Sandia National Laboratories

Flow Visualization and Processes Laboratory

Transmitted Light Imaging

Need

Fundamental study of multiphase flow and transport processes within heterogeneous porous and fractured media requires experimental techniques to measure state-variable and property data at high spatial and temporal resolutions.

Description

We have developed unique, high-resolution, 2-D field Transmitted Light Imaging Systems for use in thin (0.01 to 25mm thick) but extensive (up to over 1x1m) translucent and transparent experimental systems (i.e., silica sand packs, glass or epoxy cast fractures, micromodels). With our imaging systems, the local thickness averaged liquid/gas saturation, solute concentration, fracture gap (aperture), and/or porous media porosity are measured as variations in the transmitted light intensity at millions of points across the 2-D field through the use of high resolution, low noise, digital cameras. Gas/liquid saturation causes intensity variation by a closer matching of the index of refraction of the matrix and liquid relative to the matrix and gas. In test cases where the system is liquid saturated or the gas-liquid saturation field is steady, conservative dyes are used allowing simple light absorption to govern variations in the transmitted light intensity. A combination of theory and calibration is used to map intensity fields into quantitative fields of interest.

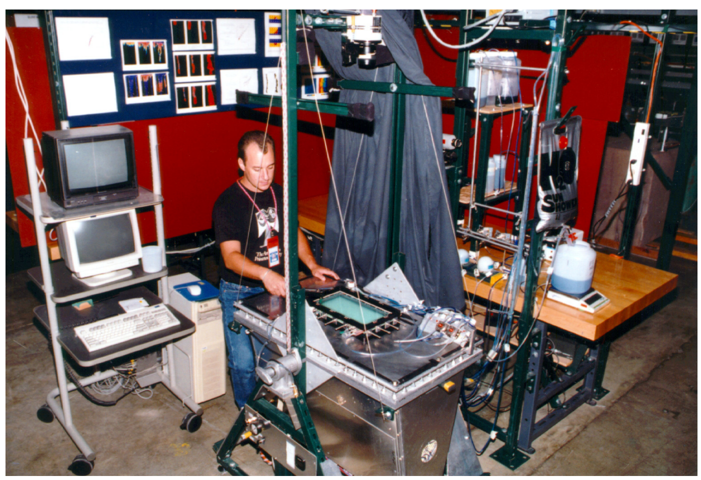

Figure 1. A fracture cell is placed on the stand of a rotating Transmitted Light Imaging System.

The light source used in our systems is a bank of high-frequency (60 MHz), high-output fluorescent lights. Light output from the fluorescent light bank is controlled in time and space through feedback circuitry. The transmitted light intensity field is recorded by means of a CCD (charge-coupled device) camera focused on the front of the experimental cell. Depending on the camera used, output is digitized into an array of 512 x 512 up to 2048 x 2048 points with gray level ranges from 256 (8 bit) up to 16384 (14 bit) according to the transmitted light intensity. Transmitted light images can be collected at rates from several times a minute at full spatial and gray scale resolution up to 30 images per second at lower 512 x 512 spatial and 256 gray level resolutions. Both fluorescent light bulbs and filters at the light source and the camera are used to optimize camera dynamic range with respect to the measurement of interest. This technique requires that the imaged system transparent to translucent. Engineered homogeneous/heterogeneous sands packs and sintered glass bead packs

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are used as controlled translucent analogs of consolidated and unconsolidated porous media while glass or epoxy casts are used to fabricate transparent fracture surfaces. Currently, the Flow Lab has 7 full Transmitted Light Imaging Systems, half of which house the light source, cell and camera on a rigid rotating frame to allow systematic variation of gravity forces. Adaptation of our systems to measure fluorescence for systematic studies of engineered florescent colloids and microbes is straightforward and in the design phase.

Advantages

In the time it takes to measure a single point by one of the traditional techniques, the Transmitted Light Imaging System yields an entire field consisting of millions of points. The system provides quantitative data at each point on fluid saturation, solute concentration, and porosity/fracture aperture at resolutions of approximately 0.5% full range.

Applications

The Transmitted Light Imaging System has application to a wide range of multiphase flow and transport problems. Quantitative images from a selection of studies are shown below.

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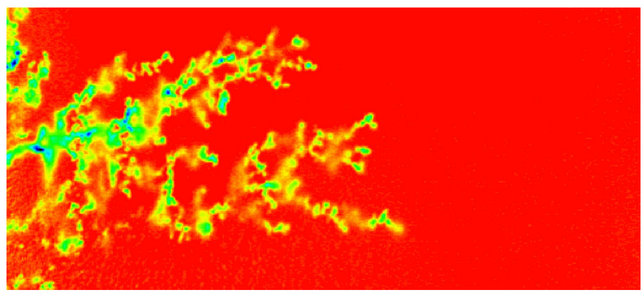

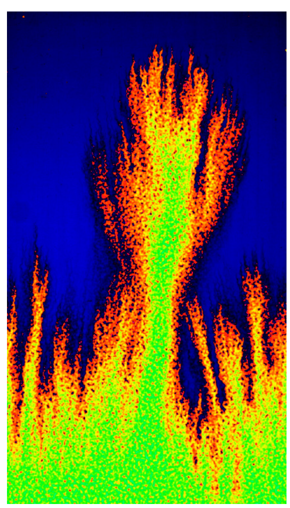

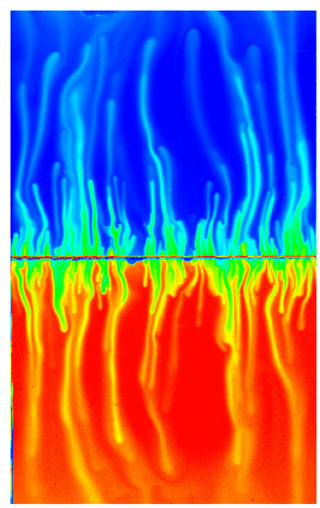

Figure 2. (top) Fingering of gas through a 60 x 25 x 0.6cm sand slab saturated with hydraulic fracturing fluid. Figure 3. (bottom left) Viscous fingering of an oil/water system in a 10 x 20cm roughened glass analog fracture. Figure 4. (bottom right) Multicomponent convection of salt and sugar solutions in a 10 x 20cm Hele-Shaw cell.