Fundamentals of Reservoir Surface Energy as Related to Surface Properties, Wettability, Capillary Action, and Oil Recovery from Fractured Reservoirs by Spontaneous Imbibition

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Goal

The project goal is to improve oil recovery from fractured reservoirs through improved fundamental understanding of the process of spontaneous imbibition by which oil is displaced from the rock matrix into the fractures.

Performer

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Herbert Fischer, Ph.D student, measures rate of oil recovery by spontaneous imbibition.

Results

The five objectives for the first 2 years of the project on the fundamentals of spontaneous imbibition have been met:

• Changes in surface energy with saturation, the source of energy that drives imbibition, have been measured for sandstones and carbonates. Simple network models have been developed that illustrate the physical phenomena that must be incorporated in a realistic model of imbibition in rocks.

• Researchers have obtained imbibition data that include novel pressure measurements that enable estimation of pressures acting during imbibition. These include the effective dynamic pressure that acts at the imbibition front and the pressure at the outlet core face that resists production of oil but previously has never been incorporated in modeling of imbibition.

• Extensive new imbibition data sets that greatly extend the parametric range of available imbibition data have been reported. Combinations of brine viscosified by addition of glycerol and oils of different viscosity have been used to investigate the effect of viscosity ratio, boundary conditions, and sample shape on oil recovery over wide ranges of viscosity.

• Researchers have reported definitive measurements of the effect of radial versus linear flow on oil recovery. Results have been matched numerically by a newly developed simulation model for imbibition that incorporates the physical mechanisms demonstrated by dynamic network modeling.

• Mathematical models have been developed that provide analytic models of similarity solutions for spontaneous imbibition.

In the final 3 years of the project, work will focus on:

• Imbibition by mixed wet rocks prepared by adsorption from crude oil. This calls for measuring surface energies of mixed wet rocks and taking specialized pressure measurements to establish the mechanism that drives imbibition at mixed wet conditions. Experimental studies of viscosity ratio, core shape, and boundary conditions will be extended to mixed wet rocks. Mathematical modeling will be adapted to the physical mechanisms that control oil production from mixed wet rocks.

• Investigation of methods of improved recovery, with special attention to fractured, low-permeability carbonates that are on the oil-wet side of mixed wettability.

Benefits

Measurements of oil recovery by spontaneous imbibition on core samples are a routine and widely applied procedure for characterization of wettability and prediction of oil recovery from fractured reservoirs. The results of this project are directly aimed at improved physical understanding of the imbibition process, improved interpretation of routinely measured data, and new approaches to increasing oil recovery from fractured low-permeability oil-wet reservoirs. Very large reservoirs of this type—from which only a small fraction of in place oil has been recovered—occur in Alaska, Wyoming, and other Lower 48 States. There is strong industry interest in prediction and improvement of oil recovery from fractured reservoirs, which ultimately would boost U.S. oil reserves and production.

Background

Massive accumulations of oil are held in fractured, low-permeability reservoirs. Injection of brine results in rapid recovery of oil contained in the fractures. Additional and substantially greater oil recovery depends on displacement by spontaneous imbibition of brine into the rock matrix and expulsion of oil via the fracture face. Spontaneous imbibition can be the determining mechanism for economic production. Spontaneous imbibition occurrence depends on the natural surface free energy of the reservoir.

However, knowledge of the reservoir surface energy and its relationship to rate and extent of oil recovery by spontaneous imbibition is surprisingly limited. Many other key questions as to the fundamental mechanism of oil recovery and means of improv-

ing oil recovery by spontaneous imbibition need to be addressed.

Summary

The fundamental mechanism of oil recovery by spontaneous imbibition is being investigated by an interdisciplinary team. Capillary pressure data and the corresponding change in surface free energy that drives spontaneous imbibition are being measured. New imbibition data, including novel pressure measurements, are being obtained. A network/numerical model is being developed with special emphasis on how imbibition is initiated and on how saturation profiles develop over time.

The basic concepts and ideas are being applied to interpretation of spontaneous imbibition in mixed-wet rocks prepared by adsorption from crude oil. Applications to improve recovery from fractured reservoirs will be tested in three ways: 1) reduced resistance to oil production at the fracture face by lowering interfacial tension, 2) increased rate of imbibition by alteration of rock matrix wettability, and 3) promotion of imbibition through manipulation of injection brine composition.

Current Status (January 2007)

This project consists of a 2-year study of the fundamentals of spontaneous imbibition followed by a 3-year investigation of the practical aspects of imbibition by mixed-wet rocks. A study objective was to increase fundamental understanding of the process of spontaneous imbibition where oil is displaced from the rock matrix into the fractures. Spontaneous imbibition is fundamentally dependent on the reservoir surface free energy, but this has never been investigated for rocks. During this year, a new method of measuring the effective capillary pressure at the imbibition front has been identified and applied. Saturations and oil/rock, water/rock, and oil/water surface areas were determined by advanced petrographic analysis. Both clastics and carbonates were studied under oil and water wet conditions. Studies are continuing with measurements of relationships between oil recovery by spontaneous imbibition and brine composition for mixed-wet rocks that show strong waterflood recovery response to changes in salinity. Studies of wettability control by adsorption from crude oil are now in progress.

Funding

This project was selected in response to DOE's Oil Exploration and Production solicitation DE-PS26-02NT15375, PRIME (Public Resources Invested in Management and Extraction), May 31, 2002.

Publications

Seth, S., and Morrow, N.R., Efficiency of Conversion of Work of Drainage to Surface energy for Sandstone and Carbonates, Proceedings of SPE Annual Technical Conference, San Antonio, TX, September 2006, SPE 102490.

Y. Zhang, and Morrow, N. R., Comparison of Secondary and Tertiary Recovery with Change in Injection Brine Composition for Crude-Oil/Sandstone Combinations, Proceedings of the 15th SPE/DOE Improved Oil Recovery Symposium, Tulsa, OK, April 2006, SPE 99757.

Fischer, H., Wo, S., and Morrow, N.R., Modeling of the Effect of Viscosity Ratio on Spontaneous Imbibition, Proceedings of SPE Annual Technical Conference, San Antonio, TX , September 2006, SPE 102641.

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Performer Contribution: $250,000 (20 percent of total)

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