Thermohydrological Response of the Yucca Mountain Single Heater Test

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Introduction

Yucca Mountain is being evaluated as a potential repository site for nuclear waste disposal in the USA. *In-situ* thermal tests included in the site characterization program are being carried out in the potential repository formation of Topopah Springs welded tuff in the Exploratory Studies Facility (ESF) at Yucca Mountain. The primary objective of the thermal tests is to develop a better understanding of the coupled thermal, mechanical, hydrological, and chemical processes likely to exist in the unsaturated rock mass surrounding the potential geological repository. The Single Heater Test (SHT) consists of a 5 m long, nominal 4 kW heating element, horizontally emplaced among 30 instrumental boreholes, which span a rock block of approximately 13m x 10m x 13m in a side alcove in the ESF. The heating phase of the SHT was initiated in August 1996 and ended after 9 months. Currently the cooling phase is being monitored. The scientific responsibility of conducting the field experiment and interpreting the thermal tests is shared among several organizations including the Sandia National Laboratories, the Lawrence Livermore National Laboratory, and the E.O. Lawrence Berkeley National Laboratory (LBNL), under the coordination of the Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O). The heating phase data of the SHT have been evaluated by the thermal testing team of the three National Laboratories [1]. Herein, we summarize LBNL's understanding of the thermohydrological response of the SHT, which includes simulations and comparison to data. Temperature, gas pressure, humidity, mechanical displacement and stresses of the rock are monitored, on at least an hourly basis, by a multitude of (530) sensors installed in numerous instrumental boreholes. Figure 1 shows schematically the layout of boreholes grouped according to their different functions. The heater hole is collared on the "Thermomechanical Alcove" wall, orienting W-E (y axis) at 2 m above the drift floor. While many boreholes housing thermal and mechanical sensors are drilled parallel to the heater hole, the hydrological holes are all orthogonal to the heater hole. These holes are designed to probe

temperature sensors at the mid-plane of the heater are displayed as a function of radial distance from the heater. The matrix and fracture temperatures from the simulations, represented by solid and dotted line, respectively, are also plotted. The simulated matrix and fracture temperatures are similar except near the nominal boiling point, where the fracture temperature slope shows a plateau. This is indicative of the presence of a region of liquid and vapor counterflow, i.e. the heat pipe effect. This region centers around 0.8 m from the heater at 3 months of heating, and moves out to about 1.2 m at the end of 9 months of heating. Figure 3 shows the fracture liquid saturation and liquid flux at 3 months. Note that drying occurs up to a radial distance of about 1 m from the heater, beyond which is a condensation zone where the fracture liquid saturation is significantly higher than the ambient value of 0.05. Downward drainage flux is appreciable in the condensation zone. Note also that the thermally induced flux is several orders of magnitude larger than the ambient percolation flux. The redistribution of the moisture content described by the numerical model is consistent with data from active testing by neutron logging, cross-hole radar tomography and air permeability tests [1], all indicating a drying zone around the heater and moisture built up outside of the drying zone.

Conclusion

The agreement between the data and simulated results indicates that the thermal-hydrological responses of the SHT in the 9 months of heating are well represented by the coupled thermal-hydrological numerical model. While heat conduction accounts for most of the temperature rise, thermohydrological coupling contributes to the heat transfer by convection, resulting in better agreement between simulations and temperature data. The thermohydrological coupling also accounts for the moisture redistribution seen by the active testing data.

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Single Heater Test

Borehole Perspective

Figure 1: Schematic diagram of borehole configuration of the Single Heater Test. The heater is collared on the Thermomechanical Alcove pointing W-E.

Figure 2: Measured and simulated temperature at 3 months. Temperatures shown are those in the center plane of the SHT block at $y = 4.5$ m.

Figure 3: Fracture saturation and liquid flux after 3 months of heating in the center plane of the SHT block at $y = 4.5$ m. The xy -plot shows a distribution of saturation and flux along the z -axis at $x=0.0$ m. Positive flux values denote upward flow, and negative flux values denote downward flow.