Flow Visualization and Processes Laboratory
X-Ray Absorption Imaging System

Need

Investigations of multiphase flow and transport processes occurring in heterogeneous porous media are hampered by the lack of experimental techniques for acquiring state-variable data at high spatial and temporal resolutions. Current laboratory techniques are generally limited in spatial or temporal resolution, maximum test media size, or require very specialized and expensive equipment.

Description

To visualize and quantify multiphase flow/transport processes occurring in heterogeneous, opaque systems (i.e., rock slabs, natural soils, opaque fields) a unique, high-resolution, x-ray absorption imaging system has been developed (Tidwell and Glass, 1994). With this technique, liquid saturation, solute concentration, and/or porosity integrated over the media's thickness are measured as variations in the transmitted x-ray intensity field. These variations are directly related to the intensity of x-ray absorption that, in turn, is related to the fluid saturation, solute concentration, or porosity at any given point in the image domain.

X-ray images are acquired by directing a beam of x-rays at the face of the test media while recording the transmitted intensity field on film secured behind the test chamber. The exposed film is developed and then placed in front of a diffused bank of high-frequency (60 MHz), high-output fluorescent lights for digital imaging.

Variation in the transmitted light intensity field is recorded by means of a CCD (charge-coupled device) camera focused on the front of the film. At present, camera output is digitized into an array of 1024 x 1024 or 2048 x 2048 points, with each point assigned a gray level between zero and 4095 according to the transmitted light intensity. The array size of the camera and the size of the test system determine the spatial resolution of the acquired image. Images shown on the next page are at a spatial resolution of 0.4x0.4 mm.

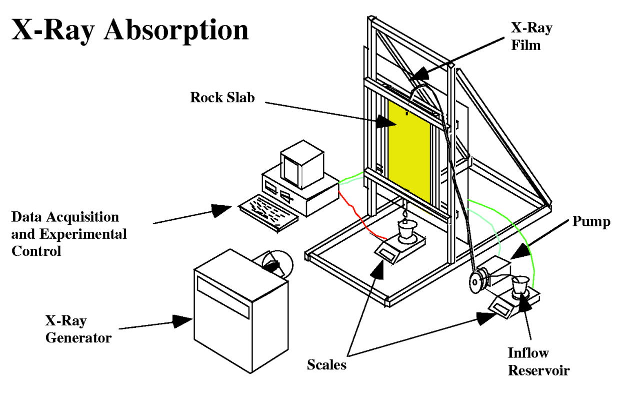


Figure 1. Schematic of the X-Ray Absorption Imaging System.

To achieve high image contrast with respect to the measured state variable, the use of a contrast enhancing agent is generally required. The iodine ion, added in the form of potassium iodide (KI), is used as it is geochemically conservative and possesses favorable x-ray absorption characteristics. The KI can be used to dope the aqueous phase in multiphase flow experiments or used as a tracer in contaminant transport experiments. The digitized gray level values are converted to water saturation through a two-step process. The first step adjusts the image according to a constant density wedge included in each image to correct for variations in the source intensity and variations in film quality. In the second step the adjusted gray level values are converted to saturation through application of linear absorption theory (Tidwell and Glass, 1994). As an independent check the total mass as estimated from the x-ray image is consistently compared to the mass balance calculated from the inflow and outflow data. In this way, the acquired images are not merely qualitative images of the transport process; rather, quantitative data on the full 2-D solute concentration field.

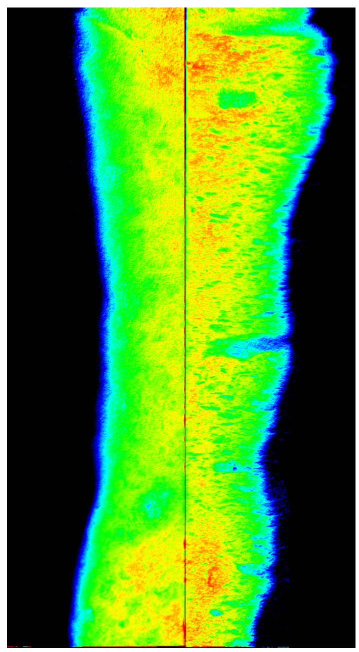
Applications

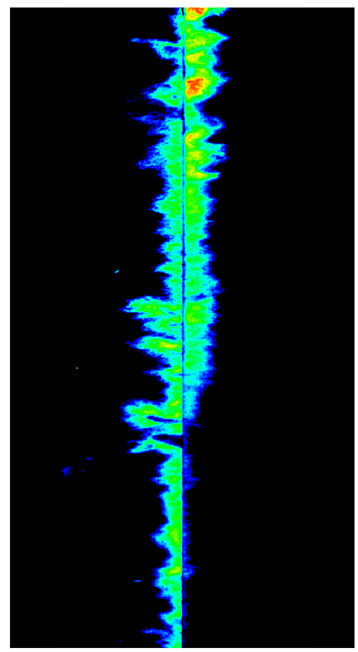
X-Ray absorption imaging has application to a wide range of multiphase flow and transport problems as shown by the figures below.

Contacts

Vincent C. Tidwell
Sandia National Laboratories
P.O. Box 5800, MS 0735
Albuquerque, NM 87185-1324
Phone: (505) 844-6025
Fax: (505) 844-6023
E-mail: vctidwe@sandia.gov

Robert J. Glass
Sandia National Laboratories
P.O. Box 5800, MS 0735
Albuquerque, NM 87185-1324
Phone: (505) 844-5606
Fax: (505) 844-6023
E-mail: rjglass@sandia.gov





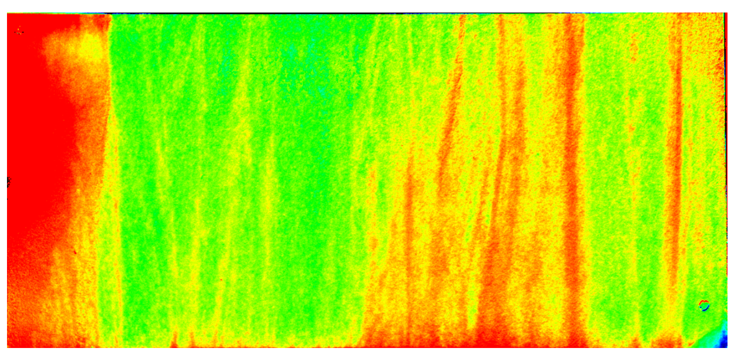


Figure 2. (top left) Matrix imbition from a flowing slot fracture formed by mating two 60 x 15 x 2.5 cm slabs of volcanic tuff. (Glass et al., 1993; Tidwell et al., 1995) Figure 3. (top right) Matrix diffusion of 10% by weight KI solution into a slot fracture flowing with deionized water. Figure 4. (bottom) Fluid saturation distribution formed by gas displacement from a heterogeneous sandstone slab. Color scale for liquid saturation is red (1)-yellow-green-blue-black (1) and for relative solute concentrate is black (1)-blue green-yellow-red (0).