Laboratory Investigation of Nonaqueous Phase Liquid (NAPL) Mobilization by Gas Bubble Flow

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Background/Objectives. Gas bubbles can significantly affect contaminant transport in both sediments and groundwater systems. Trapped gas bubbles can block pore spaces, reducing the effective hydraulic conductivity and altering aqueous phase flow paths. They can also act as mass transfer sinks for volatile organic compounds (VOCs), as VOCs partition from the water to the gas phase. Mobilized gas bubbles, created as gas bubbles expand until buoyancy forces overcome capillary trapping forces, can enhance vertical transport. This includes transport of the gas itself, for example carbon dioxide and methane in the case of biogenic gases, as well as VOCs that have partitioned to the gas phase. In some circumstances, gas bubble mobilization can also result in the transport of nonaqueous phase liquids (NAPLs) as films, coatings or layers on the gas bubble surface. It is reasonable to expect that this bubble-facilitated NAPL transport can move a greater mass of VOCs through a porous medium than what might be transported as volatized, gas-phase mass. Despite this potential enhanced transport, whose outcomes include the appearance of oil sheens created as gas bubbles break at the water surface after being transported out of contaminated sediments, there has been little controlled laboratory study to determine factors that may control bubble-facilitated NAPL transport in porous media.

Approach/Activities. A series of laboratory experiments was conducted in a thin, two-dimensional flow cell (20 cm wide × 40 cm tall × 1 cm thick) packed with medium sand. A 3 cm-tall layer of NAPL at residual saturation was emplaced (trapped) near the vertical midpoint of the cell, and air was slowly injected at a controlled rate through a needle below this NAPL source zone. The cell was backlit to allow the visualization of gas and NAPL using light transmission techniques, where differences in light intensity transmitted through the thickness of the cell, and through the translucent sand, are used to investigate local (1 mm × 1 mm) changes in gas and NAPL saturations. Experiments included a range of air injection rates and a range of NAPLs, where NAPLs were selected to represent different interfacial tensions and spreading coefficients. Complementary measurements of initial and equilibrium spreading coefficients for each of the NAPLs were also performed. NAPL mobilization was identified through observations in the initially clean sand above the NAPL source zone as well as in the free water above the sand pack. The experiments included a period of gas injection until breakthrough of the gas at the top of the cell and a period of relaxation, where no new gas was injected but previously injected gas in the cell was allowed to redistribute as a collection of mobile bubbles.

Results/Lessons Learned. Digital images captured using light transmission techniques clearly showed the migration of gas and NAPL. Gas migration occurred as bubble flow (discontinuous, unstable gas flow) through repeated mobilization, trapping and coalescence events. In some experiments, NAPL mobilization originated from the top of the NAPL source zone and moved along the bubble flow pathway, and occurred predominantly during relaxation and gas redistribution. It is expected that these results will help researchers and practitioners to identify conditions, with respect to both gas bubble flow rate and NAPL properties, under which bubble-facilitated NAPL transport could occur, the NAPL mass that could be displaced and the distance over which that displacement could take place.