In Proceedings of the Sixth Annual International Conference on High Level Radioactive Waste Management, 212-213,
American Nuclear Society, Las Vegas, Nevada, May 1-5, 1995

NEAR DRIFT TWO-PHASE FLOW PROCESSES WITHIN REGIONALLY SATURATED FRACTURED ROCK

R.J. Glass and M.J. Nicholl
Geohydrology Division 6115
Sandia National Laboratory
Albuquerque, NM 87185-1324
(505) 848-0718

Introduction

Characterization experiments are designed to yield parameters important for modeling physical processes. Characterization and validation experiments yield misleading results if processes excluded in data interpretation play a major role in experimental response. The near drift experiments at Stripa were designed and interpreted assuming single phase flow conditions. However, evidence exists that many of these may actually have been conducted with both gas and liquid present within the near drift fracture system. These two-phase flow effects must be understood and considered in future characterization and validation experiments conducted near drift in regionally saturated, fractured media.

In conjunction with Lawrence Berkeley Laboratories, we are working to: 1) identify two-phase flow processes associated with excavated drifts in regionally saturated, fractured rock masses; 2) evaluate the impact of such two-phase flow processes on near drift characterization and validation experiments; and 3) incorporate understanding of two-phase flow processes into the design and implementation of future characterization and validation experiments proposed at the Hard Rock Laboratory in Sweden.

Two significant near drift processes involving two-phase flow have been identified. Gaseous evolution and solution resulting from near drift pressure changes may impact fracture relative permeabilities and solute transport pathways. Secondly, gravity-driven air invasion may cause rapid gas phase inflow in non-horizontal fractures exposed at the drift. Here we present preliminary experiments exploring these two processes in a simple analog fracture.

Experimental System:

Two roughened glass plates (30x15 cm) were held in close contact to form a rough walled analog fracture. No-flow boundaries are implemented on the long sides of the fracture; depending on the experiment, either constant flux conditions or no-flow/evaporative conditions are implemented on the short sides of the fracture.

The transparent analog fracture allows collection of phase structure data through the use of digital imaging techniques. The transparent test cell is placed on a rotating test stand that is back lit with high-frequency fluorescent lamps. Data is acquired through use of an imaging system focused on the fracture plane; the imaging system is capable of obtaining data at 2048 x 2048 pixels of spatial resolution with a dynamic range of 4096 gray levels. In order to enhance contrast, the experimental fluid is dyed blue, using a mixture of 1 g FD&C blue #1 to 1 liter of de-ionized water. Simple light absorption theory is used to characterize both the aperture field and phase occupancy, thereby allowing measurement of phase saturation (S) under partially saturated conditions.

Experiment 1: Solution of Entrapped Air

Starting with a saturated fracture, water was slowly displaced by air to leave a complex entrapped water structure. Water flow was then established to produce a complex entrapped air structure within the connected, flowing water phase. Compared to saturated conditions, hydraulic conductivity of the partially saturated fracture was observed to be reduced by a factor of eight. Establishment of a stable phase structure was then followed by steady-state flow of de-aerated water. Over the next 24 hours, differential head across the fracture and

In Proceedings of the Sixth Annual International Conference on High Level Radioactive Waste Management, 212-213, American Nuclear Society, Las Vegas, Nevada, May 1-5, 1995

phase structure were monitored as the entrapped air dissolved into the water. Relative permeability increased significantly faster than the associated increase in wetting phase saturation, as gas dissolution activity was concentrated along high flow channels. At hourly increments, dye pulses were automatically delivered and imaged to visualize the dramatic channeling and differential advection imparted by the entrapped air phase.

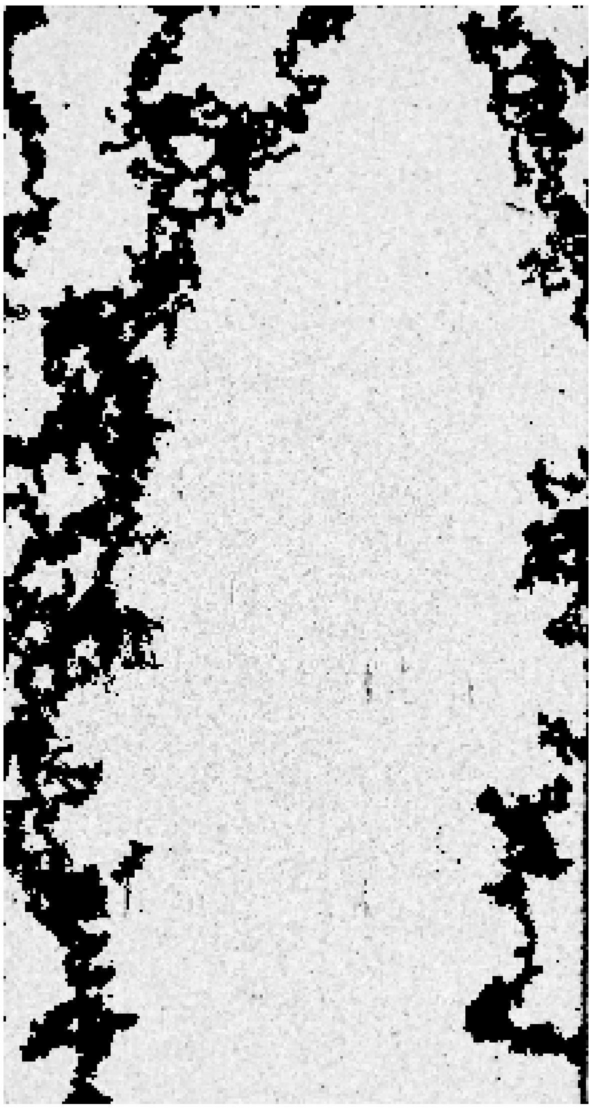

Figure 1: Composite image of gravity-driven air invasion in a vertical fracture. Images over a two day period are summed to visualize the zones where air moves upward under gravitational gradient from the bottom edge of the fracture where evaporation occurs. Air phase is denoted by black and water by light gray.

Experiment 2: Evaporation from the Bottom of a Vertical Fracture

The analog fracture was saturated, sealed at the top, and placed on the rotating test stand at a predetermined inclination. The lower boundary was left open to allow evaporation. Over a period lasting from one day to a week, images were taken to track the evolution of the drying front as it moved into the fracture.

In experiments where the fracture was near horizontal, drying within the fracture proceeded very slowly; over time, complex drying fronts were observed to evolve. In experiments where the fracture was vertical, gravity-driven air/water interfacial instability occurred, causing the formation of upward-growing, air finger structures. Once a finger acquired a vertical length greater than the difference between the air- and water-entry values of the hysteretic pressure potential/saturation curve for the fracture, it began to move rapidly upward to the top of the fracture leaving a trail of entrapped air in its wake. Figure 1 shows a composite image of the growing fingers that occurred during a number of distinct, transient fingering events.

Conclusion

In the context of near-drift, two-phase flow processes in regionally saturated fractured rock, two significant processes have been identified: gas evolution/solution and gravity-driven air invasion. Experiments demonstrating gas solution and gravity-driven air invasion were conducted. Both processes are expected to result in non-equilibrium phase structures in near-drift regions, which in turn may significantly affect the results of characterization and validation experiments in fractured rock.

Acknowledgments

This work was supported by the U.S. Department of Energy, Office of Civilian Radioactive Waste, Office of Program Management and Integration, International Programs, WBS 9.3.3.2.2