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

Quarterly Report
October 1 - December 30, 1997

By
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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-FG26-97BC15047--03

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ABSTRACT

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 and started on 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.

In this quarter we continued the examination of synergistic effects 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 and find less expensive surfactants. Also, we are refining reservoir models to handle the complex relationships of CO_2-foam and heterogeneous reservoirs. The third area of our report this quarter comprises the results from experiments on CO_2-assisted gravity drainage in naturally fractured oil reservoirs. Two more CO_2 core flood experiments have been conducted under reservoir conditions to investigate the effect of pressure on oil recovery efficiency during CO_2-assisted gravity drainage.

EXECUTIVE SUMMARY

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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. As a result of our research, the list of viable candidates for CO_2 flooding continues to expand. 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 that originated from our studies on the mechanics of oil recovery by high-pressure CO_2:

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

The current project is producing results that support and encourage 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 extensive technology transfer activities. 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.

For this quarter, three areas are summarized: advances in reservoir simulation of CO_2-foam, selecting and testing mixed surfactants as CO_2 foaming agents, and CO_2 gravity drainage tests. An expanded report on the CO_2 gravity drainage tests is also presented.

TECHNICAL PROGRESS

SUMMARY

Foam for Mobility Control. In this quarter, we evaluated properties of mixed surfactants and their effectiveness in stabilizing foam at high pressure by using a foam durability apparatus. We examined six mixed surfactant systems at a concentration of 500 ppm to determine their foaming ability and stability. These test results are 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.

When mixed surfactants were coinjected with CO_2, substantial mobility reduction and favorable selective mobility reduction were observed. A noticeable improvement in mobility achieved by using a mixture of anionic and nonionic surfactants leads us to believe that low concentrations of mixed surfactant systems can be used to improve CO_2 mobility. These favorable results provide an alternative means of selecting surfactants for foam application in different types of reservoirs. The detailed discussion and results can be found in paper SPE 39792, entitled “Use of Mixed Surfactants to Improve Mobility Control in CO_2 Flooding,” to be presented at the 1998 Permian Basin Oil and Gas Recovery Conference.

Simulating Foam on a Reservoir Scale. In order to calibrate our foam model, which was incorporated into a DOE pseudomiscible reservoir simulator (MASTER) with field data from the foam pilot test at the East Vacuum Grayburg San Andres Unit (EVGSAU), an acceptable history match model for the pilot area of the EVGSAU has to be obtained. Extensive simulation runs using MASTER have been conducted to obtain a satisfactory match of the production data from the pilot area of the EVGSAU. Part of the simulation results have been summarized in paper SPE 39793, to be presented in the 1998 Permian Basin Oil and Gas Recovery Conference.

One of the objectives of this study is to conduct a systematic investigation of CO_2 flooding using horizontal wells in conjunction with foam. MASTER, which was modified by incorporating the horizontal-well feature, is used in this investigation. The history match model for the pilot area of the EVGSAU is used as a hypothetical reservoir system. Sensitivity study on the horizontal-well feature is being performed to determine the effects of well lengths and locations on the oil recovery.

CO_2 -Assisted Gravity Drainage Experiments. We continued experimental investigations on CO_2-assisted gravity drainage in naturally fractured oil reservoirs. Two more CO_2 core flood experiments were conducted under reservoir conditions to investigate the effect of pressure on oil recovery efficiency during CO_2-assisted gravity drainage. The first gravity-stable CO_2 displacement was conducted at a pressure 50 psi below the slim tube MMP. Results indicate that oil recovery is not significantly lower than that obtained at a pressure 50 psi above the MMP. The second experiment was conducted at a pressure 300 psi below the slim tube MMP. The oil recovery is significantly lower than that obtained at a pressure 50 psi below the MMP. The relationship between oil recovery and pressure in the CO_2 corefloods is compared with those observed in slim tube and fat tube tests. Consistency is observed, with the exception that oil recoveries from the core floods were lower than those from the slim tube and fat tube tests. The experimental results indicate high efficiency of CO_2 flooding in the Wellman field, from which the core and oil samples were taken. Our test data technically support the CO_2 flooding project currently underway in the Wellman field of west Texas.

CO_2 –ASSISTED GRAVITY DRAINAGE EXPERIMENTS

Core and Oil. A 4 in.-diameter whole core with natural fractures from depth 9403.6 ft–9406.5 ft in Wellman Unit 5-10 was cut to 18.44 in. long to fit into a core holder. Porosity and vertical permeability were determined to be 6.6% and 12.7 md, respectively, under reservoir pressure, temperature, and confining stresses. Separator oil from the Wellman field was used in the experiments. The minimum miscibility pressure (MMP) of the oil is 1,600 psig.

Procedure. All the experiments were conducted at reservoir pressure and temperature under confining stress conditions. After circulating brine for more than 10 PV, a separator oil was introduced into the core. Initial water saturation in the core was achieved by circulating separator oil in the core. After six days of aging, brine was slowly injected into the core from the bottom to simulate bottomwater drive in the reservoir, and a waterflooded water saturation was established. CO_2 was finally injected into the core from the top at a very low rate to ensure gravity-stable displacement. Oil and water recovered from the core were collected after condensing. The detailed procedure was presented in the previous Quarterly Report.

Results and Comparison. Results from the two experiments and the previous experiment[1] are summarized in Table 1. Figures 1 and 2 present oil recovery curves from the two experiments. Comparison of the two curves clearly shows that the efficiency of CO_2-assisted gravity drainage was lowered in the second experiment due to low pressure. A comparison of oil recovery curves obtained from slim tube tests, fat tube tests, and corefloods for the same Wellman oil is shown in Fig. 3. The slim tube and fat tube data are from Grigg's report.[2] This comparison indicates consistent recovery-pressure relationships among the test methods, with the exception that oil recoveries from the corefloods were lower than those from the slim tube and fat tube tests.

Conclusion. Oil recovery-pressure relationships obtained from whole core CO_2-assisted gravity drainage experiments are similar to those obtained from slim tube and fat tube tests, with the exception that the oil recoveries from the corefloods were lower than those from the slim tube and fat tube tests.

Results of experiments conducted under reservoir conditions show high efficiency of oil recovery owing to CO_2-assisted gravity drainage. This result suggests that naturally fractured carbonate oil reservoirs are good candidates for CO_2 flood. The test data presented in this document technically support the CO_2 flooding project that is going on in the Wellman field of west Texas.

References

1. Grigg, R.B.: "Improved Efficiency of Miscible CO_2 Flooding Heterogeneous Reservoirs," Quarterly Report to US DOE under Contract No. DE-FG22-94BC14977.
2. Grigg, R.B.: " Wellman Field, Terry County, Texas, The Wiser Oil Company, CO_2 Miscibility vs. Solution Gas GOR and Gravity Stable Displacements," PRRC Report No. 97-19.

Table 1 - Conditions and Results of Three CO_2-Assisted Gravity Drainage Experiments

Experiment No.:	1	2	3
Core Porosity	0.0676	0.066	0.066
Core Permeability, md	15.4	12.7	12.7
Initial Oil Saturation	0.47	0.102	0.191
Oil Type	Reservoir oil	Separator oil	Separator oil
Temperature, F	150	150	150
Pressure, psig	1,650	1,543	1,320
CO_2 Injection Rate, cc/hour	20	10	2
Oil Recovery after 1.2 PV CO_2 Inj.	0.76	0.51	0.115
Oil Recovery after 2 PV CO_2 Inj.	0.78	0.57	0.148
Residual Oil Saturation	0.09	0.03	0.100

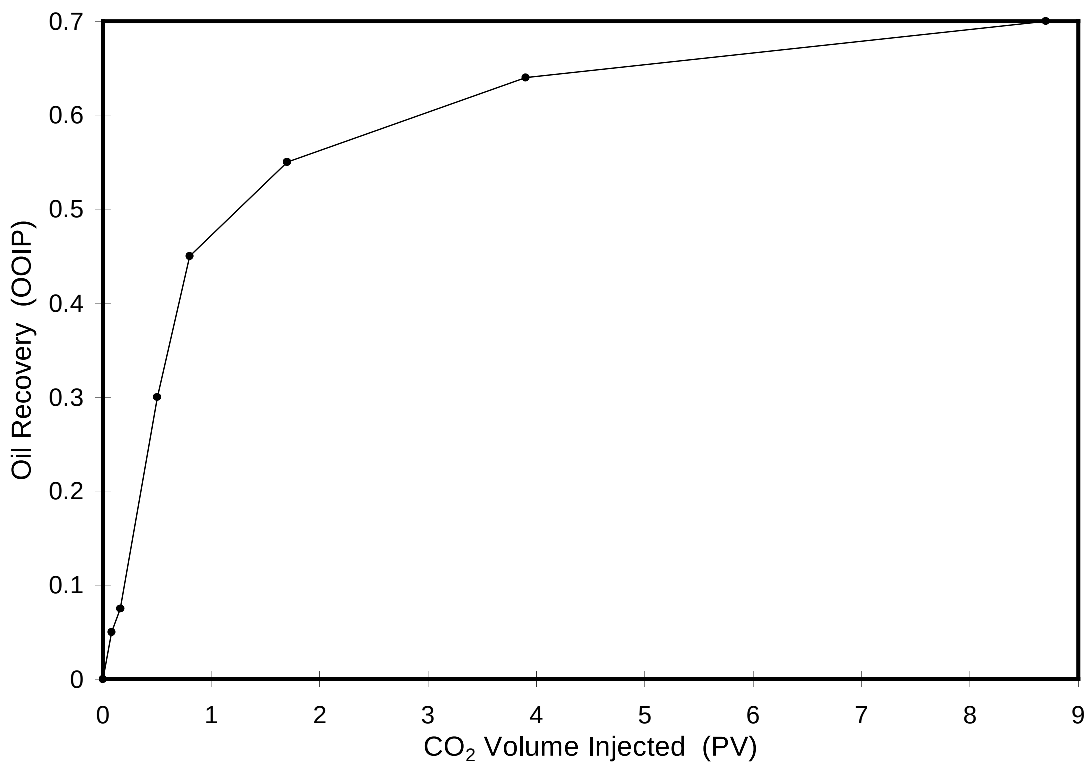

Fig. 1. Oil recovery from a CO_2-assisted gravity drainage experiment at pressure 1,543 psig.

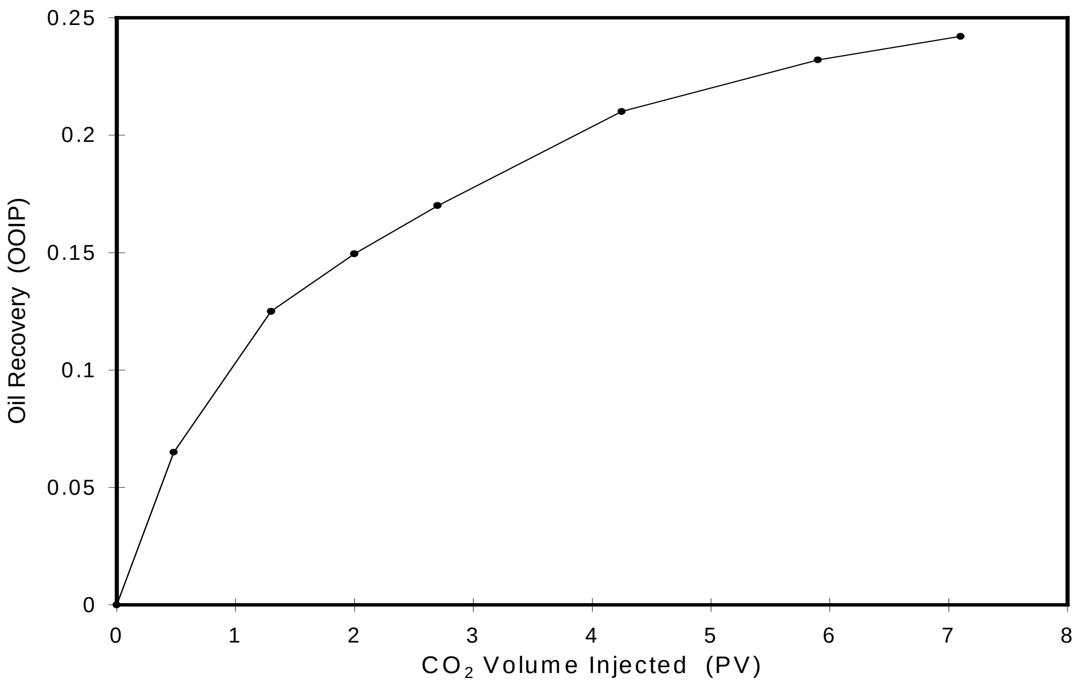

Fig. 2. Oil recovery from a CO_2-assisted gravity drainage experiment at pressure 1,320 psig.

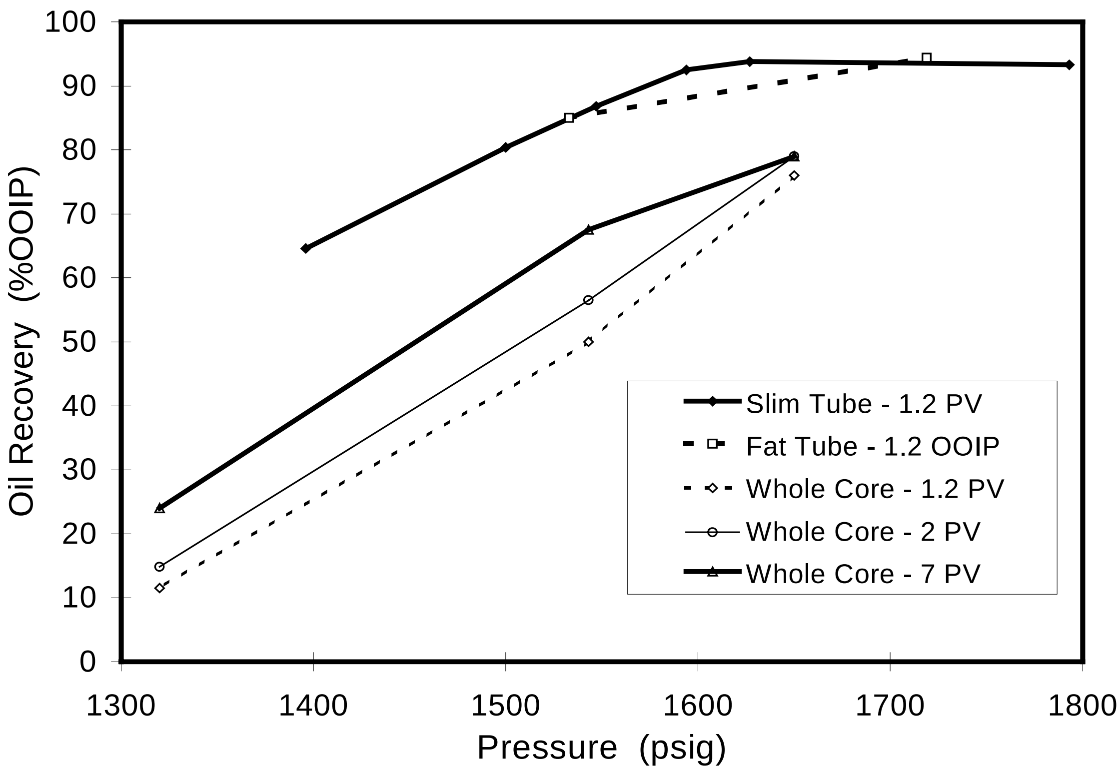

Fig. 3. Comparison of oil recoveries from CO_2-assisted gravity drainage experiments with that from slim tube and fat tube tests.