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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

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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 13° API oil. However, the previous operator was unable to develop profitably this

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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 initially 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 is using tight integration of reservoir characterization and simulation modeling to evaluate the magnitude of and alternative solutions to these problems. If the demonstration project is successful, the methodology developed may be applied to other economically marginal reservoirs that have similar producibility problems to those encountered at the Pru Fee property.

Summary of Technical Progress

Two main activities were brought to completion during the first quarter of 1996: 1) lithologic and petrophysical description of the core taken from the new well Pru 101 near the center of the demonstration site (Fig. 1) and 2) development of a stratigraphic model for the Pru Fee project area. In addition, the first phase of baseline cyclic steaming of the Pru Fee demonstration site was continued with production tests and formation temperature monitoring.

Pru Project Area

Midway-Sunset Field
Kern County, CA

Figure 1: Location map for project area and wells

Lithologic and petrographic description of Pru 101 core

A new well was drilled, cored and logged in October 1995. That same month the core was described and samples collected for analysis. The report on the core was completed in January 1996 by C.D. Jenkins, C.L. Vavra and R. Wydrinski of ARCO Exploration and Production Technology (Plano, Texas). In addition to visual core description, the analysis included petrophysical properties, textural analysis of the sand, XRD and thin-section descriptions. Petrophysical analysis of the reservoir included refinement of a Monarch Sand log model for calculation of porosity, permeability and saturations using an AIT/LDT/CNL/GR tool suite or any other Monarch well with a resistivity, density and neutron log. The report addressed questions of reservoir architecture and performance through projections of sand and barrier continuity and overall reservoir quality.

A total of 225 ft. of core was recovered from the Pru 101 well representing an approximately 85% recovery from the interval cored. A full 96% of the core recovered from the Monarch Sand consists of oil-stained sand divisible into four lithofacies: 27% medium-grained sand, 43% coarse-grained sand, 16% granule sand and 10% pebble sand. The remaining 4% of the core is comprised of non-reservoir mudstone and muddy to bioturbated fine sand. The only interval in the Monarch that may be a laterally continuous steam barrier is from 1208-1218 ft. depth. As interpreted from the log response, this interval is likely composed of interbedded muddy fine sand and medium-grained oil sand, although no core was recovered through it.

The cored interval through the Monarch Sand consists of major fining-upward sequences. A typical sequence begins with a pebble or granule sand that progresses upward through coarse grained sand, medium sand, and perhaps interbedded bioturbated or muddy sand before passing abruptly into another pebble or granule sand that begins the next sequence. Overall, however, the full section from the oil-water contact to the top of the Monarch (1106.4 to 1368.6 ft.) coarsens upward, which is consistent with a prograding shoreline and progressive filling of the basin. The proposed depositional model is a steep-faced fan-delta prograding onto a shallow marine shelf. Periodic remobilization of fan-delta deposits as debris flows generate slumps and turbidity currents that deposit the Monarch Sand. The muddy fine sands capping many of the turbidites are deposited from suspension as the flow wanes. The absence of any true marine clays indicates short periods between successive debris flows and turbidites.

The Monarch Sand in the Pru 101 core is dominantly thin-bedded. The lower part of the core, above the oil-water contact, consists of stacked, thin-bedded, highly graded (fining up) coarse to medium sand. Overlying the thin-bedded units, is a zone of pebble sand beds that contain matrix-supported cobbles. The upper part of the core consists dominantly of highly graded (fining up) coarse sand. Although sand beds are generally thin (1-2 ft.) throughout the core, they appear to be thickening upward.

Routine petrophysical analysis was conducted by CoreLab on 246 samples using a confining pressure of 500 psi. The vertical variations in measured porosity, permeability, and oil saturation (S_o) are shown in Figures 2 through 4. Medium-grained sands have the highest porosity (33.6%) due to the absence of pebbles. With the progressive inclusion of more pebbles, porosity decreases to 31.1% in coarse sands, 30.0% in granule sands, and 28.5% in pebble sands. Granule and coarse-grained sands have the highest geometric mean permeabilities (about 2700 md). Medium-grained sands are better sorted, but they have a lower mean permeability (1847 md). Pebble sands also have a lower mean permeability (2082 md) due to the poorer sorting. Two-thirds of the mudstones and one-third of the bioturbated to muddy sands have permeabilities in the range 18-27 md, which are at least two orders-of-magnitude lower than productive sands. This should be sufficient to make these fine-grained, clay-rich rocks barriers to vertical steam migration if they are sufficiently thick and laterally continuous.

Figure 2: Measured porosity and permeability in Pru 101 core

Figure 3: Measured oil saturation and permeability in Pru 101 core

Sw and So measurements from the core are of limited reliability due to the drainage of fluids from the samples, possible invasion during coring, and transition zone penetration. Nevertheless, the water saturation (Sw) minimums are instructive - 16% in coarse and granule sand, 18% in medium sand and 20% in pebble sand. These values follow the same trend as permeability distribution and provide a measure of Swirr. Similarly, the So minimums of about 13% provide a measure of the Sor to steamflooding.

Figure 4: Permeability and lithotype observed in Pru 101 core

A log analysis model for the Monarch Sand on the Pru Fee property was developed to calculate effective porosity, permeability, water saturation, non-reservoir volume and pebble volume from any well with a minimum log suite of resistivity, density and neutron curves. Although the model was calibrated to the core analyses from the Pru 101 well, it was applied to the nearby Pru 533 well (Fig. 1) for additional verification. Visual inspection of the log curves from Pru 101 and Pru 533 indicates that resistivities less than about 13 ohm-meters are non-reservoir. These intervals contain both silty sands and higher quality wet sands.

Stratigraphic model

The Midway-Sunset field produces from multiple reservoirs that range in age from Oligocene to Pleistocene; most of the oil is produced from the Upper Miocene reservoirs (Hall and Link, 1990). The reservoir at the ARCO Western Energy Pru Fee property is the Upper Miocene Monarch Sand.

The stratigraphic nomenclature applied to this part of the Midway-Sunset field is a combination of formal units, which are recognized at the surface and in the subsurface, and informal units, which are identified mostly in the subsurface. The stratigraphic

nomenclature of Callaway (1962) and Foss and Blaisdell (1968) has been adopted in this project as it is the nomenclature in most common use in the field. The Monarch Sand is an informal unit within the Antelope Shale member of the Monterey Shale (Fig 5). It typically overlies the informal Republic, Williams, and Leutholtz sands (in descending order). The Monarch Sand normally is overlain by the upper part of the Antelope Shale and the Reef Ridge Shale. However, at the location the Pru Fee property on the SW flank of the Spellacy anticline a regional unconformity removes the Reef Ridge Shale and the top of the Antelope Shale placing the Pliocene Etchegoin Formation directly on the Monarch Sand. Although no well has penetrated below the Monarch Sand at the project area, there is reason to believe that the underlying stratigraphic section is similar to that of nearby areas.

		Pru Project Area ¹		Ryder and Thomson, 1989 ²				
Pliocene	Lower	Etchegoin Formation		Etchegoin Formation				
	Upper	Monterey Shale	Antelope Shale	Monarch sand	Santa Margarita Formation	Member C Member B		
							Republic sand Williams sand Leutholtz sand	Monterey Shale
			McDonald Shale					
			Devilwater Shale					
			Gould Shale		Gould Shale Member			
			Lower					
		Temblor Formation		Temblor Formation				
Oligocene	Upper							

¹ The Monarch sand is the oldest formation penetrated in the Pru project area

² Modified for the Pru project area

Figure 5: Stratigraphic nomenclature for Midway-Sunset field

The stratigraphic model for the Monarch Sand reservoir in the project area was developed using geophysical logs, core descriptions, outcrop observations of comparable units, and petrophysical data from core plugs. There are 143 wells in the project area, of which 33 are within the Pru Fee property (Fig. 1). About 80% of the log suites were suitable for identifying and correlating stratigraphic units within the Monarch Sand. However, there were only three cores available in this phase of the project, ARCO wells Pru 101, Pru 533, and Kendon 405 located immediately west of the Pru property. All three cores have quality lithologic descriptions and petrophysical data.

Idealized Unit Geometry

Figure 6: Generalized stratigraphy of the Monarch Sand reservoir

Stratigraphic divisions recognized in the Pru 101 and Pru 533 cores and reflected in log response, particularly in conductivity, deep resistivity, and gamma ray logs, were correlated throughout the project area. Five surfaces could be correlated with a reasonable degree of confidence between most of the wells (Fig. 6). At least two of the surfaces (1 and 3) appear to correspond to laterally continuous or semi-continuous non-reservoir units that might serve as a barrier or baffle to steam injection. The procedure for selecting and correlating stratigraphic units is diagrammed in Figure 7.

Approach to Defining the Internal Stratigraphy

Figure 7: Scheme for development of stratigraphic model

Surfaces 1, 2, and 3 were recognized in all wells; however, surfaces 4 and 5 were not. The lithologic assemblage, grain size, bed thickness, and other sedimentologic features of the stratigraphic unit between surfaces 4 and 5 in the Pru 101 well suggests it was deposited as a debris flow or series of debris flows. An irregular zone of debris flows (marked by top of the highest and base of the lowest debris flow) occupy the middle to lower part of the interval between surface 3 and the oil-water contact. Although a concentration of debris flows are found in this zone, individual debris flows are located elsewhere in the core.

Thickness of the Monarch Sand gross pay (top of Monarch to the oil/water contact) decreases southeastward across the project area from about 440 feet in the northwest to less than 100 feet in the southeast (Fig. 8). This trend also is reflected in the thickness patterns of the individual stratigraphic units. A dip cross section (B-B') shows that most stratigraphic units thin to the southeast (Fig. 9). However, a strike (southwest to northeast) cross section shows limited variations in unit thickness (Fig. 10). Local thinning of some flow units in the northern part of the project area may reflect paleotopography. The unusual contour pattern in the southeastern part of the gross pay contour map (Fig. 8) reflects limited well control in this area.

Figure 8: Contour map of gross pay of Monarch Sand at Pru project area

Figure 9: Dip section through Pru project area; refer to Figure 8.

Figure 10: Strike section through Pru project area; refer to Figure 8.

The Monarch Sand within the project area, which is on the SW flank of the Spellacy anticline, is gently folded by a low-amplitude syncline that plunges southeastward. The top of the Monarch is about 440 feet above sea level in the northwestern part of the project area and about 100 feet above sea level in the southeastern part.

Activities at the Pru Fee Demonstration Site

During the early part of this quarter all major work at the Pru Fee site was successfully implemented, except for the CVCS installation and gathering line upgrade. These two actions were deferred pending evaluation of need.

The first phase of baseline cyclic steaming, begun in the last quarter of 1995, was continued during this quarter. During the first round, 70,000 barrels of steam was injected into 9 wells near the center of the Pru Fee property. Production peaked at about 90 bbls/day shortly after the close of the first round, but within a period of weeks had dropped back to about 70 bbls/day. Production was dominantly from the new Pru 101 well. The lower than expected flow rates from the refurbished older wells is attributed to completion problems that will be investigated in subsequent steam cycles. Two of the older wells came back cold immediately after steaming indicating a problem with either steam allocation among the several wells in the text or loss of steam to upper stratigraphic intervals.

The initial steam cycle demonstrated the need to better monitor both the flow of steam to individual wells and the penetration of steam into the reservoir at each well. The second round of steaming was begun under closer monitoring. This has involved injecting one well at a time and surveying the formation intervals penetrated using radioactive tracers. The second round of cyclic steaming (part of the first scheduled phase of baseline testing) was in progress as the first quarter of 1996 ended.

The temperature observation (TO) well near the center of the cluster of test wells indicated heating at the top of the Monarch Sandstone at the end of the first round of steaming. Temperature did not increase in other segments of the TO well, probably due to the relatively small volume of steam injected during the first round. The heating observed in the Tulare Formation at about 500 ft. depth may be due to leakage through poor primary cement in one of the older wells cycled.

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