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at G-Tunnel and Yucca Mountain

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DISCRETE-FRACTURE MODELING OF THERMAL-HYDROLOGICAL PROCESSES AT G-TUNNEL AND YUCCA MOUNTAIN

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I. INTRODUCTION

The U.S. Department of Energy is investigating the suitability of Yucca Mountain, Nevada, as a potential site for high-level nuclear waste storage. Decay heat can significantly improve or degrade repository performance by affecting the waste-package (WP) environment¹, and it can move substantial water vapor across various length scales². Thermally driven moisture movement has been modeled in the past using either equivalent-continuum (ECM) or (less commonly) discrete-fracture (DFM) models. The ECM assumes local thermodynamic equilibrium between the fractures and matrix within a composite representative elementary volume (see, e.g., Nitao³). It is, therefore, a single-continuum model with composite characteristic curves given as functions of bulk-averaged saturation. The DFM, on the other hand, separates the fractures and matrix into distinct domains, which, can represent disequilibrium between matrix and fractures. The DFM is well suited to investigating the dynamics of decay-heat-generated condensate, on how much water imbibes into the matrix by matrix suction or drains down fractures. However, the ECM is much more computationally efficient, so it is important to understand conditions under which the ECM is appropriate.

For further details describing this investigation the reader is referred to the work of Nitao and Buscheck⁴.

II. MODELING THE G-TUNNEL HEATER TEST

A field test⁵ was performed in 1988-1989 by Lawrence Livermore National Laboratory in the G-tunnel Complex at the Nevada Nuclear Test Site. A 3-kW, 3-m-long heater assembly was emplaced into a horizontal borehole 30 cm in diameter and was energized for approximately 130 days followed by a 65 day linear rampdown period.

The test was simulated using the NUFT (Nonisothermal Unsaturated-Saturated Flow and Transport) computer code⁶ to construct a three dimensional hybrid DFM/ECM system. A single discrete fracture is represented by a two-dimensional plane of elements that traverses the heater at its midplane. The

matrix on both sides of the fracture is 0.15 m thick and is modeled by a three-dimensional slab of elements. The rest of the model consists of a three-dimensional system of ECM elements. In this way we can efficiently model a finite heat source without the infinite-source assumption. Cases were run for fracture apertures of 100, 524, and 1048 μm , corresponding to bulk permeabilities, $k_b = 0.280, 40, \text{ and } 320$ darcies. A pure-ECM model was also run for comparison.

Temperature histories at the lower borehole wall and at points below and above the heater axis showed good agreement. The 1048- μm case shows a higher-than-measured temperature above the heater, possibly because buoyant gas-phase convection is being overpredicted. Rock matrix dryout volume, as measured by the neutron probes, was predicted reasonably well by both DFM and ECM. In the 524- and 1048- μm cases, the ECM predicts much more buildup of condensate in the matrix, whereas the DFM predicts much less because of higher condensate drainage fluxes and upward vapor dispersal by buoyant convection. Some condensate buildup is predicted by both approaches in the 100- μm case. Consistent with field measurements, the 1048- μm DFM predicts slightly more drying below and slightly less drying above the heater.

The 100- μm DFM predicts very little nonequilibrium condensate drainage in the fracture plane while there is significant condensate drainage in the 1048- μm case. At early times fracture flow in the 1048- μm case is dominated by gravity; at the end of the full-power heating period, buoyant gas-phase convection moves vapor to above the heater, where it condenses.

III. MODELING DRIFT-SCALE BEHAVIOR IN THE REPOSITORY

A DFM was developed for a drift-scale calculation simulating possible conditions at the Yucca Mountain potential repository site. A single symmetry cell from an infinite array of drifts was modeled with discrete fracture planes spaced 0.33 m apart transverse to the drift axis. Fractures of various apertures were modeled. Areal mass loadings were 40, 48, and 60 MTU/acre (MTU = metric tons of uranium equivalent), corresponding to center-to-center drift spacings of 120, 100, and 80 m, respectively. The WP centers are spaced 6 m apart in the drift and an

oldest-fuel-first receipt scenario with 26-yr-old spent nuclear fuel, and a mix of 40 BWR and 21 PWR WPs were assumed for the decay-heat-generation curve. The model extends from the ground surface to the water table. Various units were treated as horizontal layers of constant thickness, same as in Buscheck et al.⁷ Fracture aperture is uniform over all units.

An interesting result is that ECM and DFM bulk saturations agree after a few hundred years. During the first 100 yr after emplacement, the DFM predicts significant nonequilibrium condensate drainage above to below the repository while the ECM predicts very little drainage. After less than 100 yr, the nonequilibrium condensate shedding (as characterized by drainage around and below the boiling zones) ceases in the DFM, and the system approaches the same state as predicted by the ECM; both the ECM and DFM predict condensate refluxing in fractures above the repository for thousands of years after boiling fronts coalesce. Nonequilibrium condensate drainage decreases with time because local condensate flux is reduced by the decay in WP heat and the expansion of the boiling surface. When condensate flux drops below the critical flux for fracture-dominated flow⁸, nonequilibrium flow ceases.

IV. CONCLUSIONS

Gravity drainage and buoyant gas-phase convection are likely reasons why condensate buildup in the matrix was not observed in the heater test. Preferential drying below and wetting above the heater was probably caused by buoyant convection. Heat transfer in the rock was primarily by thermal conduction, and temperature predictions were good. Because of the short duration and small spatial scale of the test, the local condensate drainage flux during the test was probably much higher than for a repository beyond the first few hundred years.

DFM drift-scale repository simulations suggest that nonequilibrium condensate shedding ceases less than 100 yr after waste emplacement. The ECM agrees with the DFM after this early period.

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