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ADVANCED RESERVOIR CHARACTERIZATION AND EVALUATION OF CO_2 GRAVITY DRAINAGE IN THE NATURALLY FRACTURED SPRABERRY TREND AREA

Quarterly Technical Progress Report
July 1, 1998-September 30, 1998

By
Paul McDonald
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Report Issue Date: October 5, 1998

Performed Under Contract No. DE-FC22-95BC14942

New Mexico Petroleum Recovery Research Center
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Introduction

The overall goal of this project is to assess the economic feasibility of CO_2 flooding the naturally fractured Spraberry Trend Area in West Texas. This objective is being accomplished by conducting research in four areas: 1) extensive characterization of the reservoirs, 2) experimental studies of crude oil/brine/rock (COBR) interaction in the reservoirs, 3) analytical and numerical simulation of Spraberry reservoirs, and, 4) experimental investigations on CO_2 gravity drainage in Spraberry whole cores. Additionally, a ten (10) acre field demonstration pilot project is part of this project. This report discusses the activity, during the third calender quarter (July through September) of 1998 (fourth quarter of the projects fiscal year).

During the third calender quarter of 1998, an additional laboratory CO_2 gravity drainage experiment was completed and another started. A static imbibition study is discussed in this report. These experiments and simulations have extended and continue to extend the understanding of why the improved oil recovery mechanism of waterflood/imbibition alone is severely limited for the slightly waterwet, naturally fractured Spraberry reservoir. CO_2 gravity drainage is delineated as a beneficial enhanced oil recovery technique in this type of reservoir. In addition, field activity to implement the pilot portion of this project is discussed.

Discussion of Activity During the Quarter

A Gravity Drainage Experiment in Long, Whole/diameter Core

A laboratory CO_2 gravity drainage experiment using a long whole diameter Spraberry core under reservoir conditions was completed in August 1998. This is part of a series of laboratory experiments on gravity drainage. The core was a "stacked core" and was initially saturated with synthetic Spraberry brine. Dead Spraberry oil was then injected to attain a residual brine saturation. The core was not waterflooded prior to CO_2 gravity drainage. Note that the CO_2 was injected around the core at reservoir pressure and allowed to transfer from the matrix to the fracture as it would occur in the natural fracture system. The annulus of the core and core holder and the horizontal interface between the two stacked cores emulate a fracture system.

This particular gravity drainage experiment was conducted for 331 days, from September 17, 1997 to August 14, 1998. The temperature was maintained at reservoir temperature of 138 F but varied slightly from 135 to 140 F (57.2 to 60 C). The pressure was maintained with 1800 psig backpressure on the core. Periodically, oil and brine were removed from the bottom of the core holder and measured. During the periodic collection of the produced fluid, small amounts of CO_2 and gas were unavoidably expelled. Thus, to maintain the pressure and process, fresh CO_2 was injected into the system.

The oil recovery was 18.33% of (OOIP). The residual oil saturation and brine saturation at the conclusion of the experiment were 0.5093 and 0.3036, respectively. Molecular weight of the produced oil increased during the experiment. At the start of the experiment the molecular weight of the produced oil was less than that of the average dead Spraberry oil initially injected into the system. This indicates a dynamic miscible process.

Summary of Gravity Drainage Experiments

Six experiments on CO_2 gravity drainage were conducted using Berea and Spraberry reservoir cores. Three gravity drainage experiments were completed in the first year of the project, two the second year, and one the third (see Schechter, 1996 and Schechter, 1998). The details of these experiments have been discussed in previous publications. Imbibition experiments and modeling on core plugs have also been conducted (Schechter, June 10, 1998).

Future Work and Expansion of Gravity Drainage Experiments

During this quarter (August 1998), a procedure to investigate oil recovery by water imbibition followed by CO_2 gravity drainage was developed and initiated. The experiment will model the actual field experience of first waterflooding and then recovery by CO_2 in a naturally fractured reservoir. Expected time to accomplish this is a minimum of six months to a maximum of one year.

Imbibition Modeling of Artificially Fractured Core

In this portion of the report, a study of imbibition in naturally fractured reservoirs is presented. The study had three components:

1. A literature review revealing that several laboratory and numerical studies have been conducted regarding this subject
2. Experiments in which artificially fractured Berea and Spraberry cores were injected with Spraberry oil and synthetic Spraberry brine.
3. A numerical model developed with the commercial simulator ECLIPSE^{TM} used to replicate the experimental data.

Background

In naturally fractured reservoirs, fluid displacement in the fracture network occurs due to its higher conductivity compared to the matrix. A countercurrent exchange of fluids occurs between the matrix and fracture system. The countercurrent fluid transfer process (i.e., water imbibition) is controlled by viscous force and capillary action.

In 1952, Brownscombe and Dyes introduced the concept of a process for imbibition flooding. The process was visualized as a single fracture in which water is injected at one end and production occurs at the other end. As the injected water flows toward the producing end, it is imbibed into the matrix and releases oil, which takes the water's place in the flow stream. If the rate of natural or spontaneous imbibition into the matrix is greater than the injection rate, all of the water will imbibe into the matrix and only oil will reach the producing end of the fractures. The water-oil ratio is a function of both of the injection rate and the imbibition rate and any water injected above the rate of natural imbibition will only increase the produced water-oil ratio.

Experimental

In order to understand the imbibition process in a fractured core, a coreflood experiment at a low rate of injection was performed under reservoir temperature. A low permeability Berea core sample was cut into a cylinder, 3 in. long and 1.5 in. in diameter. The fracture pattern on the core sample was generated along the long axis using a hydraulic cutter, as shown in Fig. 8. The core halves were put back together without polishing the cut surfaces and without spacers. Synthetic Spraberry brine and Spraberry crude oil was used as wetting and nonwetting phases. The properties of rock and fluids used in this experiment are shown in Table 1.

After initially saturating the Berea core with Spraberry oil water imbibition process commenced by injecting synthetic Spraberry brine. The experimental procedure is:

1. The dimensions and weight of the core sample were measured.
2. The core sample was inserted into a Hassler-type core holder using a confining pressure of 500 psi to saturate the core with oil. About 2-5 pore volumes (PV) of Spraberry crude oil were passed through the core sample using a constant pressure of 30 psi supplied by a nitrogen tank.
3. The volume of oil effluent was measured to determine the oil rate. The absolute matrix permeability to oil was calculated using Darcy's law.
4. The oil-saturated core was taken from the core holder and covered with aluminum foil to prevent air penetration into the core sample.
5. The core was cut in half using a hydraulic cutter to generate a fracture horizontally along the axis of the core.
6. The oil-saturated, artificially fractured core was then weighed to determine core pore volume and porosity.
7. The core was inserted back into the Hassler-type core holder.
8. The effective permeability of the fractured core was determined by injecting oil into the fractured core.
9. The oil-saturated, artificially fractured core was again taken from the core holder to clean the spill oil from the core surface.
10. The core was inserted back into the core holder to start the experiment.
11. The face of the matrix was sealed off by wrapping plastic and aluminum foil around the injection end, in order to allow brine to flow only through the fracture.
12. This entire system was placed in an insulated box with constant air temperature of 138°F.
13. Spraberry brine was injected into the fracture at a constant brine rate of 4.0 cm^3/h.
14. The oil and brine produced were collected at the other end of the fractured core section for about 48 hours, at which time oil production ceased. The results are presented in Figs. 1 - 6.

Numerical Model

In numerical modeling of the imbibition flooding process, the matrix capillary pressure controlling the imbibition mechanism is the primary parameter adjusted to match the experimental data. For this study the fracture capillary pressure is set to zero. The water production rate, cumulative water production, oil production rate, cumulative oil production, oil recovery and the watercut are parameters used to match between observed experimental data and the numerical model. Once numerical analysis results satisfactorily match the experimental data, then the value of the matrix capillary pressure input into the numerical model is defined to be correct. The matrix capillary pressure will also indicate the wettability of the Berea core used in this study.

The matrix capillary pressure determined by matching the numerical and experimental data is shown in Fig. 7. This matrix capillary pressure indicates that the wettability of the matrix is strongly water-wet. From spontaneous imbibition test, an Amott number of 0.88 was determined, which confirms the Berea core as waterwet.

Results and Discussions

In the experimental process, all the oil was stored only in the matrix. The fracture was assumed to store no oil. Once brine injection was started at a constant rate of 4.0 cm^3/h, oil was produced simultaneously. However, at the beginning of injection, the water was not produced. This indicated that water was imbibing into the rock and oil was expelled from the matrix to the fracture. Also inferred is that the injection rate in the Berea porous medium is lower than the spontaneous imbibition rate. After two hours of brine injection, the spontaneous imbibition rate declined as the matrix capillary pressure was reached. Consequently, water started to be produced. Water in conjunction with oil was produced until 100% water-cut.

There are two mechanisms involved during the production of oil; spontaneous imbibition and fracture displacement mechanisms. During spontaneous imbibition, oil is expelled from the matrix to the fracture by countercurrent imbibition and is then displaced by the brine along the fracture to the production point. The displacement process is a function of brine injection rate while the rate of oil production is dependent on the imbibition rate.

Conclusions

1. Experimental imbibition flooding was performed on artificially fractured Berea core, Spraberry crude oil and synthetic Spraberry brine under reservoir temperature of 138°F and confining pressure of 500 psia.
2. Laboratory results indicate that the imbibition mechanism was observed during the brine injection process at a constant rate of 4.0 cm^3/h.
3. The numerical simulation results are being completed to match the experimental data.
4. Matrix capillary pressure was obtained from the numerical simulation after final matches were achieved.
5. The matrix capillary pressure indicates that the wettability of Berea core used in this study is strongly water-wet.

Future Activity

Ongoing and immediate future activity will consist of simulating the imbibition process in a Spraberry core.

Field Work

A major milestone of this project is to implement a field demonstration of the technology researched in the laboratory. A ten Acre pilot project is being designed and implemented in the Pioneer Natural Resources' E.T. O'Daniel Unit. There will be six water injection wells surrounding four CO_2 injection wells with three producers in a line drive configuration northeast-southwest. Seven producing wells will ring the pilot (see Fig. 9). The location of the CO_2 pilot has been shifted approximately ¼ mile north of the location identified in the original submittal. The attached plat shows the modified configuration and location of each well in the pilot.

Budget Period #2 of this project comprises of the following two tasks: Task #1 – Field Demonstration, and Task #2 – Associated Technology Transfer. The Field Demonstration task began in January 1998 and includes modifying the configuration of the CO_2 pilot; the drilling, logging and completion of the pilot producers, water injectors, CO_2 injectors and logging observation wells; and the construction of the water and CO_2 injection facilities.

Drilling

The proposed design of the pilot requires drilling a total of 16 wells:

- Six water injection wells, #25, #37, #45, #46, #47 and #48;
- Four CO_2 injection wells, #41, #42, #43 and #44;
- Three producers, #38, #39 and #40;
- Two logging observation wells.

As of September 28, 1998, two water injectors, wells #47 and #48, and all three producers have been drilled, and logged. The Upper Spraberry intervals 1U and 5U have been cored in all five of these wells and reservoir data is presently being accumulated. The dual lateral horizontal core well has been completed and the core analyzed with the analysis aiding in characterizing the Spraberry Reservoir.

Flood Facilities

The waterflood and CO_2 injection facilities are new facilities to be built for the 10 Acre demonstration pilot. Due to the position, accessibility and size of the location surrounding well #37, this site has been chosen for the water and CO_2 injection facilities. The design of the injection facility has been completed.

Future Plans

Wells #45 and #46 will be drilled and wells #25 and #37 will be converted from producers to water injectors in the fourth calendar quarter of 1998. This will complete the 1998 drilling schedule. The CO_2 injection wells and the logging observation wells will be drilled in 1999. Water injection to the pilot wells is anticipated to begin before year-end 1998.

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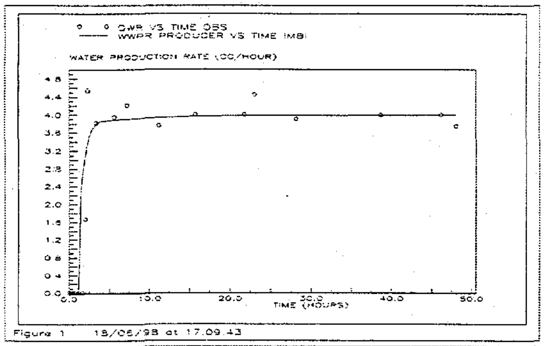
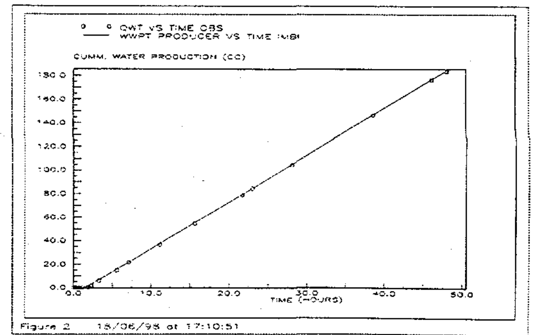
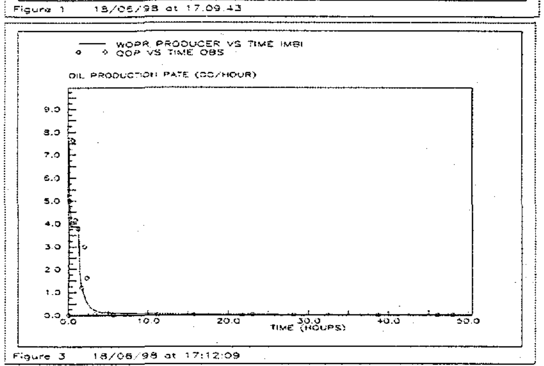
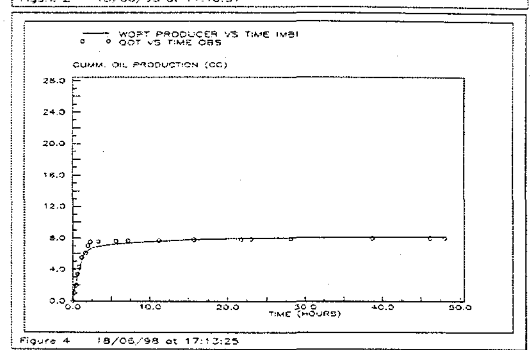
Table 1 Core and Fluid Properties for Imbibition Study of Artificially Fractured Berea Core

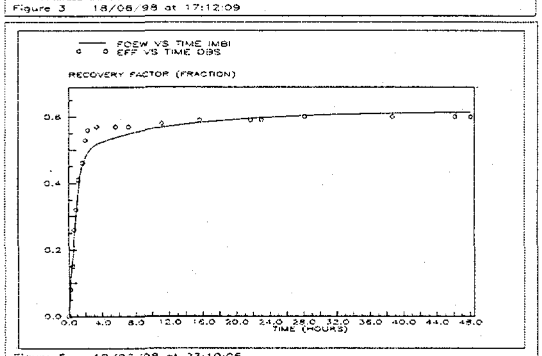
CORE PROPERTIES		FLUID PROPERTIES	
Diameter (cm)	3.786	Oil	Spraberry oil
Length (cm)	6.8936	water	Spraberry brine (synthetic)
k_m (md)	28.09	μ_o	3.52
ϕ_m (%)	17.16	μ_w	0.68
k_f (md)	3429	S_{wi}	0
φ_f (%)	1.0	S_{or}	40
w_f (cm)	0.0076	V_o (cm^3)	13.3172

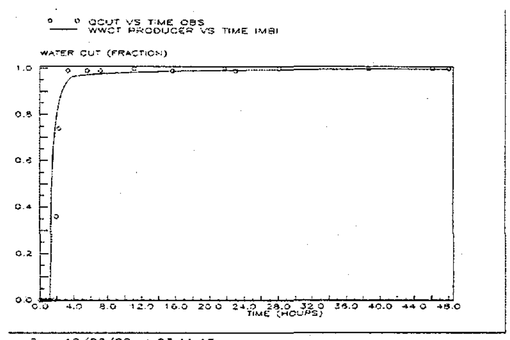












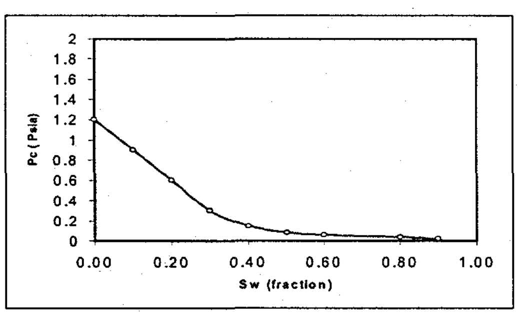


Fig. 7. Capillary Pressure Curve for artificially fractured Berea Core and Spraberry Oil and Brine imbibition

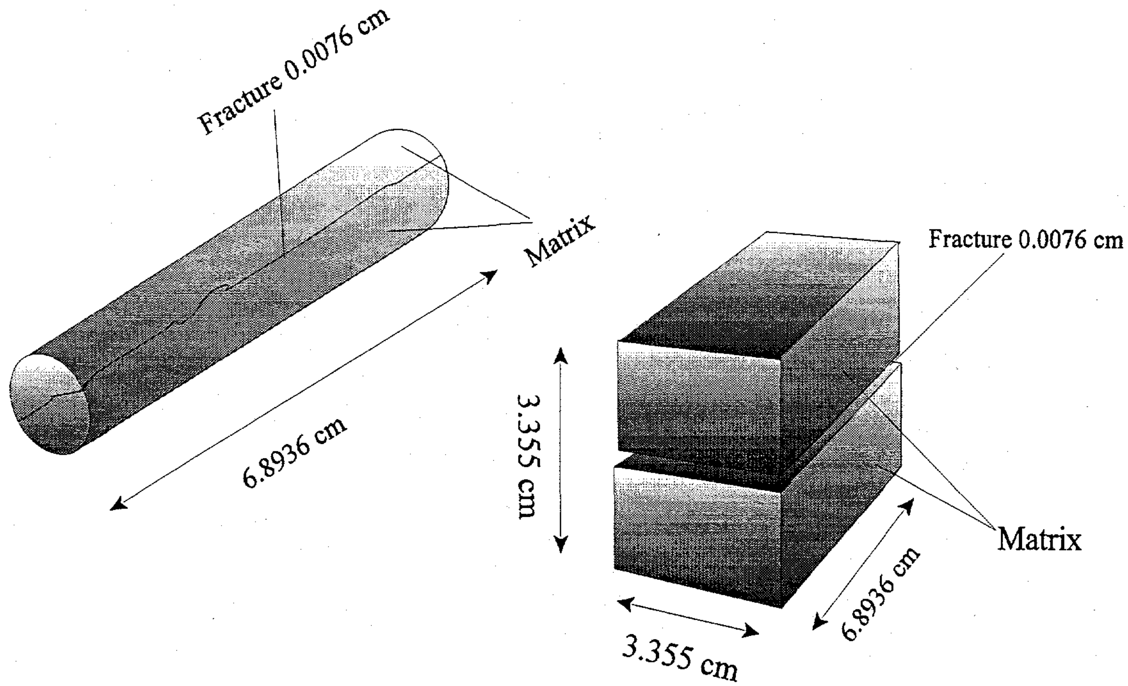


Fig. 8. Grid block modeling to represent the core. Note that the cross-section area of cube is the same for modeling purposes as the cross-sectional area of the core (i.e. 11.257 cm^2).

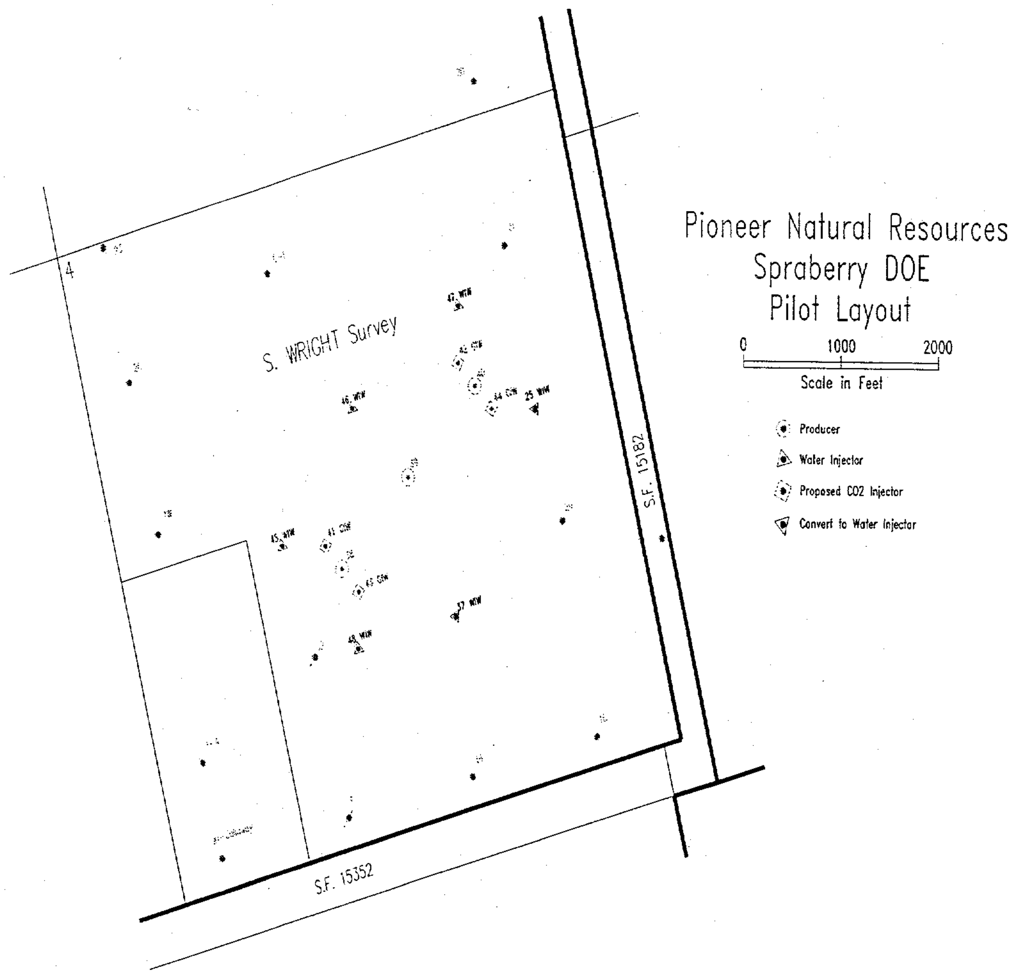


Fig. 9: Plat of Spraberry CO_2 Pilot.