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THE IMPACT OF NATURAL CONVECTION ON NEAR-FIELD TH PROCESSES IN THE FRACTURED ROCK AT YUCCA MOUNTAIN

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INTRODUCTION

The heat output of the waste to be emplaced at Yucca Mountain will strongly affect the thermal-hydrological (TH) conditions in and near the geologic repository. Recent analysis of gas flows within emplacement drifts has demonstrated that the open (not backfilled) tunnels will act as important conduits for natural convection processes (Bechtel SAIC Company, 2004; Webb and Itamura, 2004). As a result, water will evaporate from the drift walls in elevated-temperature sections of the drifts, migrate along the drifts, and eventually condense in the cooler end sections of drifts where no waste is emplaced. Thus, evaporation driven by natural convection has great potential for reducing the moisture content in the near-drift fractured rock, which in turn would reduce the potential for formation of pore water drops at the drift wall (and subsequent seepage into the opening). However, up to now, natural convection processes have been neglected in predictions of future TH and seepage behavior in the fractured porous rock at Yucca Mountain. We have developed and applied a new simulation method that couples existing tools for simulating TH conditions in the fractured formation (Spycher et al., 2003; Birkholzer et al., 2004) with modules that approximate natural convection and evaporation conditions in heated emplacement drifts.

WORK DESCRIPTION

A new simulation method was developed that simultaneously handles (1) the flow and energy transport processes in the fractured rock; (2) the flow and energy transport processes in the open drifts; and (3) the heat and mass exchanges at the interface between the rock formation and the cavity. This integrated non-iterative modeling approach ensures consistency between the thermal-hydrological conditions in the fractured rock and those in the open drift. In-drift convection and turbulent mixing is approximated with a lumped-parameter approach, following a procedure developed by scientists at Sandia National Laboratories for estimating condensation processes in waste emplacement drifts (Bechtel SAIC Company, 2004; Webb and Itamura, 2004). A lumped-parameter approximation means that the turbulent mixing is not solved in detail, but approximated as a binary diffusion process, with effective diffusion coefficients estimated from supporting computational-fluid-dynamics analyses. The lumped-parameter simulations are conducted with a newly developed version of the multiphase, multicomponent simulator TOUGH2 (Pruess et al., 1999), which includes a new module for in-drift convection. We applied the new modeling methodology to study future TH conditions in a three-dimensional model domain comprising a representative emplacement drift and the surrounding fractured rock (Figure 1). Sensitivity studies were conducted using a range of effective diffusion coefficients, corresponding to different degrees of turbulent mixing within the open tunnels

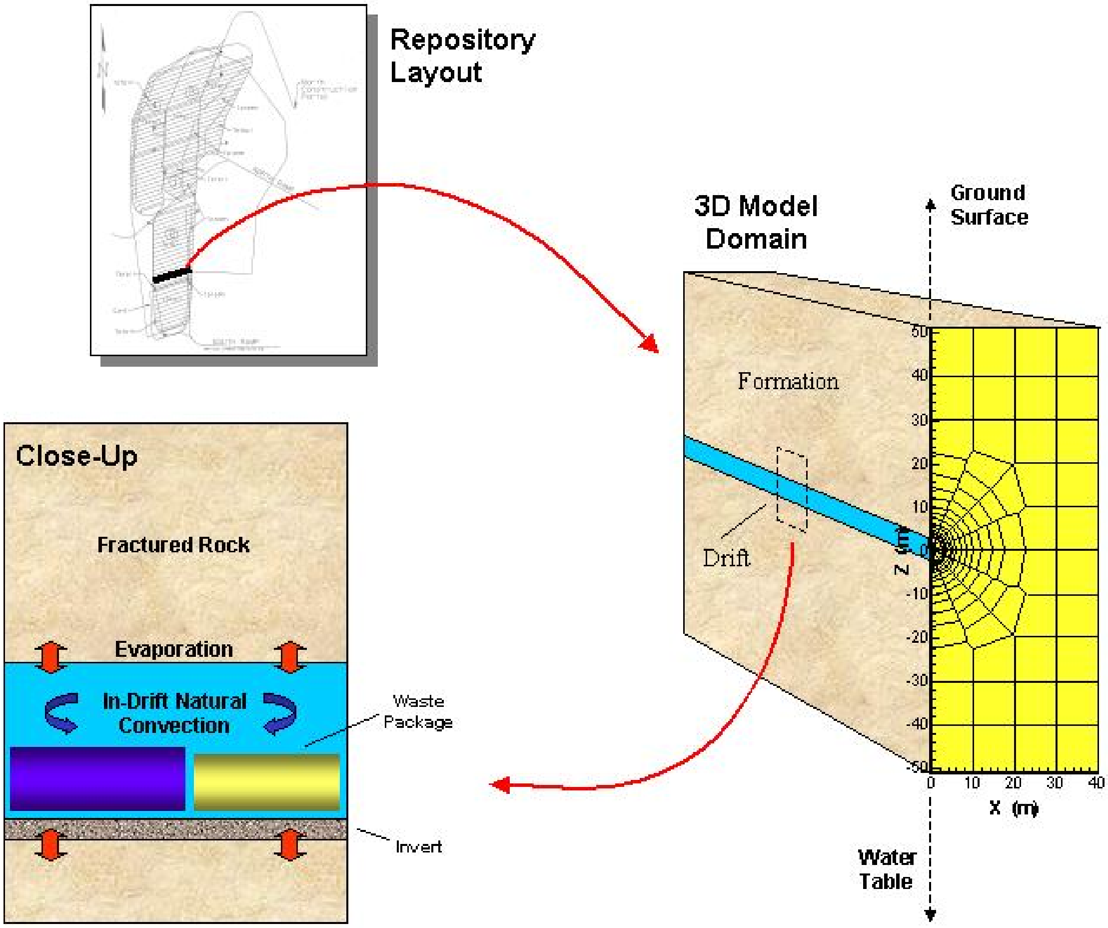


Figure 1. Schematic showing 3-D model domain with emplacement drift and fractured rock

RESULTS

Our simulation results indicate that natural convection can indeed remove significant amounts of vapor from the heated fractured rock. For cases with relatively strong convective mixing, evaporative conditions will prevail over long stretches of emplacement drifts for several thousand years after emplacement. At early times, vapor is driven from the formation into the drifts by both convective flow (from pressure buildup caused by boiling) and diffusive flow (resulting from vapor concentration gradients). At later times, diffusive flow dominates. Figures 2a and 2b show profiles of relative humidity along a section of a waste emplacement drift for two simulation cases, the first accounting for natural convection, the second neglecting this process. In the latter case, the moisture conditions in the drift are mostly in equilibrium with those in the near-field rock, since there is no driving force for moving vapor away in axial direction. In contrast, if natural convection is accounted for as in the first case, convective gas flow effectively mixes moist (hot) and dry (cool) drift sections. As a result, the relative humidity values in heated drift sections are significantly reduced compared to the non-convection case, thereby creating a vapor difference between rock and drift and allowing for evaporative drying of the rock mass. Figure 3 shows the saturation evolution in the rock matrix just above the drift crown, for the same two simulation cases, respectively. Comparison of the two cases suggests that the evaporative drying from natural convection leads to a considerable reduction of pore water close to the drifts. While both cases show full dryout at early time periods (when rock temperature is above boiling), the natural-convection case starts to rewet later and arrives at smaller long-term saturation values. Earlier studies have demonstrated that such conditions may lead to a significant reduction in seepage of formation water into emplacement drifts (Ghezzehei, 2004).

CONCLUSIONS AND DISCUSSION

Compared to previous models that neglect in-drift convection, the new modeling approach predicts evaporating conditions over long stretches of the drift walls. Such conditions reduce the amount of liquid and vapor in the near-field fractured rock and, in turn, should reduce the potential for drop formation of pore water at the drip wall with subsequent seepage into the opening. Application of this new method to drift seepage prediction models would significantly reduce the expected seepage rates at Yucca Mountain and thereby improve the predicted performance of the repository. The new model could also be used to assess innovative emplacement designs that deliberately utilize natural convection processes, to generate an in-drift environment beneficial to the performance of natural and engineered barriers.

REFERENCES

Bechtel SAIC Company, 2004. In-drift natural convection and condensation. Yucca Mountain Project Report, MDL-EBS-MD-000001 REV 00, Bechtel SAIC Company, Las Vegas, NV.

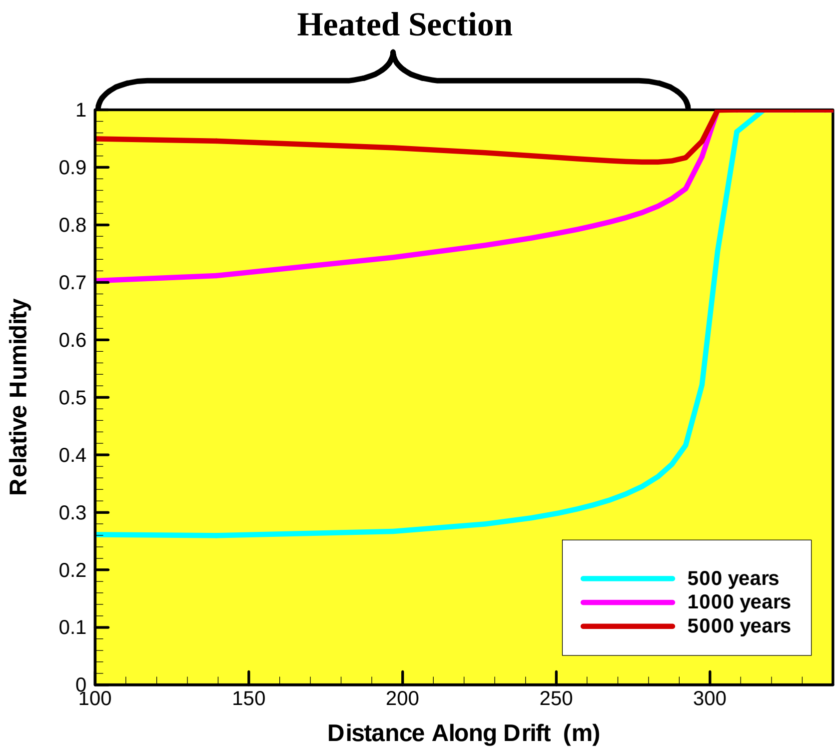
Birkholzer, J., S. Mukhopadhyay, and Y.M. Tsang, 2004. Modeling seepage into heated waste emplacement tunnels in unsaturated fractured rock. Vadose Zone Journal, 3, 819–836.

Ghezzehei, T.A., Trautz, R.C., Finsterle, S., Cook, P.J., Ahlers, C.F., 2004. Modeling coupled evaporation and seepage in ventilated cavities, Vadose Zone Journal, 3: 806-818.

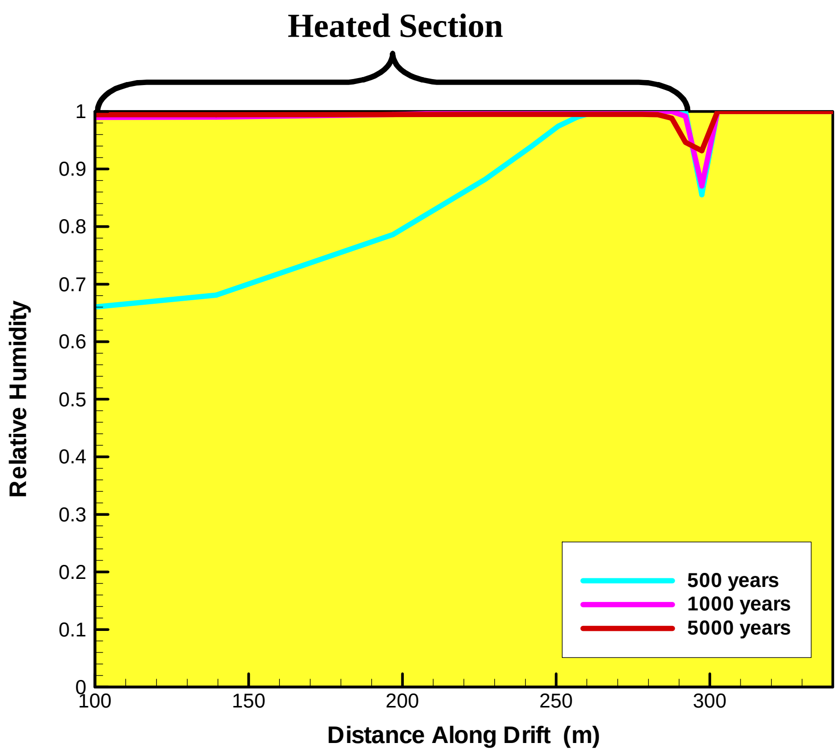
Pruess, K., C. Oldenburg, and G. Moridis, 1999. TOUGH2 User’s Guide, Version 2.0, LBNL-43134, Berkeley, California, Lawrence Berkeley National Laboratory.

Spycher, N.F., E.L. Sonnenthal, and J.A.Apps, 2003. Fluid flow and reactive transport around potential nuclear waste emplacement tunnels at Yucca Mountain, Nevada. Journal of Contaminant Hydrology, 62-63, 653-673.

Webb, S.W. and M.T. Itamura, 2004. Calculation of Post-Closure Natural Convection in YMP Drifts, Proceedings of 2004 ASME Heat Transfer / Fluids Engineering Summer Conference, Charlotte, NC.



a.)



b.)

Figure 2. Relative humidity in emplacement drift at 500, 1000, and 5000 years after waste emplacement. Profiles show a section of a drift with about 200 m of emplaced waste (heated section) and a 90 m end section. The distance along the drift is measured starting in center of the 600 m long emplacement section. Results are for a.) simulation with natural convection and b.) simulation without natural convection.

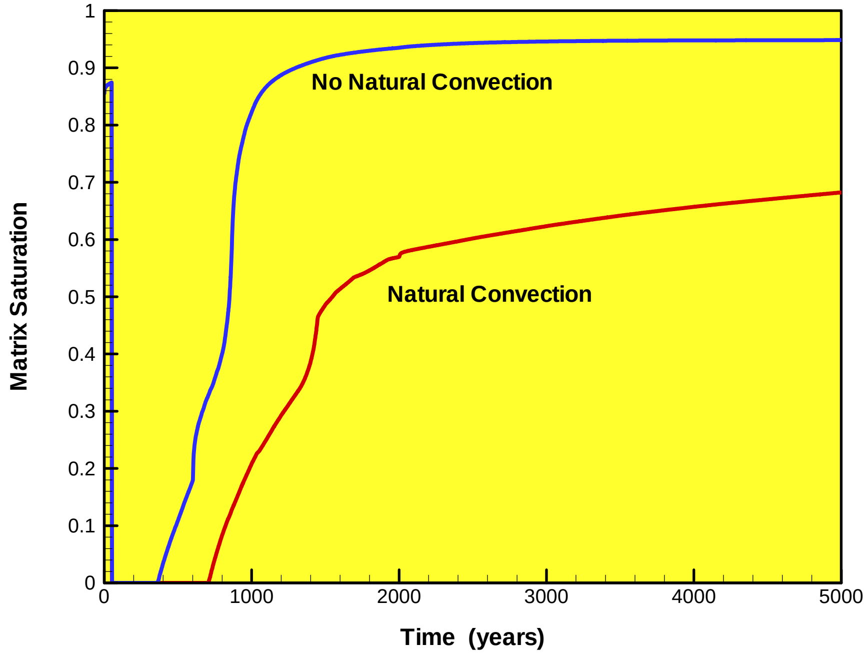


Figure 3. Evolution of matrix saturation in fractured rock just above drift crown. Saturation is shown in the center of the 600 m long emplacement section