Conf-950570--22

LBL-36386
UC-400

Lawrence Berkeley Laboratory
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EARTH SCIENCES DIVISION

To be presented at the 1995 International High-Level Radioactive Waste Management Conference, Las Vegas, NV, May 1–5, 1995, and to be published in the Proceedings

Two-Phase Flow in Regionally Saturated Fractured Rock Near Excavations

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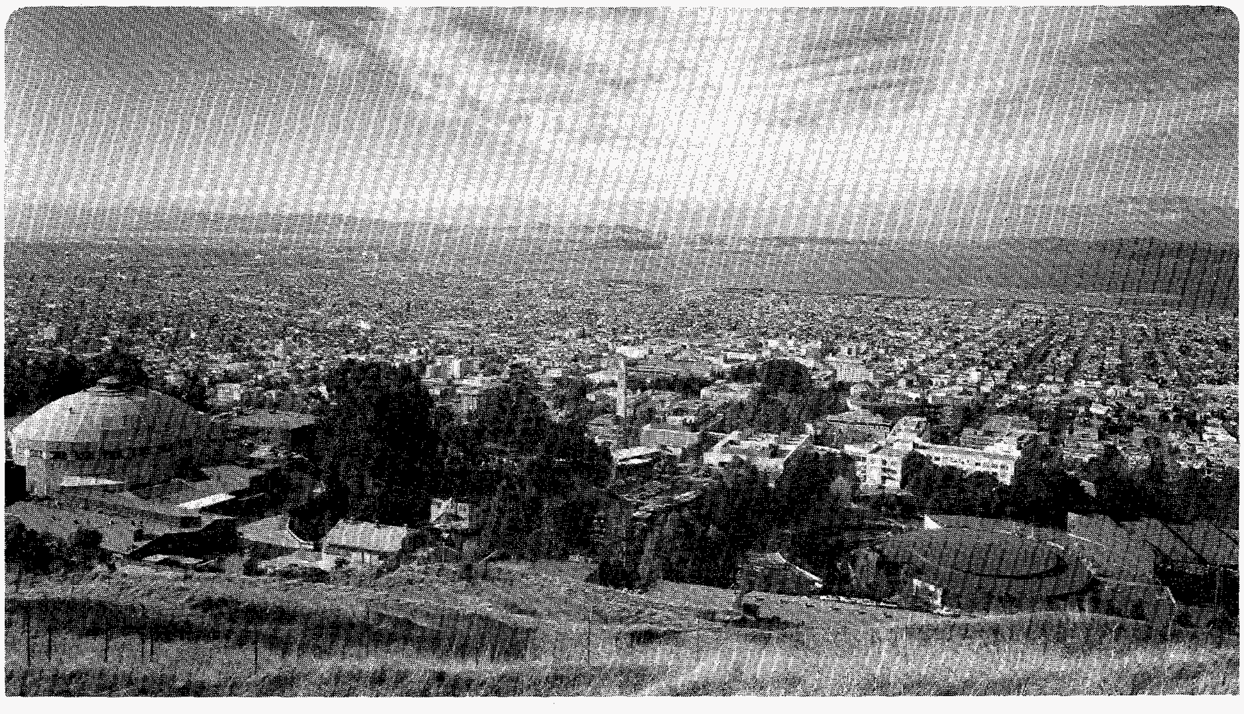

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

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This work was carried out under U.S. Department of Energy Contract No. DE-AC03-76SF00098, for the Director, Office of Civilian Radioactive Waste Management, Office of External Relations, administered by the Nevada Operations Office in cooperation with the Swedish Nuclear Fuel and Waste Management Company (SKB).

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Introduction

Hydrologic characterization for potential nuclear waste repositories relies upon data obtained from testing in excavations. The Simulated Drift Experiment in the Stripa Mine in Sweden, a fractured granitic formation below the water table, investigated excavation effects on hydrologic response[1]. Measured water inflow to the drift at atmospheric pressure was nine times less than the value predicted from the inflow to boreholes with pressure held at 2.7 bars . This flow reduction may be due to dissolved gas that comes out of solution at pressures below 2.7 bars, creating a two-phase regime.

To investigate this possibility, theoretical studies of flow through fractures when the water is super-saturated with respect to dissolved gas are carried out, using a simple analytical solution followed by a numerical model which relaxes some of the simplifying assumptions. Laboratory experiments that simulate degassing in transparent fracture replicas are conducted to test the assumptions used in the theoretical studies.

Theoretical Studies

The simple analytical solution for steady-state flow to a borehole through a finite, homogeneous medium with constant pressure contains the following assumptions: (1) chemical equilibrium between the gas and liquid phases, (2) Darcy's law modified for two-phase conditions, and (3) a constant far-field pressure. State variables and flow rates depend only on the distance from the borehole. An expression valid for linear, radial, spherical and non-integral flow geometry is derived. Numerical solutions using the TOUGH2 code[2] are obtained for the same cases as the analytical solution as well as for transient flow through infinite and heterogeneous media. Flow through idealized and realistic representations of fracture geometry is modeled.

Laboratory Experiments

Gas evolution following depressurization is simulated in two different 7.6 cm x 7.6 cm transparent fracture replicas for linear flow with constant head boundary conditions.

Figure 1 is a map of the fracture apertures[3] where white areas indicate apertures greater than 50 μm. The transmissivity of the fracture to de-aired water is first measured. Then water equilibrated with CO_2 gas at a specified partial pressure, P_{CO2}, is introduced into the fracture while the fracture outlet pressure is above P_{CO2}. Subsequently, the effluent pressure is reduced to below P_{CO2}, flowrates are monitored and the presence of the gas phase in the fracture is recorded with video photography.

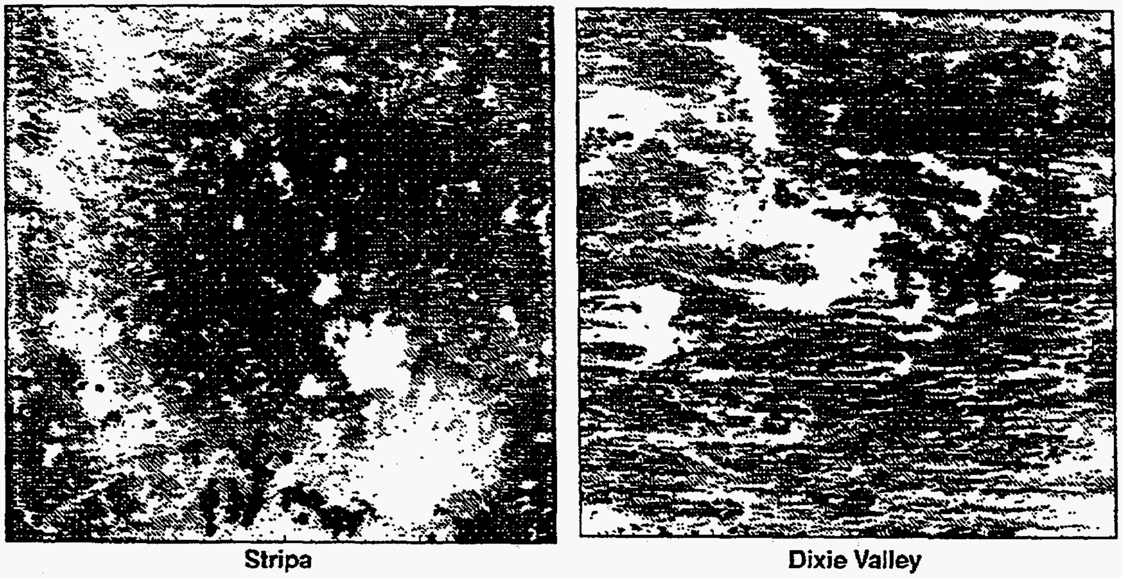

Figure 1. Aperture maps[3] of fractures used in the laboratory experiments. White areas represent apertures greater than 50 μm, black areas are less than 50 μm. Flow direction is from right to left.

Results

Theoretical predictions, laboratory measurements and field observations of flowrate versus gas contents are plotted in figure 2. The flowrate occurring for depressurization conditions, q_d is normalized by the flowrate for water-saturated conditions, q_{sat}. The gas contents are described by the degree of super-saturation, $P_{gas} - P_{effl}$, normalized by the total pressure drop through the system. Theoretical predictions from the analytical solution and from numerical simulations are consistent, but give much less flow reduction than seen in the field and laboratory data, especially at lower gas contents. Laboratory measurements of q_d / q_{sat} are close to the observed value at Stripa. Gas appears in the fracture relatively quickly following depressurization, and minimal resaturation of the fractures occurs with time. Gas accumulates in the large-aperture regions of the fracture replicas, which may explain why flow in the Stripa fracture is three times less than in the Dixie Valley fracture for similar gas contents. Figure 1 shows that the Stripa fracture has a continuous large-aperture channel across the fracture, which a tracer test shows controls single-phase flow, whereas the large-aperture regions in the Dixie Valley fracture are not connected across the fracture.

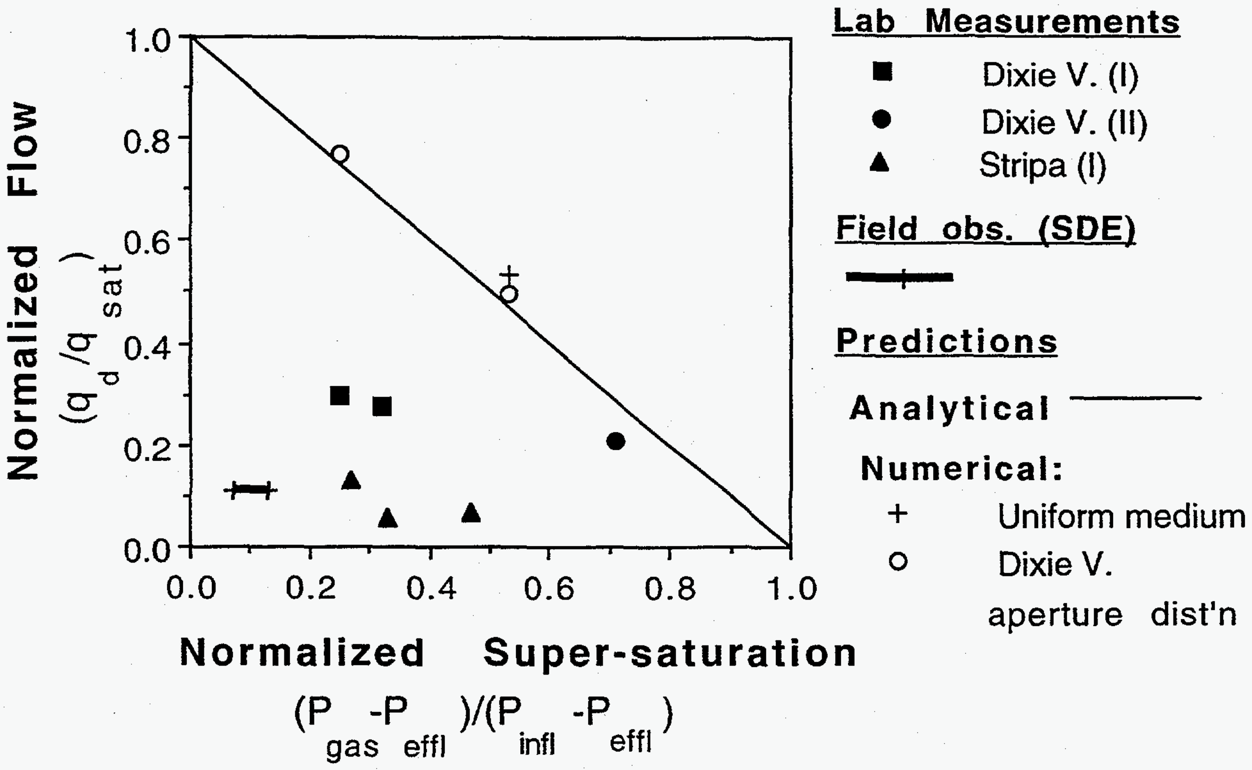

Figure 2. A comparison of laboratory, field and analytical results for flowrates under degassing conditions

Conclusions

Comparison of laboratory and field measurements with theoretical predictions suggests that the kinetics of gas/liquid mass transfer are important in describing flow reduction due to degassing. The data also suggests that the magnitude of flow reduction depends upon the location of the large-aperture regions relative to the single-phase flow path. TOUGH2 is presently being modified to account for mass transfer kinetics. The slow resaturation rates also have implications for repository behavior following closure, where oxygen in the trapped air can accelerate the corrosion of the waste canisters, as well as for predicting radionuclide transport via waste-generated gases.

Acknowlegements

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