behavior. However, differential thermal expansion and contraction caused by temperature gradients present methodological challenges for characterizing the effects of thermal cycling and requires further quantitative study to incorporate its effects into modeling the geomechanical stability of caverns during rapid cycling.

RESEARCH PROJECT SUMMARY

The research reported here was performed in parallel 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. The focus of this work was measuring the thermal expansion coefficient of Avery Island salt by performing the following:

- Uniaxial tests at temperatures of 30 degrees Celsius (°C), 50°C, and 70°C.
- Triaxial testing with constant stress on undamaged and damaged core at temperatures of 30°C, 50°C, and 70°C.

Official Copyright, SMRI
Complete File Available In Library

- Triaxial testing with constant volumetric strain on undamaged and damaged core at temperatures of 30°C and 50°C. These tests were limited to temperatures of 30°C and 50°C because of machine constraints.
- Triaxial measurements of thermal expansion coefficients according to the following program:
  – Hydrostatic pressure was held at 2 megapascals (MPa).
  – Axial stress was increased to 22 MPa while maintaining the confining stress at 2 MPa. This deviatoric stress has been shown to induce salt dilation.
  – After reaching 1 percent volumetric strain (dilation), the stress was reduced until a hydrostatic stress of 2 MPa was reached; this low stress was intended to minimize healing during subsequent measurements.

The scope of the research is restricted and intended to be exploratory in nature.

The study achieved the following main results:

- The average uniaxial measurement of the thermal expansion coefficient from all of the tests was approximately 3.9×10^{-5} K^{-1}, which is consistent with published thermal expansion coefficient data of Avery Island salt [Durham et al., 1987][1].
- Measurements of the thermal expansion coefficient from triaxial testing are summarized as follows:

  Constant stress test:

RESPEC:	Undamaged sample: 3.4×10^{-5} K^{-1}	Damaged sample: 3.2×10^{-5} K^{-1}
TUC:	Undamaged sample: 5.3×10^{-5} K^{-1}	Damaged sample: 6.3×10^{-5} K^{-1}

  Constant volumetric strain test:

RESPEC:	Undamaged sample: 4.0×10^{-5} K^{-1}	Damaged sample: 4.3×10^{-5} K^{-1}
TUC:	Undamaged sample: 3.1×10^{-5} K^{-1}	Damaged sample: 5.9×10^{-5} K^{-1}

- The average values of the thermal expansion coefficient were similar for the two laboratories (i.e., RESPEC and TUC); however, variation between the estimates from the different temperature steps was nearly an order of magnitude different and was likely amplified by sample variation in Young's modulus and Poisson's ratio (measured for each sample in the undamaged and damaged conditions). The two test laboratories also differed in the configuration of the test equipment and the method of measuring Young's modulus and Poisson's ratio.

A methodological conclusion of this research is that the constant stress-controlled test is more appropriate for measuring the thermal expansion coefficient because the calculation only involves the temperature difference and the measured volumetric strain. For the constant volume-controlled test, Young's modulus and Poisson's ratio are used in the final estimate of the thermal expansion coefficient, which introduces additional sources of uncertainty.

[1] **Durham, W. B., H. C. Heard, C. O. Boro, K. T. Keller, W. E. Ralph, and D. A. Trimmer, 1987.** *Thermal Properties of Permian Basin Evaporites to 493 K Temperature and 30 MPa Confining Pressure*, Report BMI/ONWI-633, prepared by Lawrence Livermore National Laboratory, CA, for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

Official Copyright, SMRI
Complete File Available In Library

Even with uncertainly regarding the values of individual estimates of the thermal expansion coefficient, the measurement averages were similar overall, and the thermal expansion coefficients measured before and after damaging the sample were not consistently different.