DOE/BC/14937--2

TITLE: REACTIVATION OF AN IDLE LEASE TO INCREASE HEAVY OIL RECOVERY THROUGH APPLICATION OF CONVENTIONAL STEAM DRIVE TECHNOLOGY IN A LOW DIP SLOPE AND BASIN RESERVOIR IN THE MIDWAY-SUNSET FIELD, SAN JAOQUIN BASIN, CALIFORNIA

Cooperative Agreement No.: DE-FC22-95BC14937

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Date of Report: January 19, 1996

Award Date: June 14, 1995

Anticipated Completion Date: March 13, 2000

Government Award for Current Budget Period: \$ 637,891.00

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Reporting Period: June 14, 1995-September 30, 1995

Objective

This project will reactivate ARCO's idle Pru Fee lease in the Midway-Sunset field, California and conduct a continuous steamflood enhanced oil recovery demonstration aided by an integration of modern reservoir characterization and simulation methods. Cyclic steaming will be used to reestablish baseline production within the reservoir characterization phase of the project. During the demonstration phase, a continuous steamflood enhanced oil recover will be initiated to test the incremental value of this method as an alternative to cyclic steaming. Other economically marginal Class III reservoirs having similar producibility problems will benefit from insight gained in this project. The objectives of the project are: (1) to return the shut-in portion of the reservoir to commercial production; (2) to accurately describe the reservoir and recovery process; and (3) to convey the details of this activity to the domestic petroleum industry, especially to other producers in California, through an aggressive technology transfer program.

The 40 ac Pru Fee property is located in the super-giant Midway-Sunset field and produces from the late Miocene Monarch Sand, part of the Monterey Formation. The Midway-Sunset Field was drilled prior to 1890. In 1991 cumulative production reached two billion barrels, with remaining reserves estimated to exceed 695 MMBO. In the Pru Fee property, now held by ARCO Western Energy, cyclic steaming was used to produce

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13° API oil. However, the previous operator was unable to develop profitably this marginal portion of the Midway-Sunset field using standard enhanced oil recovery technologies and chose rather to leave nearly 3.0 MMBO of oil in the ground that otherwise might have been produced from the 40 ac property. Only 927 MBO had been produced from the property when it was shut-in in 1987. This is less than 15% of the original oil-in-place, which is insignificant compared to typical heavy oil recoveries in the Midway-Sunset field of 40 to 70%. Target additional recoverable oil reserves from the 40 ac property are 2.9 MMBO. The objective of the demonstration project is to encourage a similar incremental increase in production in all other marginal properties in the Midway-Sunset and adjacent fields in the southern San Joaquin Basin.

The producibility problems thought to be responsible for the low recovery in the Pru Fee property are: (a) the shallow dip of the bedding, (b) complex reservoir structure, (c) thinning pay zone, and (d) the presence of bottom water. The project will use tight integration of reservoir characterization and simulation modeling to overcome these problems. If the demonstration project is successful, this methodology may be applied to other economically marginal reservoirs that have similar producibility problems.

Summary of Technical Progress

Geological and reservoir characterization

The designated project area, the 40 ac Pru Fee property and a corridor 500 ft in width surrounding the property, contains 143 wells of various ages. Slightly more than 100 of the wells have geophysical log suites available. In the first quarter of the project, those log suites not already in the possession of ARCO Western Energy were assembled. Where only paper logs were available, the logs were digitized. During the present quarter, the remaining suites of paper logs available from diverse sources were digitized and added to the project TerraStation database. In addition, during this quarter the core pulled from the new injection well on the site, Pru 101, was analyzed and made available for inspection by the project team. The examination of the core included:

- a. Visual core description of lithology, bedding character and oil staining,
- b. Routine analyses by Core Laboratories of 246 samples of porosity, permeability and fluid saturations,
- c. Thin section analysis of 33 samples, of which 17 were submitted for x-ray diffraction (XRD) analysis,
- d. Sieve and laser particle-size analysis conducted on 10 sand samples of a range of visual textures, and

f. A log analysis model of the Monarch Sandstone using PETCOM software to calculate effective porosity, water saturation, non-reservoir volume and permeability.

The Pru 101 well, located near the center of the Pru Fee property, entered the top of the Monarch Sandstone at a depth of 1100 ft, passed through 268 ft of dominantly medium and coarse-grained, oil-stained sand to penetrate the oil-water contact at 1368 ft depth. The base of the Monarch Sandstone was not reached in the well. About 96% of the core recovered from the Monarch Sandstone is highly porous oil-stained sand. The remaining 4% of the core is non-reservoir diatomaceous mudstone and fine sand. A full description of the core will be given in the next quarterly report.

A provisional stratigraphic framework was established using the core description, lithologic analyses, and geophysical logs from the Pru 101 well. Five potentially correlatable stratigraphic markers were identified with this well. These markers are relatively thin (2-10 ft) intervals of fine sand and diatomaceous mudstone that separate thick (30-46 ft) sandstone units. The sand packets each have distinctly different character defined by the style of bedding and/or relative abundance of matrix-supported pebble and boulder beds. The fragments are dominantly subrounded clasts of granite, gneiss and diatomaceous mudstone.

The five stratigraphic markers, the top of the Monarch Sandstone and the oil-water contact have been correlated in well logs across the study area. Using TerraStation, these "tops" have been mapped in a set of seven structure contour maps that serve as the provisional stratigraphic model for the Monarch reservoir at the demonstration site. This stratigraphic model is now being refined using geostatistical methods.

Reservoir simulation

The stratigraphic reservoir characterization revealed that the reservoir between top of the Monarch to the oil-water contact consisted of six high-permeability oil-bearing zones separated by thin zones of relatively lower permeability. The effect of the thicknesses and permeabilities of the separating surfaces on oil production was examined using a series of thermal simulations. All the simulations were performed using STARS, a thermal reservoir simulator developed by Computer Modeling Group, Calgary, Canada.

The thickness, permeability sensitivity studies were performed using a two-dimensional model that represented the stacked nature of the reservoir. One other objective of these investigations was to study response to three different types of thermal treatments; the conventional cyclic steam process, the conventional steam-flood and a combination of cyclic steam and the steam-flood processes. The combination process was explored since it is a general practice in the field to stimulate oil producers in steam-flood processes.

In the two-dimensional model, there were 15 blocks in the horizontal direction. There were six oil-bearing layers of 50 feet each separated by five lower-permeability layers. The permeability of the oil bearing zones was 3000 mD (based on the average

permeability of the core-plugs from the recently drilled well on PRU). The permeability of the separating surfaces was varied from 10 - 1000 mD and the thickness was varied from 0.5 - 2 ft. Using the thickness-permeability data of the separating surfaces, homogeneous (single-layer) analogs of the multi-layer heterogeneous reservoirs were also constructed. The sensitivity studies were performed using eight wells.

The conventional cyclic steaming process consisted of 20 cycles of half year duration each (for a total project period of 10 years). In each cycle, two weeks of injection was followed by a week of soak period, with a production period of about 20 weeks. All the eight model wells were treated using identical operating parameters. Approximately 5000 barrels of steam (water equivalent) was injected into the bottom third of the formation for each well. In the conventional steam-flood, there were four injectors alternating with four producers. The injection rate in the steam-flood operation was 30 barrels a day per well. The combination cyclic-flood process was essentially the same as the steam-flood except that the producers were steam stimulated after every two years.

The effect of the permeability of the surfaces on the cyclic process is shown in Figure 1. As can be seen from the figure, the production was not very sensitive to the interbedded surface permeability unless the surface permeability was 10 mD. The surface thickness was constant at two feet in these simulations. The effect of surface thickness on cumulative oil production is shown in Figure 2. Surface thickness had even less of an impact on oil production. The surface permeability was constant at 300 mD in these simulations. Results of the multi-layered model with its homogeneous analog are compared in Figure 3. For these well defined multi-layer systems, results from homogeneous analogs are more or less identical to the actual heterogeneous representations.

For identical set of reservoir characteristics, cumulative production from the conventional steam-flood and the combination cyclic-flood was essentially equal (about 47% of the original oil in place for a 3-year project). The cumulative recovery from the conventional cyclic process was about 42% of the oil in place after 10 years of operation. The steam-oil ratios for the cyclic (10-year), the steam-flood (3-year) and the combination processes were 16, 18 and 13 respectively. Thus, from an operational stand-point, the cyclic-flood combination appeared to be the best option. These conclusions will have to be validated using more realistic reservoir representations.

Figure 1 Effect of the permeability of lower-permeability layers on cumulative oil recovery in the conventional cyclic process

Figure 2 Effect of the thickness of the lower-permeability layers on cumulative oil recovery in the conventional cyclic process

Figure 3 Comparison of the cumulative production for the true multi-layer case with its homogeneous analog

Install lease production facilities

Except for two activities postponed for later in 1996, all planned actions related to the installation of production facilities at the Pru Fee demonstration site are complete. The topography has been mapped. All flowlines are now installed. The production header has been rebuilt. The conversion of the existing free water knockout (FWKO) to wet lact and the old wet lact on site to the Pru well tester are finished. Momentarily on hold are installation of CVCS lines and upgrading of the Pru gathering line.

All of the work on the new producer and observation well drilled during the first quarter of the current Budget Period is complete.

Return wells to production

The idle wells on the Pru Fee property have been inspected, repaired and returned to production. The first of two planned baseline steam injection cycles is now complete and the project wells are producing a total of 50-60 BOPD. The database has been created for tracking the well performance during this testing period. The temperature observation wells were logged three times to evaluate the effectiveness of the first cyclic injection. The temperature increase in the reservoir from 104°F to 148°F indicated good penetration of the producing interval.

Technology transfer

A poster presentation summarizing the initial progress made on this project, *Integrated, multidisciplinary reservoir characterization, modeling and engineering leading to enhanced oil recovery from the Midway-Sunset field, California*, was accepted for presentation at the 1996 Annual AAPG meeting in San Diego. The paper is an invited contribution to the session on "*Application of New Technologies to Enhance Oil Recovery*".

Project Management

The first quarterly project review meeting was held in Bakersfield, California on 24-26 October for the purpose of reviewing the work done in preparing the Pru Fee demonstration site for the baseline tests, examining the core from the new injector well Pru #101, and viewing a stratigraphic section in the Williams Sandstone, which is analogous to the target reservoir in the Monarch Sandstone. The outcrops examined are at Crocker Canyon in the Tremlor Range west of the Midway-Sunset field. The lithology and bedding characteristics of the Williams Sandstone at Crocker Canyon are virtually identical to those of the Monarch Sandstone in the Pru #101 core.

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