Integrated, Multi-Scale Characterization of Imbibition and Wettability Phenomena Using Magnetic Resonance and Wide-Band Dielectric Measurements

DE-FC26-04NT15518

Goal

The objectives of the proposal are to develop methods for obtaining realistic configurations of two immiscible fluids as a function of wettability and geologic characteristics and to use these fluid configurations as a basis for predicting and explaining macroscopic (core-scale) behavior, including the relationships among relative permeability, wettability, and laboratory and log measurements of nuclear magnetic resonance (NMR) and broadband dielectric response. The ultimate objective is to measure dielectric and NMR responses in a range of sedimentary rocks and to use state-of-the-art multi-scale modeling to interpret these measurements to quantify wettability and relative permeability at the core and log scales.

Performers

University of Texas at Austin
Austin, TX

Rice University
Houston TX

Results

The main accomplishments over the past 6 months are outlined in the Project Summary.

Wideband dielectric data for the complex conductivity and permittivity of 4 partially saturated rocks (1 KHz to 10 MHz) were completed. A sample of the data is presented in Figure 1. The same samples are being sent to Rice University for NMR measurements.

To ensure uniform saturation of the samples, CT scan experiments were performed on core samples to measure the saturation distribution in partially saturated samples that are then used for dielectric measurements. As seen in Figure 2 the saturation profiles are quite uniform.

The research team developed and successfully tested an algorithm for the pore-scale numerical simulation of NMR and DC electrical resistivity in the presence of coating-clay distributions in clastic rocks. The algorithm is based on random walks that simulate the restricted diffusion of protons in the pore space occupied by either water or water-oil mixtures distributed in accordance to capillary pressure stability. Sensitivity analysis performed with the numerical algorithm enabled the prediction of variations of Archie's cementation and saturation exponents in the presence of thin oil wetting films and hysteresis cycles due to water-oil fluid displacement. Figure 3 shows an example of simulation results compared to laboratory measurements. The agreement between simulations and measurements is very good.

Benefits

This project brings together several advanced technologies for better interpretations of laboratory and wireline data to obtain petrophysical properties. New NMR techniques and dielectric measurements results in more accurate and less uncertain estimates of hydrocarbon saturations and rock flow properties. Advanced modeling of NMR and dielectric response for the first time brings a microscopic justification for the effective-medium response of complex rock formations. This effective-medium response provides new ways to quantify types of fluids and their saturation in complex pore structures. Finally, the project performers are to interpret laboratory and field measurements in terms of physically representative models of the processes that form sedimentary rocks. The latter, recently demonstrated approach offers an unprecedented capability method for quantitatively and predictively linking grain–scale geometry and surface chemistry to core scale behavior.

Background

The project was initiated in 2004 as a joint effort between the University of Texas and Rice University. A lack of measurements and pore scale understanding and the opportunity of combining two measurements, NMR and dielectric response of rocks, led to the formation of this team.

Summary

Project researchers have:

- A PhD dissertation was completed that presents a general method to compute the electrical and NMR response of porous media, given the pore structure and wettability (fluid distribution).
- Several papers were published and presented at conferences (please reference list).
- Obtained wideband dielectric data for the complex conductivity and permittivity of 4 partially saturated rocks (1 KHz to 10 MHz). A sample of the data is presented in Figure 1.
- CT scan experiments were performed on core samples to measure the saturation distribution in partially saturated samples that are then used for dielectric measurements (Figure 3).
- Developed and successfully tested an algorithm for the pore-scale numerical simulation of NMR and DC electrical resistivity in the presence of coating-clay distributions in clastic rocks. The algorithm is based on random walks that simulate the restricted diffusion of protons in the pore space occupied by either water or water-oil mixtures distributed in accordance to capillary pressure stability. Sensitivity analysis performed with the numerical algorithm enabled the prediction of variations of Archie’s cementation and saturation exponents in the presence of thin oil wetting films and hysteresis cycles due to water-oil fluid displacement. Figure 3 shows an example of simulation results compared to

laboratory measurements. The agreement between simulations and measurements is very good.

Current Status (May 2006)
The project was initiated in October 2004 and is in its second year (of a three-year project).

Funding
This project was selected in response to DOE's Oil Exploration and Production, Reservoir Efficiency Processes, Solicitation DE-PS26-04NT15450-3A, February 2, 2004.

Publications

1. Toumelin, E., and Torres-Verdín, C., 2005, Influence of oil saturation and wettability on rock resistivity measurements: a uniform pore-scale approach (Expanded Abstract): Society of Petrophysicists and Well Log Analysts (SPWLA) 46th Ann. Logging Symposium, New Orleans, LA, June 26-29.
2. Toumelin, E., Torres-Verdín, C., and Bona, N., 2005, A new pore-scale framework for the simulation and interpretation of wide-band dielectric measurements (Expanded Abstract): Society of Core Analysts (SCA) 19th International Symposium, Toronto, Canada, August 21-25.
3. Toumelin, E., Torres-Verdín, C., and Bona, N., 2005, Improving the petrophysical assessment of rock-fluid systems with wide-band electromagnetic measurements (Expanded Abstract): Society of Petroleum Engineers (SPE) 2005 Ann. Internat. Mtg., Dallas, TX, October 9-12.

Project Start: October 1, 2004
Project End: September 30, 2007

Anticipated DOE Contribution: $797,685
Performer Contribution: $395,626 (33% of total)

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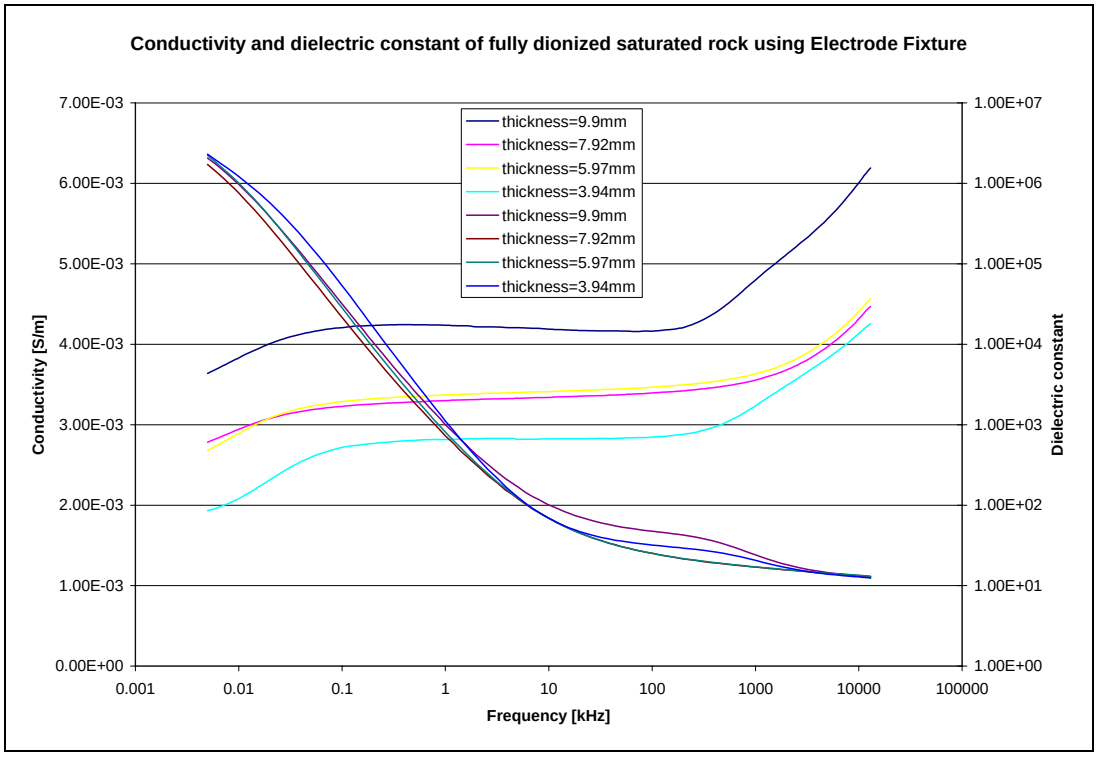

Figure 1. Conductivity and dielectric constant of fully water-saturated Berea sandstone with varying core sample thickness.

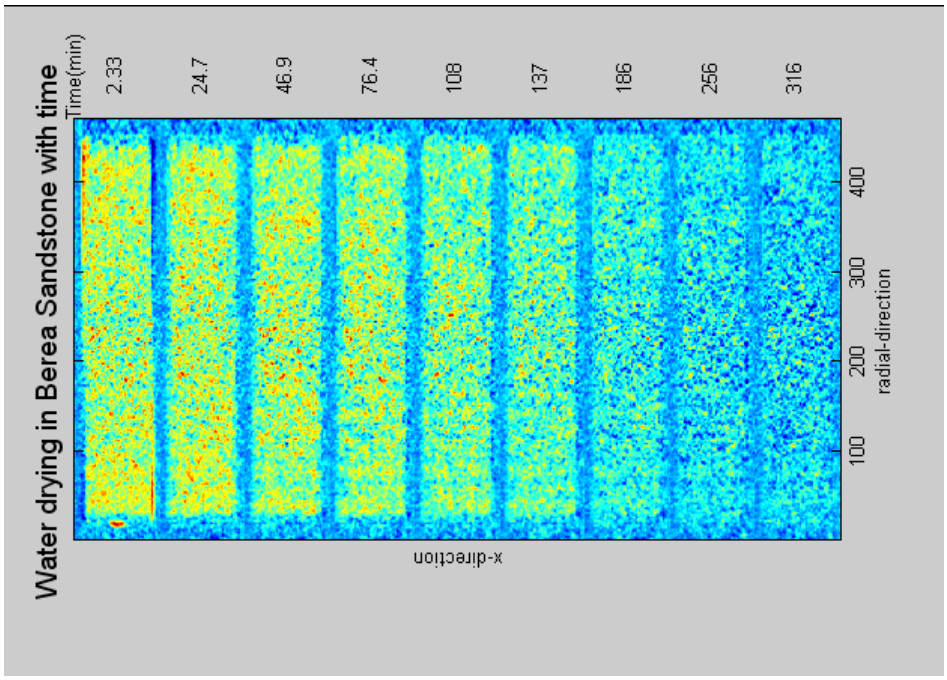

Figure2. CT scan of Berea sample saturation profile

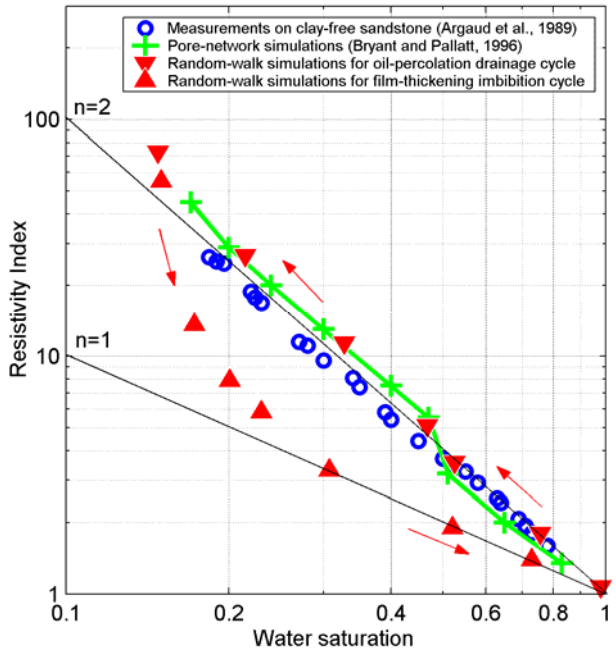

Fig. 3. Evolution of resistivity index during primary drainage on a 20 p.u. clean water-rock rock: measurements performed on clay-free sandstones, pore-network simulation results with cemented Finney pack neglecting thin-film conduction, and random-walk simulation results carried out on the same ideal pack but allowing thin-film conduction. The imbibition cycle simulated for this pack also exhibits hysteresis