A Sensitivity Study on the Impact of Fracture-Matrix Heat Transfer in Hot Fractured Rock

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RESEARCH OBJECTIVES

The objective of this research is to improve our understanding of thermal seepage (seepage of water into drifts at above-boiling average temperatures in the near-drift fractured rock) by evaluating the applicability and impact of fracture and matrix (F-M) interface reductions in heat-transfer problems. Our goals are to (1) demonstrate that our predictive thermal-hydrological (TH) model used for Yucca Mountain can explain the seepage observations from a laboratory heater experiment conducted at the Center for Nuclear Waste Regulatory Analyses (CNWRA experiment), (2) to identify the F-M area formulation best suited for this purpose, and (3) to evaluate whether the test conditions and observations of the CNWRA experiment are representative of the TH conditions expected at Yucca Mountain.

APPROACH

We first developed a conceptual framework for dual-continuum modeling of TH processes that can handle flow channeling in fractures and the related interface reduction in F-M heat transfer. Then, in a sensitivity analysis, we varied the degree of F-M interaction by applying different interface reduction formulations known from ambient flow and solute transport studies. The sensitivity study was performed using the CNWRA experiment (Figure 1) as a simulation example. Both experimental conditions and simulation results are compared with what is expected at Yucca Mountain.

ACCOMPLISHMENTS

Our simulation results stress the importance of understanding and adequately simulating the degree of heat transfer between the matrix and flowing water in fractures: Simulation cases featuring interface reduction for heat transfer exhibit early and consistent arrival of water at the drift crown, even though the matrix temperatures remain above boiling. Thermal seepage is possible under these conditions, which is consistent with the findings from the CNWRA experiment. In contrast, if interface reduction is not considered at all or is only applied to liquid-exchange processes, water is prevented from arriving at the drift crown by a fully efficient vaporization barrier. We conclude that the sensitivity cases featuring interface reduction for F-M heat transfer are generally better suited to represent the CNWRA test results than those assuming that heat is conducted over the full geometric area.

SIGNIFICANCE OF FINDINGS

That the thermal seepage observations in the CNWRA experiment could be reproduced with models that account for reduction of heat transfer between fractures and matrix provides confidence in the predictive TH models for Yucca Mountain, which utilize similar conceptual approaches for F-M interface reduction.

Our simulation analysis furthermore indicates that the CNWRA experiment was operated at conditions extremely favorable for thermal seepage, in particular (1) the rather small boiling region near the drift, and (2) the strong gravity-driven downward flow in response to forced water release from the top. These conditions are not representative of those expected at Yucca Mountain, where the boiling region is much larger and the downward flow characteristics are much different in magnitude and temporal evolution.

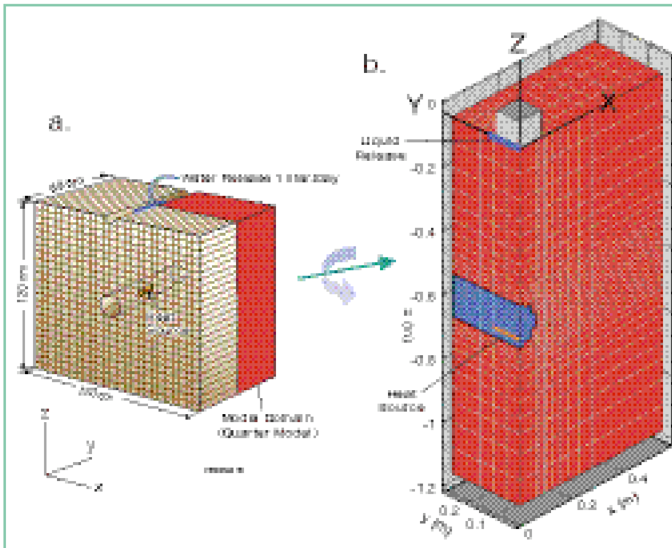

Figure 1. Schematic of (a) CNWRA heater experiment and (b) simulation domain

RELATED PUBLICATIONS

Birkholzer, J.T., S. Mukhopadhyay, and Y.W. Tsang, Modeling seepage into heated waste emplacement tunnels in unsaturated fractured rock. Vadose Zone Journal, 3, 819–836, 2004. Berkeley Lab Report LBNL-53894.

Birkholzer, J.T., and Y. Zhang, On water flow in hot fractured rock—A sensitivity study on the impact of fracture-matrix heat transfer. Vadose Zone Journal (submitted), 2005. Berkeley Lab Report LBNL-57667.

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