# *Modeling Wettability Alteration Using Chemical EOR Processes in Naturally Fractured Reservoirs*

## DE-FC26-04NT15529

### Goal

The goal of this research is to develop a simulation tool to improve the understanding of multiphase-surfactant, alkaline, hot water, or surfactant enhanced oil recovery (EOR) processes in naturally fractured oil reservoirs. The emphasis is on innovative EOR processes that reduce the interfacial tension, reduce the mobility ratio, and enhance production by altering wettability.

### Performer

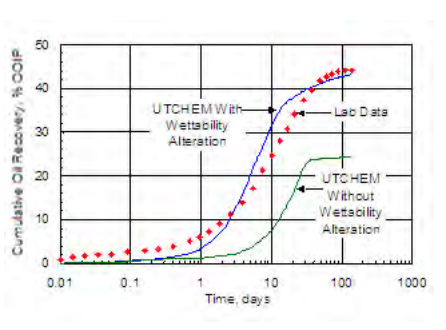
*University of Texas at Austin*
*Austin, TX*

### Results

Researchers have developed and implemented a model in the UTCHEM chemical simulator to account for wettability alteration as the result of surfactant injection. The model presently takes into account the changes in the relative permeability, capillary pressure, and capillary desaturation curves. Several simulations were performed to test the validity of the model.

To date, researchers have:

- Developed and implemented a model for wettability alteration in UTCHEM.
- Validated the model and its implementation by successfully history matching the published laboratory imbibition cell test results in a mixed wet carbonate matrix rock.
- Performed simulations with the improved model to scale up the processes involved in the oil recovery from the mixed-wet naturally fractured oil reservoirs from laboratory scale to field scale.
- Performed field-scale simulations with different wettability conditions.
- Conducted surfactant flooding simulations in fractured reservoirs with wettability alteration.
- Compared several published dimensionless times for the rate of spontaneous imbibition.




Comparison of simulated and laboratory imbibition oil recovery.

### Benefits

The chemical simulator UTCHEM was enhanced by adding the capability of modeling wettability alteration during chemical EOR processes. This addition will provide a unique simulator that can model surfactant floods in naturally fractured reservoirs by coupling wettability effects on relative permeabilities, capillary pressure, and capillary desaturation curves. This is a new and potentially very important application of simulation technology that has never been attempted despite the enormous volumes of oil remaining in naturally fractured reservoirs. Numerical simulations are needed to scale up and predict the performance of field-scale applications of chemical EOR. The improved chemical compositional simulator resulting from this project will enable the development of cost-effective chemical EOR processes because it can model surfactant phase behavior, temperature-dependent fluid properties, and wettability-dependent petrophysical properties in naturally fractured reservoirs. This simulator will be the first to incorporate all of these features. UTCHEM can now aid to scale up the process from laboratory to field scale.

### Background

Laboratory surfactant and hot-water floods have shown a great potential to increase oil recovery from reservoirs that are naturally fractured and have low-permeability oil-wet/mixed-wet matrix rocks. The mechanisms for increased oil recovery are the combined effects of reduced interfacial tension, reduced mobility ratio, and wettabillity alteration. All of these mechanisms are favorable for increased capillary imbibition. These processes have not been tested at either the pilot or field scale mainly due to lack of complete understanding of the complex mechanisms involved. The goal of this project is to adapt an existing numerical reservoir simulator, UTCHEM, to model chemical and thermal processes that effect wettability alteration in naturally fractured reservoirs.

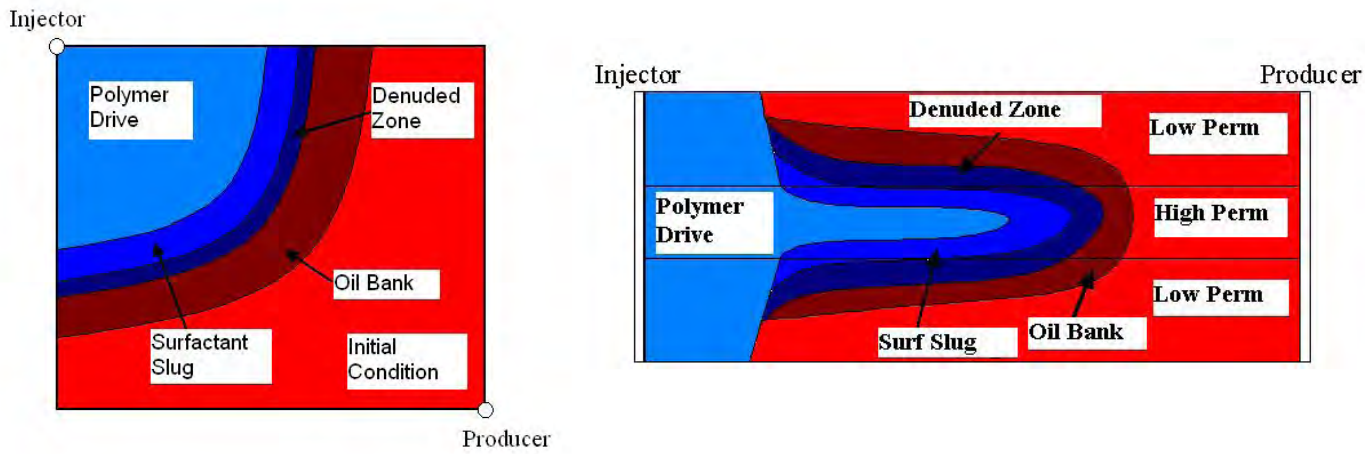
### Summary

The performance of waterflooding in naturally fractured reservoirs is normally low. This is due to the fact that most of the fractured reservoirs are oil-wet or mixed-wet and as a result have a low tendency for imbibition of injected water into the matrix. The main oil recovery mechanism in these reservoirs is imbibition of the injected water into the matrix and expulsion of oil to the fractures; therefore, the tendency of the matrix rock for imbibing the injected fluid plays an important role in oil recovery from these nonconventional reservoirs. It is desirable to change the wetting state of the matrix rocks to more water-wet conditions in order to increase the rate of imbibition of the injected water. This can be achieved by injection of a surface active agents or surfactants.

Surfactant solutions have two important effects on the rock/fluid system. The first effect is reduction of interfacial tension between the trapped oil and injected aqueous phase and therefore solubilization and mobilization of trapped oil. The second effect is the alteration of the wettability of the matrix rock towards more water-wet conditions, which would increase the brine imbibition rates.

The primary focus of this research is on surfactant processes that recover additional oil through ultralow interfacial tension and wettability alteration. A secondary objective is to model the wettability alteration during hot water injection, which enhances oil recovery by mobility reduction and wettability alteration. The combination of surfactant and hot water injection is being investigated to assess the potential for improved oil recovery of moderately heavy oils in naturally fractured reservoirs.

The effect of surfactant on wettability alteration was modeled and implemented in UTCHEM by changing relative permeability, capillary pressure, and capillary desaturation curves. The model was validated by a successful comparison with the published imbibition-cell surfactant experiments. Three-dimensional simulations of dilute surfactant flooding in a naturally fractured reservoir model demonstrated the signifi-




Left: Areal schematic of the SP process. Right: Cross section schematic of the SP process.

cance of wettability alteration from mixed wet to water wet conditions on increasing the oil production. The simulation tool developed aids in a mechanistic understanding of low concentration surfactant flooding in fractured carbonate reservoirs. With the wettability alteration capability in UTCHEM, several EOR processes that use chemicals such as surfactants—polymer and alkali, or in some cases, mixtures of them that recover additional oil through low interfacial tension and wettability alteration—can now be simulated.

The enhanced simulator will make it possible to select and optimize the best candidates for field application and tailor an EOR process design to the particular characteristics of each reservoir. It can also aid in the scale-up of the process from the laboratory scale to the field scale. The scale-up is crucial to predict the time required to achieve the same performance under field conditions, taking into the consideration matrix block sizes, matrix block heights, and other uncertain field conditions.

## Current Status (February 2007)

The project ended in the second year of a 3-year term.

## Funding

This project was selected in response to DOE's Oil and Gas Technologies Program solicitation DE-PS26-04NT15450, November 4, 2003.

## Publications

M. Delshad, N. Fathi, G.A. Anderson, G.A. Pope, and K. Sepehrnoori, "Modeling Wettability Alteration in Naturally Fractured Reservoirs," SPE 100081, paper presented at the 2006 SPE/DOE Symposium on Improved Oil Recovery, Tulsa, OK, April 22-26, 2006, pp. 1-10.

G. Anderson, M. Delshad, C.B. King, H. Mohammadi, G.A. Pope, "Optimization of Chemical Flooding in a Mixed-Wet Dolomite Reservoir," SPE 100082, paper presented at the 2006 SPE/DOE Symposium on Improved Oil Recovery, Tulsa, OK, April 22-26, 2006, pp. 1-12.

Anderson, G., "Simulation of Chemical Enhanced Oil Recovery Processes, Including the Effects of Reservoir Wettability," MS thesis, University of Texas at Austin, May 2006.

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

**Anticipated DOE Contribution:** $445,000
**Performer Contribution:** $116,651 (20 percent of total)

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