

Wettability and Oil Recovery by Imbibition and Viscous Displacement from Fractured and Heterogeneous Carbonates

DE-FC26-02NT15344

Goal

The project goals are to:

- Relate wettability alteration of carbonate surfaces to methods of wettability control of carbonate rocks by adsorption from selected crude oils.
- Measure oil recovery and characterize wettability by spontaneous imbibition measurements for strongly water-wet carbonate rocks and for the same rocks after systematic changes in wettability induced by adsorption from crude oil.
- Investigate the sensitivity of oil recovery to displacement rate for carbonate rocks.

Performers

University of Wyoming
Laramie, WY

New Mexico Institute of Mining and
Technology
Socorro, NM

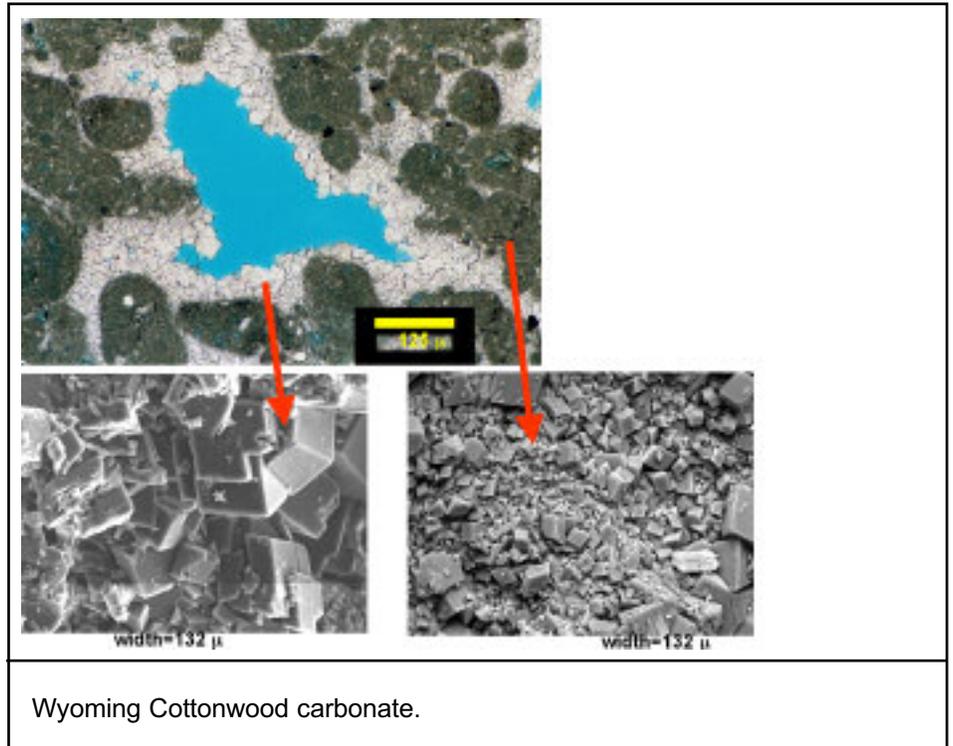
Results

Wettability alteration at carbonate surfaces has been measured for more than sixteen crude oils. Correlations for imbibition into carbonate rocks for very strongly water-wet and crude oil-induced wettability variations have been reported. Sensitivity of oil recovery to flow rate has been demonstrated for heterogeneous outcrop limestone for very strongly water wet conditions and for mixed wettability states established by adsorption from crude oil.

Sources of outcrop carbonate rock have been identified and unique comparisons have been made for oil recovery by spontaneous imbibition and waterflooding for very strongly water wet versus a range of mixed wettability states for different rock types and crude oils. Rate sensitivity of waterflood residual oil originally observed for reservoir carbonate rocks has been demonstrated.

Benefits

Major advances have been made in methods of wettability control in carbonates that serve as model rocks. The completed



parametric studies of oil recovery by spontaneous imbibition and viscous displacement will find many other applications in improved oil recovery and reservoir diagnostics. These results confirm and explain the unexpected but repeatedly observed sensitivity of oil recovery to injection rate reported by industry for reservoir carbonate cores. Companies (mainly independents) operating in States, such as Wyoming, in which a substantial fraction of in place oil is held in heterogeneous and fractured carbonates, have direct economic interest in this project.

Background

About one-half of U.S. oil reserves are held in carbonate formations. The remaining oil in low permeability fractured carbonate reservoirs is a major domestic target for improved oil recovery. This study addresses quantification of crude oil/brine/rock interactions and the impact of heterogeneity on oil recovery by spontaneous imbibition and viscous displacement.

The problem of wettability and oil recovery from carbonate reservoirs was recognized throughout the oil industry as being largely unexplored. Both laboratory and field evidence of sensitivity of waterflood recovery to flow rate, even down to field rates, revealed phenomena that could be turned to advantage with respect to improved recovery. For example, increased injection pres-

sure, increased injectivity, decreased well spacing, or lowering of interfacial tension, would lead to additional oil recovery.

Summary

In this project, researchers have:

- Identified sources of outcrop carbonate rock.
- Identified crude oils for oil recovery studies from contact angle measurements.
- Made unique comparisons for oil recovery by spontaneous imbibition and waterflooding for very strongly water-wet conditions versus a range of mixed wettability states.
- Demonstrated the rate sensitivity of waterflood residual oil at below and above field flow rates for heterogeneous outcrop carbonate rock.

Wettability-alteration characteristics of crude oils measured at carbonate surfaces were related to the properties of the crude oils. The effect of wettability on oil recovery was investigated for limestones that cover more than three orders of magnitude in permeability and a factor of four variations in porosity.

The rate sensitivity of oil recovery to waterflooding has been demonstrated for very strongly water-wet and mixed-wet heterogeneous carbonate rocks.

Homogeneous samples exhibit the least rate sensitivity at any wetting condition. These results are consistent with reservoir condition tests reported by industry researchers.

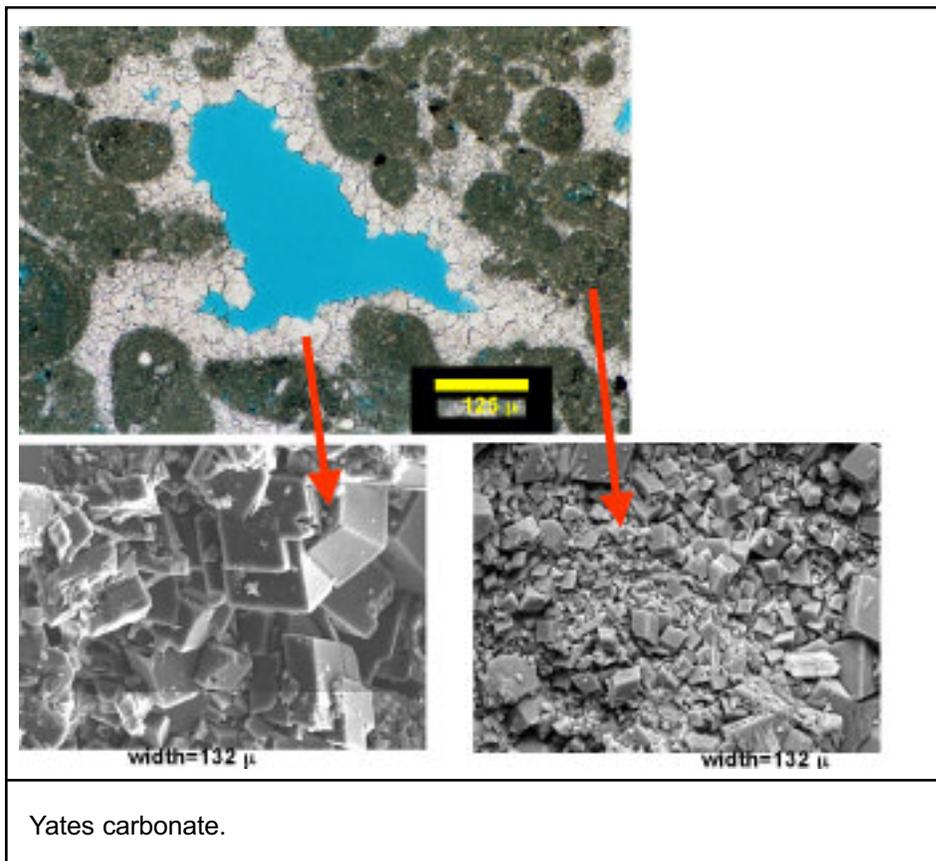
Current Status (June 2006)

All aspects of the project have been completed. A six month no cost extension was requested mainly to allow completion of tracer test work that will utilize equipment at the University of Bergen, Department of Physics. (Two Ph.D students from the University of Wyoming spent the summer at U.Bergen with Prof. Arne Graue).

Industry has shown strong interest in this project. They continue to see rate sensitivity of oil recovery for many carbonate reservoirs and are likely to provide matching support for further work on rate effects and relative permeabilities for carbonate rocks. The advances made in wettability control for a variety of rock types (including sandstones) provides the opportunity for study of variation in relative permeabilities resulting from systematic change in wettability.

Funding

This project was selected in response to DOE's Oil Exploration and Production solicitation DE-PS26-01NT41048.



Yates carbonate.

Publications

Quarterly Reports to DOE on Federal Assistance Program/Project Status Report.

Tie, H.G., Tong, Z.X., and Morrow, N.R., "The Effect of Different Crude Oil/Brine/Rock Combinations on Wettability through Spontaneous Imbibition" Proceedings of the International Society of Core Analysts Annual Meeting, Pau, France, Sept., 2003.

Fischer, H., Morrow, N.R., and Mason, G., "Application of water desorption/adsorption isotherms data to characterization of micro- and meso-porosity in sandstone and carbonate rocks" Characterisation of Porous Solids, in press.

Tie, H. and Morrow, N.R., "Oil Recovery by Spontaneous Imbibition Before and After Wettability Alteration of Three Carbonate Rocks by a Moderately Asphaltic Crude Oil:", presented at the International Society of Core Analysts Annual Meeting, Toronto, Canada, August 21-34, 2005.

Tie, H. and Morrow, N.R., "Low Flood Rate Residual Saturations in Carbonate Rocks" to be presented at The International Technology Conference, Doha, Qatar, Nov. 21-23, 2005

Project Start: July 18, 2002

Project End: January 17, 2006

Anticipated DOE Contribution: \$749,522

Performer Contribution: \$333,315 (30 percent of total)

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