DE-FG26-97BC15747--02

Improved Efficiency of Miscible C02 Floods and Enhanced Prospects for C02 Flooding Heterogeneous Reservoirs

Quarterly Report
July 1 - September 30, 1997

By
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Work Performed Under Contract No.: DE-FG26-97BC15747

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Quarterly Technical Progress Report

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

DOE Contract No. DE-FG26-97BC15747

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Report Date:	October 31, 1997
Contract Date:	June 1, 1997
Completion Date:	May 31, 2000
DOE Award of 1st year:	$319,548
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Reporting Period:	July 1, 1997–September 30, 1997

PRRC Report 97–34

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ABSTRACT

A new 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 and started on June 1, 1997. This work will examine 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.

The first full quarter of this project has been completed. We began examining synergistic affects of mixed surfactant versus single surfactant systems to enhance the properties of foams used for improving oil recovery in CO_2 floods. The purpose is to reduce the concentration of surfactants or finding less expensive surfactants. Also, we are examining the effect of oil saturation on the development of foam in CO_2-surfactant solution systems. CO_2 flooding of low permeability, vugular, and fracture reservoirs are another major thrust of this project. Work conducted this quarter involved simulating gravity stable floods using large core samples; results showed excellent recovery in a low permeability vugular core.

EXECUTIVE SUMMARY

A new 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 and started on June 1, 1997. This work will examine 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.

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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 continues 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.

Continued support for oil recovery research by CO_2 flooding has been provided by the U.S. Department of Energy for an additional three years through a grant entitled: "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 extension will continue 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 will proceed 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

Conformance Control/Sweep Efficiency

Experiments were performed to evaluate properties of mixed surfactants and their effectiveness in stabilizing foam at high pressure using a foam durability apparatus. We examined various mixed surfactant systems, such as alpha olefin sulfonate and ethoxylated alcohol sulfate, at low concentrations (less than 500 ppm) to determine their foaming ability and the stability of the foam. The test results were used in conjunction with our foam flowing tests to study the potential for using mixed surfactants at low concentration to improve mobility control in CO_2 flooding.

Experiments were conducted on a fired Berea sandstone core with CO_2 , CO_2 /brine, and CO_2-foam at different saturations of brine, surfactant solution, and oil. The breakthrough time and increment of fluid recovery were recorded and compared. Without the presence of oil in the core, CO_2 breakthrough time increased when the core was initially saturated with the surfactant solution versus brine. The breakthrough of CO_2 was delayed further when CO_2 and surfactant were coinjected in the core. When oil was present in the core, the breakthrough time of CO_2 was reduced in all comparable cases, but was longest when CO_2 was coinjected with surfactant solution. Thus, the presence of oil was found to affect the performance of CO_2 and foam during the flooding process.

CO_2 -ASSISTED GRAVITY DRAINAGE IN A VUGULAR CORE

Minimum miscibility tests were performed on recombined reservoir fluid from the Wellman Unit. Tests were performed on three samples having solution gas-to-oil-ratios (GOR) ranging from 150 scf/bbl to 600 scf/bbl. The influence of GOR on the minimum miscibility pressures (MMP) was found to be minimal. The MMP at reservoir temperature of 151°F was found to be 1600±25 psig. Increasing the GOR increased the MMP only slightly.

A core test simulating a gravity drainage CO_2 flood was performed using reservoir core and 400 GOR recombined reservoir oil. A 4 inches diameter by 28 inches length of whole core from depth 9403.6 ft - 9406.5 ft from the Wellman Unit was oriented vertically in a core holder. The pore volume (PV) was determined to be 390 cubic centimeters (6.76% porosity) by brine injection and had a vertical brine permeability of 15.4 md.

The following procedure was used to condition the core and simulate an upward waterflood and a downward CO_2 flood:

1. 10 PV of brine was injected into the core at 150°F and 1900 psig.
2. Dead oil was injected into the core and aged ten days at the above temperature and pressure.
3. Separator oil was injected into the core until water saturation was reduced to 23%.
4. Recombined reservoir oil was then injected into the core and aged for three days.
5. Brine was slowly injected into the core from the bottom vertically upwards to simulate a upward water drive in the Wellman reservoir. A total of about 5 PV of brine was injected into the core. The final average water saturation was 53%.
6. CO_2 was then injected into the top of the core at a rate of 20 cc per hour. During CO_2 injection, the temperature was maintained at 151°F and pressure of 1650 psig.

Water and oil production from the core during CO_2 injection are presented in Figure 1. This figure shows that oil and water were not produced proportionally. For the first 150 cc of CO_2 injected, the produced liquid was essentially water alone; thereafter water production decreased and oil production increased rapidly. This result indicates the formation of an oil bank at the CO_2 front during a gravity-stable CO_2 displacement. Figure 2 shows back-calculated changes in water and oil saturations in the core during CO_2 injection. After 0.5 PV of CO_2 injection, essentially all of the mobile water was removed from the core with a final water saturation of under 20%. After 1.3 PV of CO_2 was injected, residual oil was reduced to about 10% PV, or a final oil recovery of 79% OOIP after the water flood. This could represent a gravity-stable CO_2 flood after a good water flood or in a water-oil transition zone.

Oil saturation was decreased another 3% PV by injecting CO_2 to increase the pressure to 1740 psig, followed by a three day CO_2 soak at 1740 psig and 156°F. Then injecting another 0.3 PV of CO_2 at a rate of 50 cc per hour with a back pressure of 1650 psig, soaking that for another nine days, and finally injecting another 4.3 PV of CO_2 at high flow rates. After blowdown and flushing the core with methanol and chloroform, all but about 2.5% PV of the liquid hydrocarbon was accounted for in produced fluids. The system was then resaturated with brine and the core PV was found to be close to PV determined initially.

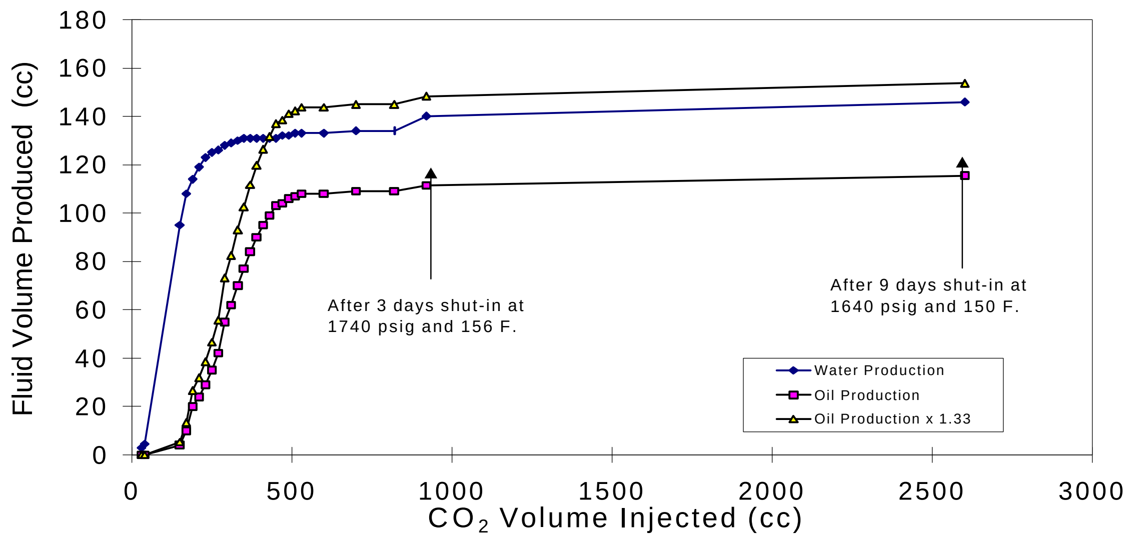

Figure 1, Fluid Production versus CO_2 Throughput during CO_2 - Assisted Gravity Drainage

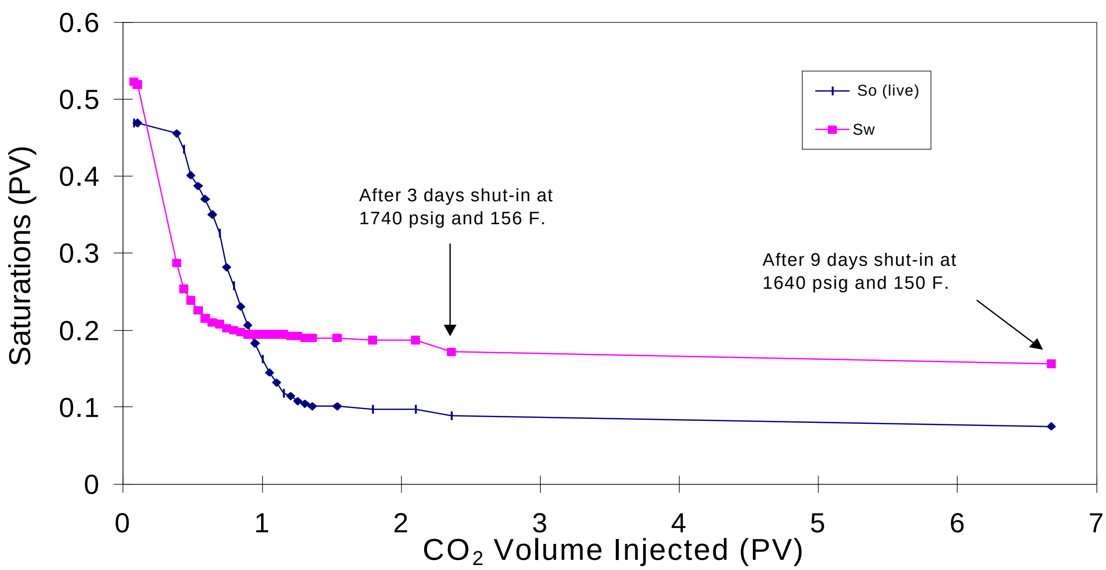

Figure 2, Changes in Fluid Saturations in the Wellman Unit Whole Core during CO_2 - Assisted Gravity Drainage