Investigation of Pore Scale Processes That Affect Soil Vapor Extraction

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Research Objective

Dense nonaqueous phase liquid (DNAPL) contamination in the vadose zone is a significant problem at Department of Energy sites. Soil vapor extraction (SVE) is commonly used to remediate DNAPLs from the vadose zone. In most cases, a period of high recovery has been followed by a sustained period of low recovery. This behavior has been attributed to multiple processes including slow interphase mass transfer, retarded vapor phase transport, and diffusion from unswept zones of low permeability.

Prior attempts to uncouple and quantify these processes have relied on column experiments, where the effluent concentration was monitored under different conditions in an effort to quantify the contributions from a single process. In real porous media these processes occur simultaneously and are inter-related. Further, the contribution from each of these processes varies at the pore scale and with time.

This research aims to determine the pore-scale processes that limit the removal of DNAPL components in heterogeneous porous media during SVE. The specific objectives are to: 1) determine the effect of unswept zones on DNAPL removal during SVE, 2) determine the effect of retarded vapor phase transport on DNAPL removal during SVE, and 3) determine the effect of interphase mass transfer on DNAPL removal during SVE, all as a function of changing moisture and DNAPL content. To fulfill these objectives we propose to use magnetic resonance imaging (MRI) to observe and quantify the location and size of individual pores containing DNAPL, water, and vapor in flow through columns filled with model and natural sediments. Imaging results will be used in conjunction with modeling techniques to develop spatially and temporally dependent constitutive relations that describe the transient distribution of phases inside a column experiment. These constitutive relations will be incorporated into a site-scale transport model to evaluate how the different processes affect SVE performance in practical applications. This will allow decision makers to better assess the risk associated with vadose zone contamination and the effectiveness of SVE at hazardous waste sites.

Research Progress and Implications

The project commenced on September 15, 1999. In the brief time since the project began, we have focused our efforts on initial planning and organization. We have one part-time graduate research assistant and one undergraduate research assistant that just began working on the project in January of 2000; and we are actively searching for one post-doctoral associate and another graduate assistant.

The part-time graduate research assistant, a Ph.D. student in electrical engineering, is developing a computer algorithm that will be used to interpret the images from our flow-through column experiments. As described in our project proposal, magnetic resonance imaging will be used to take 3-D "snapshots" of the distribution of water, NAPL, and air in columns purged with vapor at selected time intervals. Each snapshot (or image) will contain up to 256^3 voxels (a voxel is a 3-D pixel); and each voxel will have a single gray scale value that is a function of the phase (or phases) in the voxel. For example, voxels that contain water will be light, voxels that contain NAPL will be light gray, and

voxels that contain air will be black. The computer algorithm under development presently uses thresholding and nearest neighbor arguments to count the number of discrete NAPL blobs (i.e. the number of clusters with a common gray scale value) in an image. Further development will allow us to quantify parameters such as the surface area of each NAPL blob, the surface area distribution of all NAPL blobs, the number of water filled pores, and the surface area distribution of water filled pores.

The undergraduate research assistant, a student in civil and environmental engineering, is conducting sorption/desorption experiments on dry solids. As described in our project proposal, we will measure sorption and desorption rates at different relative humidities. As a first step toward completing this task, the undergraduate research assistant has packed columns with dry solids and is preparing to contaminate them.

Planned Activities

The part-time graduate research assistant will complete development of the algorithm that will be used to analyze imaging results by June of 2000. This student will apply the algorithm to imaging results that we are currently collecting on another project that is examining NAPL dissolution under water saturated conditions.

The undergraduate student will complete sorption and desorption experiments on dry solids by June of 2000. A part-time graduate student will be hired in the Fall of 2000 that will start sorption and desorption experiments at different relative humidities. These experiments will take approximately 1 year to complete.

A post-doctoral research associate will be hired in the Summer or Fall of 2000 to conduct flow-through column experiments using MRI. The student will develop MRI pulse sequences to image the various phases inside of a flow-through column. The student will also develop a flow-through column setup that allows us to vary moisture and NAPL content inside the column. In the next year we expect to complete development of the MRI pulse sequences and development of the column setup. In the following year multiple experiments will be imaged and analyzed with the developed algorithm.

A full-time graduate research assistant will be hired in the summer or Fall of 2000 to begin development of a mathematical model that accounts for pore-scale variations in residual NAPL and water. In the next year this student will begin by modifying an existing one-dimensional model of vapor-phase transport to account for the impact of spatially variable relative humidity upon sorption. The model results will be validated through comparison with laboratory experiments.