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Quarterly Technical Progress Report

IMPROVED EFFICIENCY OF MISCIBLE CO_2 FLOODS AND ENHANCED PROSPECTS FOR CO_2 FLOODING HETEROGENEOUS RESERVOIRS

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ABSTRACT/ EXECUTIVE SUMMARY

A grant, "Improved Efficiency of Miscible CO_2 Floods and Enhanced Prospects for CO_2 Flooding Heterogeneous Reservoirs," DOE Contract No. DE-FG26-97BC15047, was awarded that began June 1, 1997. This project examines three major areas in which CO_2 flooding can be improved: fluid and matrix interactions, conformance control/sweep efficiency, and reservoir simulation for improved oil recovery.

This report discusses the activity during the calendar quarter covering October 1, 1999 through December 31, 1999 that covers mostly the second fiscal quarter of the project's third year.

Injectivity experiments were performed on two Indian limestone cores. In tests on the first core, a variety of brine, CO_2, WAG, and oil contaminant injection schemes indicated injectivity reduction due to phase conditions and contamination. The results are only quantitative because of plugging and erosion in the core. To date, tests on the second core have investigate te effects of long-term brine stability on the reduction of fluid-rock interaction, in order to quantify fluid effects on injectivity.

We continue to develop a new approach in reservoir simulation to improve the history matching process on clusters of PCs. The main objective is to improve simulation of complex improved oil recovery methods, such as CO_2-foam for mobility control and sweep enhancement.

Adsorption experiments using circulation and flow-through methods were used to determine the loss of surfactants for economic evaluation. A sacrificial agent, lignosulfonate, was used to reduce the adsorption of the primary foaming agent in both Berea sandstone and Indiana limestone. The lignosulfonate has also shown a chromatograph effect, advancing more rapidly through the reservoir, thus initially adsorbing onto the rock before the primary foaming agent arrives. Therefore, considering the simplicity of operation and economics of reducing the cost of expensive surfactant to improve oil recovery, coinjection of lignosulfonate with the primary foaming agent might be a practical approach to consider for field application.

INTRODUCTION

Because of the importance of CO_2 flooding to future oil recovery in New Mexico, west Texas, and the United States, the Petroleum Recovery Research Center (PRRC) pursues a vigorous research program to improve the effectiveness of CO_2 flooding in heterogeneous reservoirs. The results of our research continue to expand the list of viable candidates for CO_2 flooding. Our primary interests are to include more low-pressure reservoirs and many more heterogeneous or fractured reservoirs in our research.

Support for oil recovery research by CO_2 flooding is continuing by the U.S. Department of Energy under the current three year grant: "Improved Efficiency of Miscible CO_2 Floods and Enhanced Prospects for CO_2 Flooding Heterogeneous Reservoirs." The New Mexico Petroleum Recovery Research Center (PRRC) is well known as a premier institution for improved oil recovery (IOR) research and, in particular, for its research on the use of high-pressure CO_2 injection. The project continues the progress on understanding CO_2 flooding in heterogeneous reservoirs, further the development of methods to enable CO_2 flooding in more heterogeneous reservoirs, and continue the dissemination of this information to promote successful implementation of these methods. The research is proceeding in three related areas:

- Fluid and matrix interactions (understanding the problems): interfacial tension (IFT), phase behavior, development of miscibility, capillary number (Nc), injectivity, wettability, gravity drainage, etc.
- Conformance control/sweep efficiency (solving the problems): reduction of mobility using foam, diversion by selective mobility reduction (SMR) using foam, improved injectivity, WAG, horizontal wells, etc.
- Reservoir simulation for improved oil recovery (predicting results): gravity drainage, SMR, CO_2/foam flooding, IFT, injectivity profile, horizontal wells, and naturally fractured reservoirs.

All areas originate from research on the mechanics of oil recovery by high-pressure CO_2. Experience gained during the current project is relevant to our continued efforts. Future research in each of the three areas will increase both the quantity of oil produced and the efficiency of oil recovery from CO_2 flooding. Special attention will be given to disseminating research results through an extensive technology transfer effort. Because of the importance of CO_2 flooding in New Mexico reservoirs, additional funds are being provided through a combination of state and industry funds.

SUMMARY OF TECHNICAL PROGRESS

This report discusses the activity during the calendar quarter covering October 1, 1999 through December 31, 1999 that covers mostly the second fiscal quarter of the project's third year.

Injectivity

A 20-in. long oolitic Indiana limestone core was flooded in a 2-in. diameter core holder in a constant-temperature air bath (100°F). The core outlet pressure was held at 2000 psi. Brine and oil compositions were those of the Teague-Blinebry Reservoir. A series of floods were performed, including brine, CO_2, WAG, oil, and oil displaced by brine, CO_2, and WAG. After the flooding series (about three months) the core was removed and examined. Severe erosion in the form of channeling was observed. The core was sliced into inch-thick sections. The channel extended slightly more than halfway down the core length and varied in diameter from approximately 0.25 in. at the inlet face to 0.125 in. Only minor bifurcating channels were seen. The core slices were photographed and samples will be sent for SEM analysis to examine compositional changes along the length of the core.

The data suggest that the core experienced a number of alterations during the course of the experiment. That a plugging effect occurs is shown by the pressure differential (DP) data during exposure to brine and CO_2. Subsequent to oil injection followed by brine and CO_2, there is an observed decrease in the DP data attributable to the development of the channel. Even with the DP drift due to initial plugging and latter channeling, the effect of multiphase flow on injectivity was evident. As expected, two and three phases present caused severe injectivity reduction. When a small amount of oil is injected, simulating contamination from other zones or dirty water, the pressure increase or injectivity reduction can persist for several WAG cycles.

A second oolitic Indiana limestone core (2 in. in diameter and 14 in. long), cut from the same rock, was flooded. A series of brine stability tests were conducted using the same brine as in the previous core, as well as a new brine of 10kppm NaCl. Caught water samples were analyzed to check for compositional changes that might signal rock alteration. The Blinebry brine appeared to cause core plugging. The 10kppm NaCl brine gave a stable response (as good as ever observed).

Further tests on the core will indicate if minor DP trends are due to particulate plugging at the core face or some alteration process within the core. The core will then be subjected to oil injection and further flooding using the same strategies as in the first core.

Reservoir Simulation

In this quarter, we continued to develop a new approach to improve the history-matching process on cluster of PCs. The main objective is to improve simulation of complex improved oil recovery methods, such as CO_2-foam for mobility control and sweep enhancement. Simple Java-based software, MASTER Web, has been implemented to connect/communicate PCs for carrying out the simulation. MASTER Web, a loosely coupled (with no shared memory) parallel system configured in a master-slaves fashion, is sufficient for history matching since there is no need for inter-slave-processor communication. Utilizing parallel simulation across the Internet (the World-Wide Web), this novel technique not only aims to improve history matching, but does it economically on cluster of ordinary PCs, thus making it affordable for smaller oil companies. This new method is being tested on the history matching of East Vacuum Grayburg-San Andres Unit (EVGSAU) of New Mexico. Part of the preliminary results will be presented at the SCS International Conference on Web-Based Modeling and Simulation, San Diego, January 23-27, 2000. (Guadalupe Janoski, Andrew H. Sung, Shih-Hsien Chang, Reid B. Grigg, "MASTER Web: A Petroleum Reservoir Simulation Tool," to be presented at the SCS International Conference on Web-Based Modeling and Simulation)

Conformance Control/Sweep Efficiency

In this quarter, we completed adsorption tests on Indiana limestone rock samples, and prepared and submitted two technical papers to SPE/DOE Improved Oil Recovery Symposium to be held in Tulsa, April 3-5, 2000.

In adsorption experiments, circulation and flow-through methods were used to determine the loss of surfactants for economic evaluation and to design an optimum surfactant injection scheme. The results from circulation method showed that lignosulfonate could reduce the adsorption of a primary foaming agent Chaser™ CD1045 by 15-29% in Indiana limestone. This percentage of reduction is slightly lower than the results found in Berea sandstone (24-60% as reported in the previous quarter).

The results from the flow-through method showed that the adsorption of lignosulfonate and CD1045 onto the rock is a reversible process. The principal effect of reversible adsorption on the transport of solute flow in porous media is to decrease the solute material's velocity relative to that of the fluid that carries it. As a result, chromatographic separation of surfactant mixture occurs when the mixtures are flowing through the porous media. This behavior was observed when lignosulfonate and surfactant CD1045 were coinjected into the rock sample. During the coinjection, the lignosulfonate molecules tend to move ahead of surfactant CD1045 and form two separate fronts in the effluent profiles.

The tendency of the lignosulfonate front to move ahead of the surfactant front during the propagation provides the benefits of protecting the surfactant form adsorbing onto the rock surface as well as delaying the surfactant's direct contact with hydrocarbon. Both factors are considered to affect the effectiveness of foam during the foam displacement process. Therefore, considering the simplicity of operation and economics of reducing the cost of expensive surfactant to improve oil recovery in laboratory tests, coinjection of lignosulfonate with primary foaming agent might be a practical approach to consider for field application.