Evaluating the Influence of Pore Architecture and Initial Saturation on Wettability and Relative Permeability in Heterogeneous, Shallow-Shelf Carbonates

DE-FC26-04NT15516

Goal

The principal project goal is to develop models for oil-water relative permeability through the transition zone. Models will address a range of moldic-porosity lithofacies representative of Kansas and Midcontinent shallow-shelf carbonate reservoirs that account for the influence of wettability and pore architecture. Reservoir simulation studies on theoretical reservoir architectures and two example reservoirs, from which core will be obtained and studied, will demonstrate the importance and application of the models.

Performers

University of Kansas
Kansas Geological Survey
Lawrence, KS

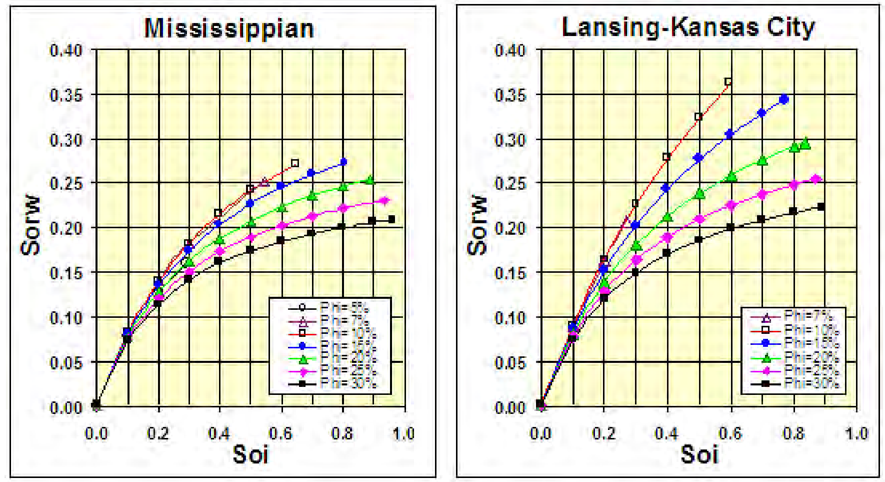
Murfin Drilling Company, Inc.
Wichita, KS

Results

Project products will include an online database and models for wettability and oil-water imbibition relative permeability for different initial saturations, obtained using representative oils and moldic carbonate lithofacies from Kansas fields (e.g., moldic Mississippian-age carbonates and oomoldic Lansing-Kansas City group limestones). Models developed to date predict imbibition oil-water relative permeabilities for different initial water saturations that define relations applicable to the transition zone-dominated reservoirs predominant in the Midcontinent. The practical importance and application of these relative permeability and wettability models is demonstrated by using reservoir simulation studies on theoretical/generic and actual reservoir architectures.

Benefits

For the shallow-structure, transition-zone dominated, carbonate reservoirs of the Midcontinent, over- and under-prediction of performance is critical to successful improved/enhanced recovery program design, decisions, and operations. The project will provide data and tools to help operators better characterize these reservoirs by providing more-accurate relative-permeability models that include effects of wettability, pore character, and starting saturations.



Crossplot of residual oil saturation to waterflood, S_{orw}, versus initial oil saturation, S_{oi}, for Mississippian and Lansing-Kansas City rocks derived from models developed in project. Maximum values of S_{oi} shown for each porosity curve were defined by S_w at h=60 ft and represent approximate "irreducible," S_{wirr}, or critical saturation, S_{wc}. For each curve as $S_{oi}\rightarrow 0$: Sorw$\rightarrow$0 and for the suite of curves as $\phi\rightarrow 0$: $S_{wirr}\rightarrow 1$ and $S_{oi}\rightarrow 0$. The progressive shift of the curves to higher S_{orw} for any given Soi with decreasing ϕ result from the decrease in *C* with decreasing ϕ.

Reservoir performance modeling based on these realistic relative-permeability/capillary pressure inputs, as opposed to conventional inputs, will enable optimal improved and enhanced recovery program design. Improved reservoir modeling and management will lead to increased oil recovery that might otherwise be lost and may reduce improper abandonment, inefficient completion strategies, and excessive water production. Online databases and models will facilitate small, independent operator access and utilization of the results and could result in millions of barrels of additional oil production in Kansas and elsewhere in the Midcontinent region.

Background

For many shallow-shelf carbonate reservoirs in the United States, basic petrophysical properties (e.g., porosity, absolute permeability, capillary pressure, residual oil saturation, resistivity, and relative permeability) vary significantly horizontally, vertically, and with scale of measurement. In addition, many of these reservoirs produce from structures of less than 10-20 meters, and due to their position in the capillary pressure transition zone, they have variable initial saturations and relative permeability properties from the base to top of the reservoir. Rather than being simpler to model, these reservoirs challenge characterization and simulation methodology. As these reservoirs approach maturity and implementation of infill drilling and enhanced recovery programs are initiated or considered, access to and utilization of accurate relative permeability models is critical to accurately predicting recovery and therefore to successful reservoir management.

Summary

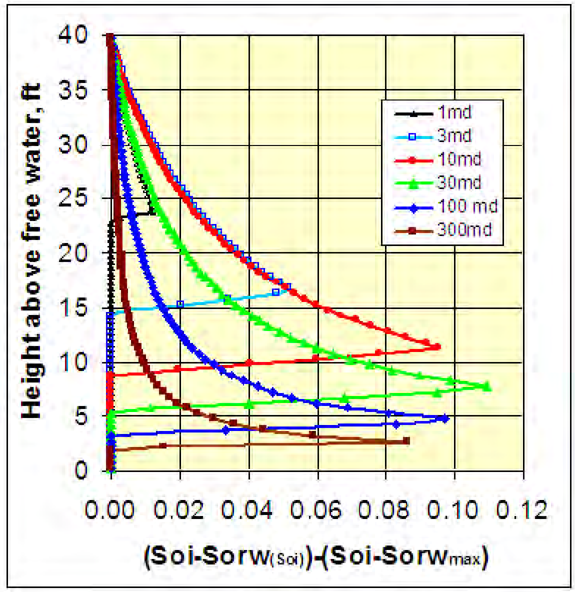
Collected oil samples from Arbuckle, Lansing-Kansas City, Mississippian, and Viola formations have had basic properties measured and exhibit a range of 16-44° in API gravity and a viscosity (μ)-API gravity (γAPI) correlation generally similar to the Beal (1946) correlation using a modified equation: $\ln(\mu 100) = -3.11+166.13/\gamma API$. Oil-brine interfacial tension at 60°F (σ 60) ranges from 20-48 dyne/cm and is weakly negatively correlated with API gravity: $\sigma 60 = 40.7–0.24\ \gamma API$. Drainage and imbibition oil-water relative permeability measurements show that "irreducible" water saturation (Swi) increases with decreasing permeability and that residual oil saturation to waterflood (Sorw) increases with increasing initial oil saturation (Soi) for a given rock type, interpreted to be due to enhanced trapping by emplacement of oil in fine pores, and consistent with the Land (1971) equation.

For the carbonate rocks studied, utilizing the format of the Land equation, the trapping constant, C, increases with increasing porosity, resulting in less trapping. This relationship, when coupled with increasing Swi with decreasing porosity and permeability, results in a systematic dependence of Sorw on porosity/permeability and Soi. With Soi decreasing with depth in transition zones, proper modeling of relative permeability (kr) in the transition zone setting requires a suite of relative permeability curves that reflect changes in kr with changing Soi and Sorw. Utilizing a suite of kr curves in reservoir simulation shows that both oil and water recovery are greater than predicted from models utilizing kr curves with a constant Soi and Sorw. Two fresh cores obtained from the Arbuckle and Lansing-Kansas City exhibit reservoir rock properties typical of these formations in Kansas reservoirs. Preliminary wettability results indicate intermediate- to water-wetness.

Simple layered reservoir simulation models indicate that perforation strategy in transition zone intervals can be optimized by utilizing foot-by-foot relative permeability curves down through the transition zone and evaluating oil recovery income versus water-handling expense for each interval perforated. These models help to understand the sustained low oil production rate and the high water rates that are often observed in the Mississippian and Lansing-Kansas City reservoirs in Kansas.

Current Status (February 2007)

The project is nearing completion. Core and oil sampling and basic analysis were completed in Year 1. Fresh Arbuckle and Lansing-Kansas City cores from two fields were analyzed to produce the family of relative permeability curves. The family of relative permeability curves was derived and applied during the second year. Geomodels have been constructed for basic reservoir architectures and are being evaluated for two field sites. These results validate and expand the use of the Land equation in shallow-shelf carbonates and help to explain the high oil recovery and high water productions rates from these reservoir systems. Primary ongoing tasks involve continued relative permeability measurement, theoretical and real geomodel construction, and reservoir simulation. A no-cost extension was given in September 2006.



Incremental recoverable saturation versus height above free water level for Mississippian rocks of various permeabilities. Incremental recoverable saturation is defined as the predicted recoverable saturation where S_{orw} varies with S_{oi} (S_{oi}-$S_{orw}(S_{oi})$ less the predicted recoverable saturation for a constant S_{orw} where S_{orw} is the maximum S_{orw} value, which is obtain at height = 40 ft (12.2 m), S_{oi}-S_{orwmax}. Variable S_{orwvar} allows greater oil recovery in portions of the transition zone and approaches the fixed S_{orwmax} values at the maximum reservoir height. Fluid densities assumed for capillary pressure relations used in developing relations were $\rho\omega$ = 1.05 g/cc and ρo = 0.82 g/cc.

Funding

This project was selected in response to DOE's Oil Exploration and Production solicitation DE-PS26-04NT15450-2C, November 4, 2003.

Publications

Byrnes, A.P., and Bhattacharya, S., Influence of Initial and Residual Oil Saturation and Relative Permeability on Recovery from Transition Zone Reservoirs in Shallow-Shelf Carbonates, SPE 99763, 2006 SPE/DOE Symposium on Improved Oil Recovery, Tulsa, Oklahoma, April 22-26, 2006, 11 pgs.

Byrnes, A.P., and Bhattacharya, S., Seminar presented to the Kansas Geological Society, Wichita, KS, on November 10, 2004.

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

Anticipated DOE Contribution: $220,031
Performer Contribution: $53,269 (19 percent of total)

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