Mechanistic Studies of Improved Foam EOR Processes

DE-FC26-01BC15318

Program

This project was selected in response to DOE's Oil Exploration and Production solicitation DE-PS26-01NT41048 (December 1, 2000). The objectives of this part of the solicitation were to access oil not recoverable by conventional methods by developing improved methods of gas, chemical, and microbial flooding for light oil recovery.

Project Goal

The project goal was to provide the scientific and engineering basis for improved design of foam processes for enhanced oil recovery, by studying polymer-enhanced foam, gas trapping in the presence of foam, and mechanisms of foam generation.

Performer

University of Texas
Austin, TX

Project Results

Numerical models and simulation studies of foam mechanism were developed to improve prediction of foam movement through the reservoir. An area of unstable foam generation was identified that provides important information for foam design in field applications.

Benefits

This research provides the foundation for more-accurate predictive modeling of foam processes to improve oil recovery, improve process design, enable wider application of foams and gas injection, and increase domestic oil production.

Background

Injection of gases, including steam, carbon dioxide, and produced field gas, accounts for nearly all the enhanced oil recovery production in the United States, or about 12% of total U.S. oil production. The processes are efficient in recovering oil in portions of the oil reservoir where the gas flows, but the failure of gas to sweep through much of the reservoir reduces both the number of projects attempted and the rate of oil recovery in ongoing projects. Creating foams with gas, water, and surfactant (detergent) solution within the oil reservoir offers one means to increase this "sweep efficiency." The proposed research aims to improve foam processes through studies of their mechanisms, leading to more-predictive computer modeling of foam processes and improved process design.

Project Summary

The model for gas trapping incorporated into the UTCHEM simulator was used to fit data on gas trapping during liquid injection after foam. The model predicts mobilization of gas near an injection well during liquid injection in an alternating-slug process, enhancing liquid injectivity. University of Texas experiments verified the model for foam generation based on foam mobilization at a critical pressure gradient. Their data also identified an unstable foam-generation regime that may dominate field applications of foam constrained by moderate injection pressures. Researchers incorporated a simple model for this mechanism into the "population balance" framework for foam simulation. The model confirms the existence of an unstable regime at intermediate pressure gradients. Researchers drafted a manuscript on the foam-generation work.

Conclusions from the project are as follows:

• Interactions between foam and polymer.

– For the polymers, oils, and surfactants tested, it appears from coreflood pressure gradient that polymer destabilizes foam somewhat, raising water saturation and water relative permeability. Increases in observed pressure gradient resulted from the increased viscosity of the aqueous phase.

– For the same polymers and surfactant, polymer does not stabilize foam in the presence of decane or 37.5 API gravity crude.

– Complex behavior, in contradiction to the expected two steady-state strong-foam regimes, was sometimes observed.

– Theory predicts that polymer should make the flow of foam more shear-thinning than without polymer. In the high-quality regime, where pressure gradient is controlled by water transport at fixed water saturation, the shear-thinning nature of the aqueous polymer solution would make flow shear-thinning. In the low-quality regime, where the rheology depends on the resistance to movement of gas bubbles, flow is predicted to be more shear-thinning because of the presence of polymer.

• Gas trapping.

– A new model for gas trapping has been incorporated into a foam simulator. This model can fit steady-state data for the two strong-foam flow regimes. In limited trials, it also fits the transition period between foam injection and injection of liquid following foam. The simulator will be most helpful in modeling liquid injectivity in SAG foam processes.

– Coreflood experiments measured the average liquid saturation in a core during liquid injection following foam. Data implied that liquid does not uniformly sweep the core but only contacts a portion of the trapped gas.

– CT studies confirm that liquid fingers through foam rather than displacing it. Because of this fingering, surfactant-free brine injected after foam does not displace the surfactant solution initially present or destroy foam as rapidly as predicted in one-dimensional (1-D models).

– The yield stress of foam is the origin of gas trapping and relative premability effects with foam.

– CT imaging showed that the 1-D model used to infer trapped- and flowing-gas fractions from gas tracer effluent data have several shortcomings. They are noted in the report. In spite of the uncertainty, some trends are still evident.

• Foam generation

– The consensus view in foam research has been that foam is created by roof snap-off, governed liquid and gas velocities, and the geometry of the pore throats and pore bodies. A review of these individual studies cited in support of this mechanism shows there is no substantial support for this mechanism for steady-state foam generation in homogeneous porous media.

– If pressure gradient is fixed, rather than injection rates, one observes an unstable state between coarse foam (or no foam) and strong foam. This state may have practical importance in field applications with limits on injection pressure.

– A population-balance model incorporating a lamella-creation function that depends on pressure gradient fits numerous features observed in foam generation experiments. This model indicates that the details of the lamella-creation function have little effect on the high-quality and low-quality strong-foam regimes, if strong foam is formed.

– The population-balance foam simulator, applied to dynamic foam displacements, confirms the stability of the coarse- and strong-foam states and the instability of the intermediate state. The model predicts a transition from coarse foam to strong foam as injection rates increase, in agreement with experiments.

– Fractional-flow models can be modified to account for sudden changes in properties such as foam generation and foam collapse.

– A pore-network model for foam generation resolves two paradoxes troubling researchers' finding that foam is created by mobilization and division of lamellae by pressure gradient. First, the network model shows how new lamellae are created near the inlet of the porous medium to replace those mobilized and transported downstream. Second, the model reconciles the two halves of the theory of Rossen and Gauglitz (1990) at the percolation threshold.

– A series of experiments in sandpacks found several effective ways of enhancing foam generation. Other studies indicate the same trends in foam behavior are observed in sandpacks as in consolidated core, but at lower pressure gradients.

Current Status (October 2005)

This project has been completed.

Publications

Kim, Dong, and Rossen, Steady-State Flow Behavior of CO2 Foam, SPE 89351, presented at 2004 SPE/DOE IOR Symposium, Tulsa, OK, April 2004.

Rossen and Bruining, Foam Displacements With Multiple Steady States, SPE 89397, presented at 2004 SPE/DOE IOR Symposium, Tulsa, OK, April 2004.

Kam and Rossen, A Model for Foam Generation in Homogeneous Porous Media, SPE Journal 8, 417-425, December 2003

Cox, Neethling, Rossen, Schleifenbaum, Schmidt-Wellenburg, and Cilliers, A Theory of the Effective Yield Stress of Foam in Porous Media: The Motion of a Soap Film Traversing a Three-Dimensional Pore, Colloids Surfaces A: Physicochem Eng. Aspects 245, 143-151, 2004.

Rossen and Van Duijn, Gravity Segregation in Steady-State Horizontal Flow in Homogeneous Reservoirs, Journal of Petroleum Science Eng., 43, 99-111, 2004.

Shan and Rossen, Optimal Injection Strategies for Foam IOR, SPE Journal 9, 132-150, 2004.

Kam and Rossen, A Model for Foam Generation in Homogeneous Media, SPE 77698.

Mamun, Rong, Kam, Liljestrand, and Rossen, SPE 77557, Extending Foam Technology From Improved Oil Recovery to Environmental Remediation.

Project Start: September 1, 2001
Project End: December 31, 2004

Anticipated DOE Contribution: $639,525
Performer Contribution: $172,163 (21% of total)

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