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Project ERKP634: Coupled Processes Influencing the Transport of Uranium over Multiple Scales

Transient Flow Centrifugation for Determining Unsaturated Hydraulic Properties of Hanford Sediments

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Abstract

Knowledge of the hydraulic, geochemical and mineralogical properties of sediments is essential for predicting the fate and transport of U(VI) within the vadose zone. Centrifugation provides an efficient way to characterize key hydraulic properties, such as the capillary pressure - saturation curve and relative hydraulic conductivity function. Steady state flow centrifugation, using the unsaturated flow apparatus (UFA), may be subject to error since it ignores the capillary profile. Transient flow centrifugation using an ultra rock core centrifuge (URC) can eliminate this problem and is widely used by the oil and gas industry to characterize reservoir rocks. However, it has been largely overlooked in environmental applications. This poster reports on ongoing studies at the University of Tennessee using a URC to measure the unsaturated hydraulic properties of sediments form the Hanford site.

ERSP Project Background

Our ERSP project (ERKP634) represents the first application of the URC to environmental contamination issues, although the system has been utilized by the oil and gas industry for decades. We will quantify the hydraulic properties of disturbed and intact sediments at the individual sedimentary layer scale. This hydraulic data will complement layer-scale geochemical and mineralogical studies performed at Oak Ridge National Laboratory (ORNL) and Stanford University. We will use the layer-scale hydraulic, geochemical, and mineralogical parameters in a variety of composite medium, fractal, and numerical modeling approaches to predict the transport of U(VI) in a large sedimentary sample comprised of multiple sedimentary layers. The overall goal of our project is to validate approaches to predict reactive transport over increasing length scales.

Introduction

Centrifuges provide a quick and sound way to measure the capillary pressure versus saturation, $q(\psi)$ and relative permeability versus saturation, $K(\theta)$, relationships of porous media. In soil physics, the method is known mainly through the unsaturated flow apparatus (UFA). However, this method has not been widely adopted because of high capital investments, coupled with design and interpretation issues. Funding by NSF-IF has made it possible for the University of Tennessee (UTK) to acquire a state-of-the-art transient flow URC-628 centrifuge system.

There are several advantages to using this system: **1)** measurement of both q(y) and K(q) under transient flow conditions, **2)** wide range of angular frequencies (RPM) and thus, capillary pressures, **3)** a fully automated acquisition system, and **4)** active support and development of the instrument.

This poster presents ongoing work at UTK to take the URC system through a thorough testing program, with the aim of:

- applying the transient flow method to soil and unconsolidated sediments,
- hydraulic characterization of individual layers from the Hanford subsurface.

Centrifuge basics

The basic principle behind the method is the displacement of a higher density fluid by a lower density fluid or gas by applying a centrifugal force. Both q(y) and K(q) can be measured with a centrifuge under steady-state or transient flow conditions. Under steady-state flow conditions fluid is injected at constant RPM. A time-independent pressure and saturation gradient will develop from which the hydraulic properties at that RPM and capillary pressure can be calculated. Under transient flow conditions the volumetric outflow at constant RPM is monitored through time. The rate of decay of outflow with time is used for calculating the relative saturation and hydraulic conductivity at that RPM and capillary pressure. Several RPM's are selected to construct $q(\psi)$ and $K(\theta)$ relationships. The URC-628 is based on transient flow conditions.

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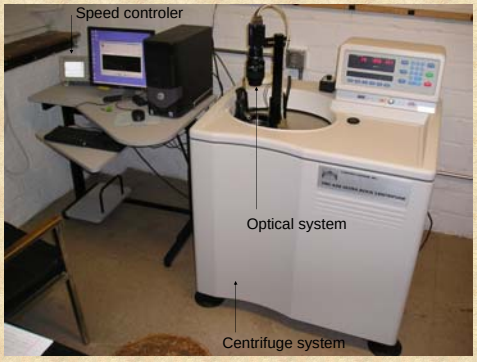

Figure 1. The URC-628 Utra-Rock Centrifuge setup at UTK

Centrifuge Measurements

The URC-628 (Ultra-Rock Centrifuge) is designed and manufactured by Coretest Systems Inc. (Fig. 1). The centrifuge rotor has slots for holding three sample buckets. Each sample bucket contains a sample holder and a receiving cup (Fig. 2), which can be mounted in such a way that either drainage or imbibition by a denser fluid is measured. The angular frequency range is between 400 and 16,500 RPM.

The amount of water that is collected in the receiving cup is directly proportional to the saturation. The interface between air and water is traced through time by the optical system. A light source in the centrifuge shines through the transparant receiving cup. The brightness of the transmitted light is captured with DLS video camera, that is timed by a laser operated triggering system.

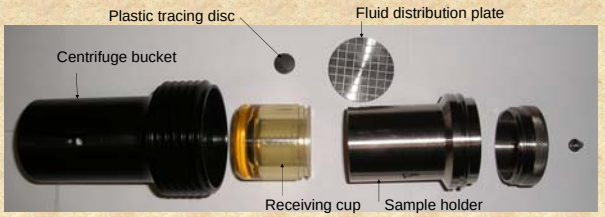

Figure 2. Assembly used for drainage experiments

Automated data aquisition system

An image consists of brightness versus pixel distance (Fig. 3). Going away from the axis of rotation, three main parts can be recognized in the curve. Images are captured at a high frequency in order to detect rapid changes in the interface position.

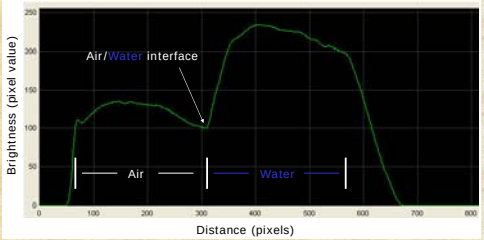

Figure 3. Example of the brightness variation over the length of the receiving cup

Interpretation of raw data

Image analysis software provided with the URC-628 allows tracking of the migration of the air-water interface and conversion of this data to a time-series of fluid volume produced (Fig. 4). The fluid production data is the basic information used for extracting the $\theta(\psi)$ and $K(\theta)$ relationships.

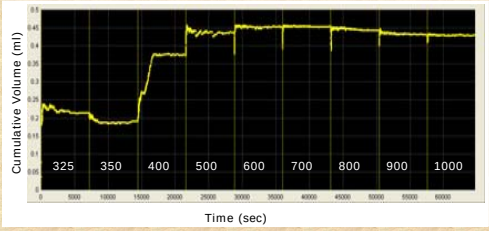

Figure 4. Example of the water volume produced over time for an 18 hour test on a Berea sandstone core.

Inverse Modeling of Production Data

Progress to date has resulted in the succesful extraction of $\theta(\psi)$ from synthetic centrifuge data. Measurements for this analysis consist of RPM and average saturation pairs. We are interested in $\theta(\psi)$ at a point. Inverse models that convert the RPM – average saturation pairs to pressure saturation relationship at the inlet face of a core sample can be devided into differential (numerical) and integral (iterative) types. An example of each type applied to a synthetic centrifuge data set is shown in Fig. 5.

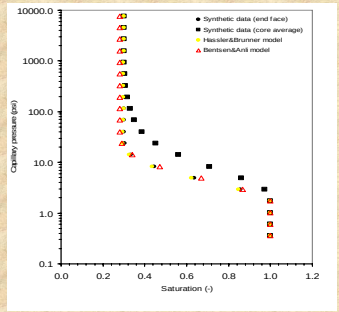

Figure 5. Example interpretation of synthetic centrifuge data using the Hassler-Brunner (differential) method and the Bentsen-Anli (integral) method.

Future Developments

The URC-628 rock centrifuge is currently being thoroughly tested prior measurements of $\theta(\psi)$ and $K(\theta)$ on sediments from individual layers of the Hanford subsurface. The following tests are proposed:

- calibration of optical system and distance and volume measurements made by the optical system
- additional inverse modeling to extract the $K(\theta)$ function
- repeated measurements on replicate samples of media with known hydraulic properties to quantify precission of the experimental procedures
- comparison of measurements with results of other measurement methods (including centrifuge measurements of other labs) to quantify the accuracy of the URC-628 centrifuge system.

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