Brine Availability Test in Salt, a Heated Borehole Experiment at the Waste Isolation Pilot Plant, New Mexico, USA - 20233

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ABSTRACT

The Brine Availability Tests in Salt (BATS) is a US Department of Energy Office of Nuclear Energy (DOE-NE) supported activity as part of the Spent Fuel and Waste Disposition (SFWD) Campaign where we are performing simultaneous heated and control experiments in adjacent horizontal boreholes in the WIPP Salt Disposal Investigation drifts as part of experimental Phase 1 [1,2,3]. Phase 1a of BATS, a low-cost, small spatial-scale experiment performed in order to design instrumentation and methods for further experimentation in the URL, has been completed (June 2018 – May 2019) and is described elsewhere .e.g. [4,5,6]. In coincidence with multiple physical parameters that will be measured over the duration of the experiment, we will be measuring the liquid and vapor phases of H_2O as well as its isotopic content (not measured in Phase 1a). Three different forms of water occur in natural salts: as fluid in macro scale (mm size) inclusions, as intergranular free H_2O and as H_2O incorporated in hydrous minerals [7]. Each of these forms has potentially different stable-isotope signatures and will be influenced differentially by heat induced transport and by interaction with introduced tracers [8,9]. Continuous measurement of vapor phase H_2O isotopes during borehole heating will be impacted by several effects: 1) evaporation as liquid brine flows into the borehole and evaporates completely or partially into the dry N_2 stream; 2) steam from dehydration of hydrous minerals, that may enter the borehole; and 3) hydrous minerals that may form in the borehole (preferentially incorporating heavier isotopes). The continuous time series collected over the course of the heating test will be combined with analyses of pre-test and post-test collected samples of test site salt to investigate the contributions of each of the three water types as H_2O is mobilized due to the effects of heating.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico is a US DOE facility developed for long-term storage of transuranic (TRU) waste. Covering ~4000 hectares (~16 square miles), WIPP facilities are located in a Permian Period (250 MYBP) salt formation 600 m (~2000 feet) thick beginning 260 m (~850 feet) below ground surface. In addition to TRU storage, WIPP houses a unique Underground Research Lab (URL) with ongoing research that includes particle astrophysics, waste repository science, mining technology, low radiation dose physics, fissile materials accountability and transparency, and deep geophysics.

Salt formations are considered an ideal repository for heat generating nuclear waste (HGNW) due to their extremely low permeability, high thermal conductivity and self-healing capability. Uncertainties associated with brine chemistry and mobility near heat generating waste however, compel ongoing research to better understand and predict the long term behavior and evolution of storage facilities. Heat sources within salt may establish so called “heat pipes” where boiling of water vapor and subsequent condensing of steam within the formation create a multiphase convection system. While the presence of heated brine may corrode waste canisters the development of “heat pipes” may support storage efforts through the precipitation of salt around the canisters. To reduce these uncertainties and improve model forecasts for HGNW storage in salt, we are undertaking heated borehole experiments at the WIPP URL. Numerical models are being developed and calibrated at LANL to support the field test design.

DESCRIPTION

Simultaneous heated and control experiments in adjacent horizontal boreholes are illustrated in Figure 1. Each main borehole is located centrally in an array of satellite boreholes (main boreholes and satellite boreholes can be observed on the schematic of the wall face in Figure 1. with the control array on the far left next to the white control boxes and the heated array in the right center) that are instrumented to measure temperature distribution and strain with thermocouples, fiber-optic distributed strain (DSS) and temperature (DTS) sensing, acoustic emissions (AE) monitoring, ultrasonic travel-time tomography and electrical resistivity tomography (ERT).

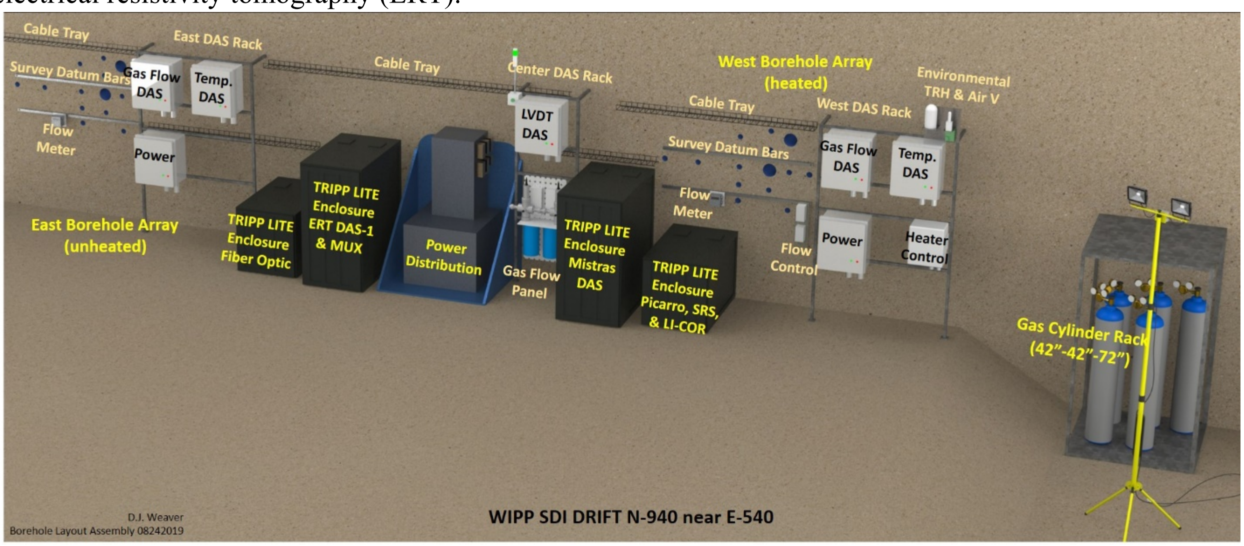

Figure 1: A draft layout of the boreholes, instrumentation and sundry associated equipment.

There is one central 3.7 m (12 ft) long (12.2 cm [4.8 in] diameter) HP borehole in each array. The 750-Watt quartz lamp heater and centralized borehole-closure gage are mounted behind the 11.4 cm (4.5 in) diameter 0.6 m (2 ft) long Aardvark packer via a pass-through 2.5 cm (1 in) steel pipe. The packer is set approximately 1.5 m (4.9 ft) deep into the borehole. There are two 0.6 cm (¼ -in) stainless steel gas lines passing through the packer: one connected to ultra-high purity (UHP – 99.999%) bottled N_2 (inflow) and the other connected to the downstream gas instrumentation (outflow) (green line of Figure 2). External instruments, instrument control and data logging are all housed in the cabinetry between borehole arrays of Figure 1 while flow control, temperature control and sundry other items are housed in the lateral white enclosures.

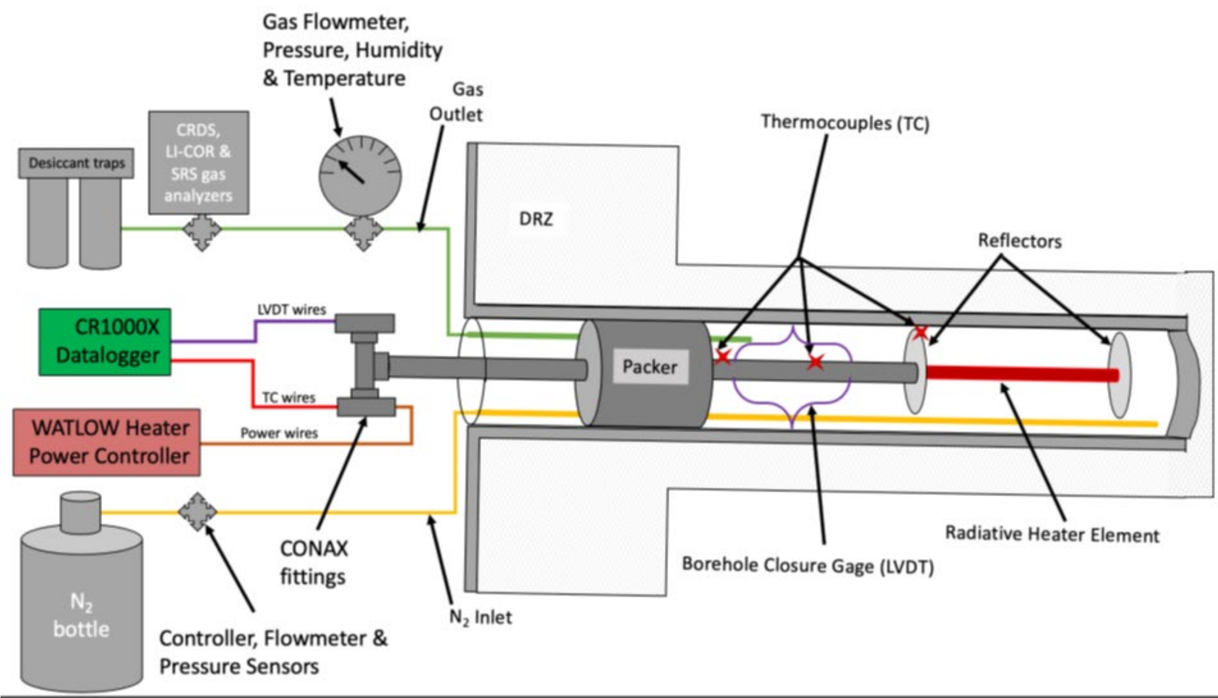

Figure 2. Schematic of the borehole/packer/continuous sample flow system.

In order to perform continuous analysis of various gas phase tracers, dry nitrogen (N_2) will be circulated through the open volume behind the packer and delivered to the external analyzers via the outflow stem of the packer. The mass flowrate of gas (reported at Standard Temperature and Pressure) will be monitored both upstream and downstream of the packer to confirm the mass balance of N_2 flowing through the system as an indication of any leaks of the packer-isolated interval through time. Downstream of the flowmeter after the packer, there will be a pressure relief valve and a pair of plumbing tees and three-way solenoid valves to allow switching the gas streams from the two boreholes between the two branches of gas analyzers instruments.

The suite of analyzers that will perform continuous analyses of the outflow include a Picarro Cavity Ringdown Spectrometer/CRDS (H_2O vapor and isotopic content), LI-COR 820 (CO_2/H_2O), and SRS gas analyzer (AMU scans 2-180 AMU) and will be shared between the two borehole tests (heated and unheated). The gas plumbing will be switched between the Picarro/SRS branch and the LI-COR branch periodically via solenoid-actuated three-way valves. The Picarro analyzer reports the H_2O concentration (μmol/mol or ppmv) as well as the stable oxygen and hydrogen isotopes (expressed as ratios relative to the universal standard, Standard Mean Ocean Water/SMOW), while the LI-COR analyzer reports mmol/mol H_2O and μmol/mol CO_2. The SRS gas analyzer is a quadrupole mass spectrometer designed for atmospheric pressure inlet pressures. The analog outputs from the LI-COR will be connected to a Campbell Scientific CR1000X datalogger, while the Picarro and SRS gas analyzers have their own logging computers.

A tracer of particular interest and the focus of this paper is the stable isotopic content ($^2H/^1H$ and $^{18}O/^{16}O$) of native and introduced waters. Three different forms of water occur in natural salts: as fluid in macro scale (mm size) inclusions, as intergranular free H_2O and as H_2O incorporated in hydrous minerals. Each of these forms has potentially different stable-isotope signatures and will be influenced differentially by heat induced transport and by interaction with introduced tracers. Continuous measurement of vapor phase H_2O isotopes during borehole heating will be impacted by several effects: 1) evaporation as liquid brine flows into the borehole and evaporates completely or partially into the dry N_2 stream; 2) steam from dehydration of hydrous minerals, that may enter the borehole; and 3) hydrous minerals that may form in the borehole (preferentially incorporating heavier isotopes). The continuous time series collected over the course of the heating test will be combined with analyses of pre-test and post-test collected samples of test site salt to investigate the contributions of each of the three water types as H_2O is mobilized due to the effects of heating.

DISCUSSION

To date in Phase 1 we have performed an initial 11 day test of the Picarro system prior to the planned start of the heating experiment (Figure 3). Start of the heating experiment is planned for mid-January, 2020.

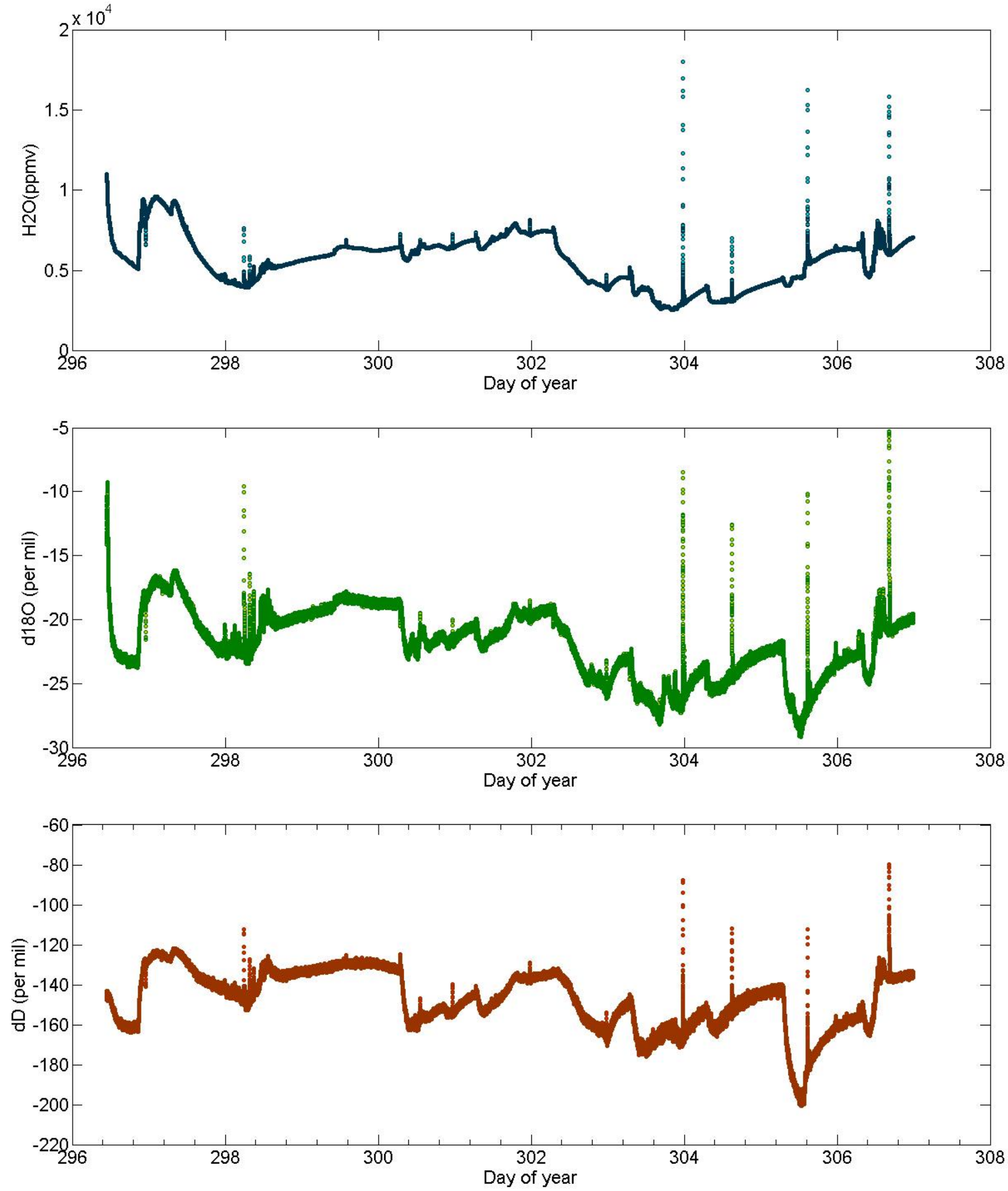

Figure 3. H_2O concentration (blue), $d^{18}O$ (green) and d^2H (dD, red).

As can be seen in the first panel of Figure 3, there is some natural variability of H_2O concentration over time (μmol/mol shown as ppmv). As these results are very recent, we have not had time to investigate correlation of these concentration measurements with any other physical parameters being measured at the borehole. The results do demonstrate however that the analytical system is functioning as expected and that results are within the analytical range of the instrument. We note also that the second two panels showing the ^{18}O isotopic content (green) and ^{2}H (D) isotopic content (red) also are within normal analytical range as expected (isotopic content is expressed as a ratio relative to the universal isotopic standard, Standard Mean Ocean Water/SMOW and reported as per mil). Finally, we note that although the three measurements appear to have coincidental profiles, there are certain specific time-points e.g. early on day 300 and midday of day 305 where the isotopic signals have rather large excursions relative to the rather minor change in concentration. These are just a couple of examples of the type of behavior where we believe the isotopic signatures will lend addition insight into brine migration. Heated testing is planned to begin mid-January 2020 and additional data will be available and presented at WM2020.

CONCLUSIONS

Preparation for Phase 1 of the Brine Availability Test in Salt is underway at the WIPP. This test includes a heated and unheated array of boreholes installed within a drift of the URL with a variety of instrumentation aimed at assessing the origin and abundance of brine to sources of heat. Along with other instrumentation, a Picarro CRDS, LI-COR 820, and SRS gas analyzer will be used to analyze the isotopic signature of the brine produced by the heated and unheated array. We hope to be able to differentiate between inter-granular brine, fluid inclusions, and water bound within hydrated minerals through our isotopic analysis. The ultimate goal being to reduce the uncertainties associated with brine availability, improve our understanding of the complex processes within salt, and to increase our confidence in simulations used to predict long term storage security. This test is being actively conducted, with only preliminary data available at this time, the latest available data will be presented at the WM2020 meeting.

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