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Visualization and Quantification of Diffusion Processes in Consolidated Materials

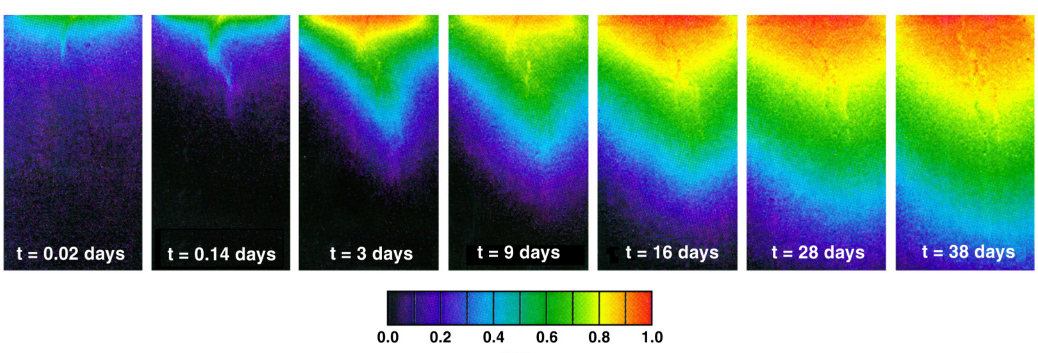
Need

Diffusion is recognized as a potentially important process in the transport of solutes in the subsurface. The transfer of mass via diffusion from high-permeability, advection-dominated domains into and out of low-permeability, diffusion-dominated domains can significantly affect contaminant migration at all scales. Understanding and predicting matrix diffusion can, therefore, be critical to environmental remediation programs and nuclear waste storage in geologic media. Sandia National Laboratories' Flow Visualization and Processes Laboratory provide a unique capability to both *visualize* and *quantify* diffusion in opaque samples through X-ray absorption imaging.

Description

To visualize and quantify diffusion processes occurring in heterogeneous, opaque systems (*i.e.* rock slabs, natural soils, and ceramic plates) a unique, high-resolution, x-ray absorption imaging system has been developed. Experiments can be run on a variety of samples at centimeter to meter scales. Visualization of the processes is in two-dimensions. Initial and boundary conditions can be controlled to the specifications desired. For example, a constant concentration boundary condition can be set on one side of a sample with no-flow boundaries approximated on all other sides (see figure below). Flow boundaries, analogous to fractures, can also be approximated. Diffusion or diffusion coupled with advection can be studied.

The X-ray absorption imaging technique is as follows. X-ray images recorded on film are taken of the samples at different times throughout the experiment. The transmitted X-ray intensity at each point in the sample is a function of the porosity and tracer concentration integrated over the full thickness of the rock slab. The X-ray images are then digitized by placing the film in front of an electronically-controlled bank of high-frequency, high-output fluorescent lights and recording the transmitted light intensity field



Digitized x-ray images showing time sequence of relative concentration (C/Co) fields in 7 x 4 cm sample of dolomite. Note local enhancement of diffusion associated with small fracture at upper end of sample.

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with a CCD (charged-coupled device) camera. The CCD camera output can be digitized into a 1024 x 1024 or 2048 x 2048 point array with each point assigned a gray-level between zero and 4095 according to the transmitted light intensity. Experiments to date have had a resolution of 0.25-mm by 0.25-mm pixels.

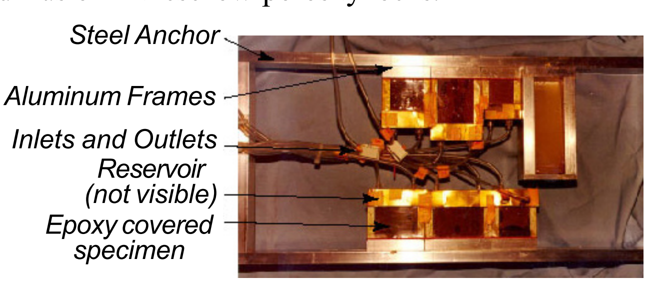
Using linear absorption theory, the digitized gray-level values are converted to relative solute concentration at the pixel scale. Porosity at each pixel can also be calculated from the images of the sample completely saturated with tracer to a sample void of tracer. Diffusion coefficients and normalized cumulative mass at the pixel resolution or the scale of the whole sample can be calculated from the relative concentration data.

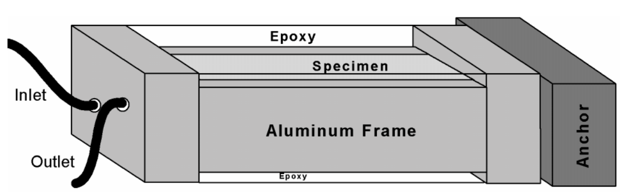
Photograph showing x-ray imaging process: x-ray emitter (A), test cells (B), x-ray film (C).

Applications

To date, the application of the diffusion visualization techniques have been applied to programs addressing issues for nuclear waste storage in geologic media. The Waste Isolation Pilot Plant (WIPP) is the U. S. Department of Energy's transuranic waste deep geologic repository in southeastern New Mexico. Visualization experiments have been and are being conducted on samples from the Culebra Dolomite considered to be a potentially important off-site pathway. The purpose of the experiments are to 1) provide another line of evidence for the importance of diffusion in the Culebra Dolomite, 2) quantify the difference in diffusion rates as a function of the heterogeneity of the samples (e.g. fractures, vugs, intercrystalline and interparticle porosity), and 4) gain a better understanding of the controls on diffusion, and 5) visualize advection and diffusion in the same system. A model of multiple rates of diffusion has been hypothesized for this dolomite layer based on field tracer tests. The laboratory experiments give the opportunity to test the multirate conceptualization as well as other conceptual models of flow and transport in a controlled environment. The results of the experiments, along with field-testing and numerical modeling work, will contribute to the conceptual model, testing the parameterization of the multirate model, and assisting in the determination of how to apply the multirate model or an appropriate simplified model at different scales (in both time and space).

There has also been international interest in our techniques of visualizing and quantifying diffusion processes in the laboratory. We are currently designing experiments for the Japanese Power Reactor and Nuclear Fuel Development Corporation (PNC) for the purpose of understanding of flow and transport processes relevant to waste disposal in crystalline rock. PNC is interested in investigating the multi-rate behavior of radionuclide diffusion in fractured crystalline rock in order to differentiate diffusion in fracture-filling material from diffusion into the matrix. The experiments will allow for testing the effectiveness of this technique on low-porosity rocks. Countries such as Sweden and Switzerland are also studying areas crystalline rocks for nuclear waste disposal and are interested in diffusion in these low-porosity rocks.





(B)

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