Quarterly Technical Progress Report

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

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DISCLAIMER

ABSTRACT

Work has progressed in each of the three project areas during this quarter. Two technical papers were prepared for and presented at the 1997 SPE International Symposium on Oilfield Chemistry. Two new surfactants have been tested for foam properties, including selective mobility reduction, and added to our data base on foam properties. A synthetic core has been constructed that provides constant permeability throughout several series of coreflood tests. We are continuing our examination of simulation procedures to history-match production data from a CO_2-foam field pilot test, and concentrating on developing a reservoir description. We are continuing experimental work using whole core and crude oil under reservoir conditions to investigate the effect of water saturation on the efficiency of CO_2 gravity drainage. After CO_2 injection, results indicated that oil production was lower while water was being produced, and that the rate increased after water production stopped. We believe that the excessive free water in the core hindered oil recovery during the earlier stage, due to competing two-phase relative permeabilities.

EXECUTIVE SUMMARY

Task 1: The technical paper, "Assessment of Foam Properties and Effectiveness in Mobility Reduction for CO_2 Foam Floods," was prepared and presented at the 1997 SPE International Symposium on Oilfield Chemistry. The paper covers five surfactants tested earlier for their foam properties. Work is progressing on evaluating surfactants and their foam properties under high pressure conditions by using a foam durability apparatus. Two surfactants, Witcolate™ 1259 and Witcolate™ 1276, were tested in this quarter and the new data were added into our existing database for correlation between foam properties in the bulk phase and in porous media. The new data support the earlier conclusion that foam stability and interfacial tension correlate with selective mobility reduction.

Task 2: The changing permeability of the core during a series of foam tests is a significant factor in determining foam coreflood test parameters. A series of tests often requires hundreds of pore volumes of fluids to pass through the core. During this quarter, a new core was developed that should eliminate this problem and provide a constant base line. We ran a series of tests, which showed that this core has a constant permeability, as anticipated. We continued to examine procedures for history-matching production data from CO_2-foam oil production. The model mechanisms seen are very sensitive to the reservoir description. We have been examining different methods to develop a reservoir description.

Task 3: The technical paper, "A Simple and Accurate Method for Determining Low IFT from Pendant Drop Measurements,"[2] was prepared for and presented at the 1997 SPE International Symposium on Oilfield Chemistry. The paper described a new method for IFT determination developed on the basis of a force balance on the lower half of the pendant drop. The method developed is especially accurate for low-IFT systems where wettability effects often render classical LaPlace methods inaccurate. The investigation of CO_2 gravity drainage in fractured reservoirs continues. We have an ongoing experiment using whole core and crude oil under reservoir conditions to investigate the effect of water saturation on the efficiency of CO_2 gravity drainage. Before CO_2 injection was initiated, the core was waterflooded to model a secondary waterflood, producing oil in the imbibition mode. After CO_2 injection, oil production was lower while water was being produced concurrently, and then increased after water production ceased. We believe that excessive free water in the core hindered oil recovery during the earlier stage due to competing two-phase relative permeabilities. After 167 days, oil recovery reached 0.24 OOIP in a low-permeability reservoir core.

INTRODUCTION

Because of the importance of CO_2 flooding to future oil recovery potential in New Mexico, west Texas, and the entire United States, the Petroleum Recovery Research Center (PRRC) pursues a vigorous research program. We are investigating new concepts to improve the effectiveness of CO_2 flooding in heterogeneous reservoirs. We conduct research in three closely related areas: 1) application of selective mobility reduction (SMR) in foam flooding, 2) increased economic viability of floods at reduced CO_2 injection pressures, and 3) understanding the mechanisms that occur when CO_2 flooding in tight, vertically fractured reservoirs is considered. All of these areas have the potential to increase oil production and reduce production costs in fields presently under CO_2 flooding. Also, the results of this research should expand the list of viable candidates for future CO_2 flooding to include low-pressure reservoirs and many more heterogeneous or fractured reservoirs.

SUMMARY OF TECHNICAL PROGRESS

In this quarter, two technical papers were presented at the 1997 SPE International Symposium on Oilfield Chemistry. One paper, "Assessment of Foam Properties and Effectiveness in Mobility Reduction for CO_2 Foam Floods,"[1] covered five surfactants tested earlier for their foam properties and SMR potential. The second paper, "A Simple and Accurate Method for Determining Low IFT from Pendant Drop Measurements,"[2] described a new method for IFT determination, developed on the basis of a force balance on the lower half of the pendant drop.

Task 1

We are continuing our efforts to evaluate surfactants and their foam properties under high pressure conditions by using a foam durability apparatus. The properties determined from these tests include the interfacial tension of surfactant solutions with dense CO_2, critical micelle concentration of each surfactant, foaming ability of each surfactant, and foam stability. Two surfactants, Witcolate™ 1259 and Witcolate™ 1276 were tested in this quarter and the new data were entered into our existing database for correlation between foam properties in the bulk phase and in porous media.

The new data correlate well with the existing correlation we established using five different types of surfactants, as reported in our last quarterly report.[3] We found that the effectiveness of mobility reduction of foam in porous media was well-correlated with the stability of foam in the bulk phase. The interfacial tension reduction factor (IFTRF), defined as a ratio of the interfacial tension between CO_2 and brine to the interfacial tension between CO_2 and surfactant solution, was another important factor in the correlation. An increase of IFTRF leads to an increase of the mobility reduction factor and more favorable selective mobility reduction in foam displacement in a composite core consisting of differing permeabilities.

Task 2

A significant deterrent to determining foam coreflood test parameters was the changing permeability of the core during a series of foam tests, which occurs in many cores because of the hundreds of pore volumes of fluid that pass through the core during a series of tests. During this quarter a new type of core was developed that should eliminate this problem and help determine base lines for the different tests. This core was made by fusing glass beads. Fine beads were used, allowing permeabilities well below 100 md, which is in the range of many reservoir cores. The new core has maintained constant permeability under various foam test conditions. Currently, a new series of foam coreflood tests is being performed for various CO_2 fractions at 4.2 cc/hr. These follow tests with other rates, single phase CO_2 and brine injection, and co-injection of CO_2 and brine injections (WAG).

We continued to examine procedures for history-matching production data from CO_2-foam oil production. The model mechanisms seen were very sensitive to the reservoir description. We examined different methods to develop a reservoir description. We began to use the East Vacuum field CO_2-foam pilot test to calibrate our foam model and develop methodology in reservoir description.

Task 3

We continued to progress in the experimental investigation of CO_2 gravity drainage in fractured reservoirs. We conducted an experiment using whole core and crude oil under reservoir conditions. The effect of water saturation on the efficiency of CO_2 gravity drainage was investigated. The reservoir core had 11% porosity and 0.38 md water permeability. The core was first saturated with water. Oil was then injected into the core for establishing an initial water saturation of 30%. After establishment of initial water and oil saturations, water was injected into the core again to reduce oil saturation in the core. The purpose of the second water injection was to simulate waterflooding in a field reservoir. Water injection was terminated when a water saturation of 45% was achieved in the core. The core was then placed vertically in a drainage cell and CO_2 was introduced into the drainage cell at a pressure near the MMP. Oil recovered during gravity drainage was collected through a condenser to minimize vaporization.

Figure 1 presents the results of oil recovery and back-calculated water saturation in the core versus time. During the early stage of the experiment, both water and oil were produced from the core. Water production ceased on day 55 of the drainage test when 6% of the water in place had been produced. The oil recovery rate increased after water production stopped. We believe that free water in the core hindered oil recovery during the earlier stage due to competing two-phase relative permeabilities (including CO_2, there may be three flowing phases in the core). After 167 days, the oil recovery is 0.24 OOIP. We will continue such experiments in the future.

REFERENCES

1. Tsau, J.-S. and Grigg, R.B.: "Assessment of Foam Properties and Effectiveness in Mobility Reduction for CO_2-Foam Floods," paper SPE 37221 presented at the 1997 SPE International Symposium on Oilfield Chemistry, Houston, 18–21 Feb.
2. Guo, B. and Schechter, D.S.: "A Simple and Accurate Method for Determining Low IFT from Pendant Drop Measurements," paper SPE 37216 presented at the 1997 SPE International Symposium on Oilfield Chemistry, Houston, 18–21 Feb.
3. Grigg, R.B. and Schechter, D.S.: "Improved Efficiency of Miscible CO_2 Floods and Enhanced Prospects for CO_2 Flooding Heterogeneous Reservoirs," Quarterly Technical Progress Report, DOE Contract No. DE-FG22-94BC14977, October 1, 1996 through December 31, 1996.

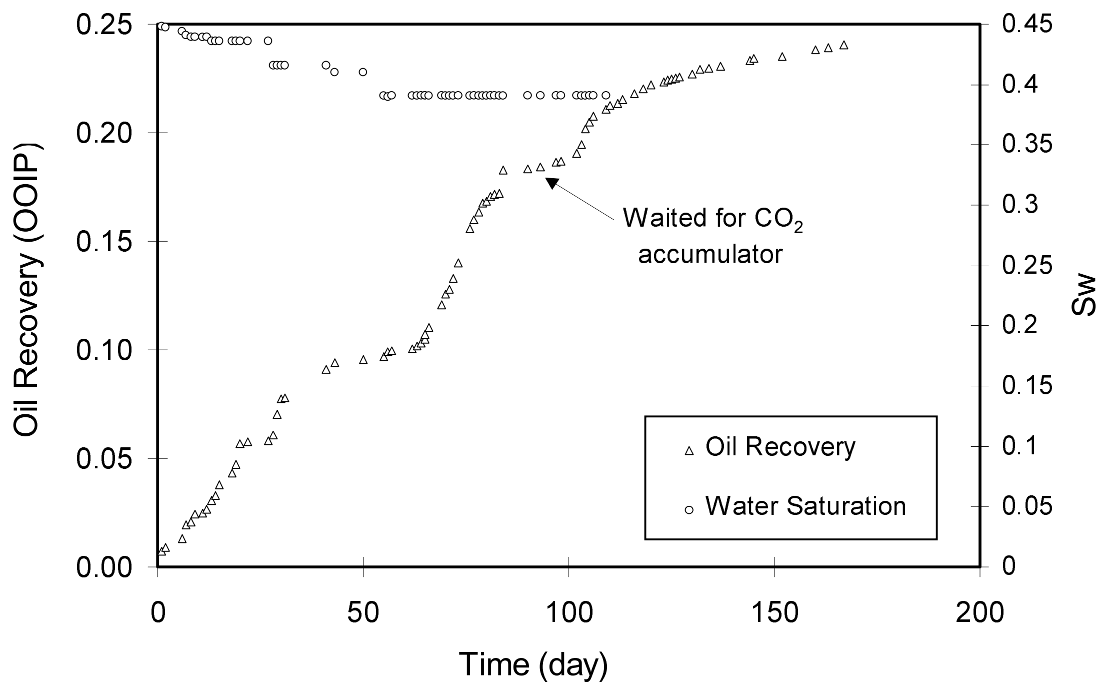

Fig. 1. Oil recovery and water saturation in the core during a CO_2 gravity drainage experiment in a low-permeability reservoir core at reservoir conditions.