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Integrated Approach Towards the Application of Horizontal Wells to Improve Waterflooding Performance

(Contract No. DE-FC22-93BC14951)

Submitted by

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Contract Date : January 1, 1993

Completion Date : December 31, 1996

Reporting Period : July 1 - September 30, 1993

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Objectives

The overall purpose of the proposed project is to improve secondary recovery performance of a marginal oil field through the use of a horizontal injection well. The location and direction of the well will be selected based on the detailed reservoir description using integrated approach. We expect that 2 to 5 % of original oil in place will be recovered using this method. This should extend the life of the reservoir by at least 10 years.

To accomplish the goals of the project, it is divided into two stages. In Stage I, we will select part of the Glenn Pool field (William B. Self Unit), and collect additional reservoir data by conducting cross bore hole tomography surveys and formation microscanner logs through newly drilled well. In addition, we will also utilize analogous outcrop data. By combining the state of the art data with conventional core and log data, we will develop a detailed reservoir description based on integrated approach. After conducting extensive reservoir simulation studies, we will select a location and direction of a horizontal injection well. The well will be drilled based on optimized design, and the field performance will be monitored for at least six months. If the performance is encouraging, we will enter into second budget period of the project.

If continued, the second budget period of the project will involve selection of part of the same reservoir (Berryhill Unit - Tract 7), development of reservoir description using only conventional data, simulation of flow performance using developed reservoir description, selection of a location and direction of a horizontal injection well, and implementation of the well followed by monitoring of reservoir performance.

By comparing the results of two budget periods, we will be able to evaluate the utility of collecting additional data using state-of-the-art technology. In addition, we will also be able to evaluate the application of horizontal wells in improving secondary recovery performance of marginal oil fields.

A successful completion of this project will provide new means of extending the life of marginal oil fields using easily available technology. It will also present a methodology to integrate various qualities and quantities of measured data to develop a detailed reservoir description.

Summary of Technical Progress

The overall report is divided into three sections. In the first section, we discuss the preliminary results based on the cross bore hole seismic surveys. In the second section, we discuss the geological description of the Self Unit. In the last section, we present petrophysical properties description of the reservoir followed by the flow simulation results. Based on a thorough evaluation of the geological and flow simulation results, we will finalize the initial test well location within the next month followed by drilling of the well in early November.

Geophysical Data Collection

A crosswell seismic test was performed in the Self Unit under Upland Resources management (Kiefer, Southeast Creek County) on August 24, 1993. This report focuses on the data acquisition parameters of the test survey. The purpose of the test was to establish the signal quality for various raypath lengths. The information will be used to locate the position of the Vertical Test Well (VTW) relative to the four existing receiver wells. The VTW will be used as the source well. The optimum wavelet quality will be a determining factor in locating the VTW.

TEST DATA ACQUISITION

The crosswell test survey was performed in two cased wells 660 ft apart. The receivers were placed in Well 62 and the source in Well 72. The survey was conducted from a recording truck approximately half-way in between the source-receiver well pair. Source and incoming signals (raw data) were transmitted through wireline cables. The data were loaded on the computer hard disk which then was transferred on to 88 megabyte tapes. The size of the test data is approximately 20-25 megabytes.

The basic receiver for this test was a hydrophone group of 3 receivers inserted in the fluid-filled well. The hydrophone separation was 8 ft. A piezoelectric transducer source was used to generate a sweep signal at a frequency range of 200-2000 Hz with a 0.125 ms time sample interval. A "listen time" of 0.5 s yielded 4000 samples per trace ($0.5 \text{ s} / 0.125 \text{ ms} = 4000 \text{ samples}$).

Figure 1 explains the crosswell test survey acquisition geometry in detail. Acquisition is defined by four coverage zones ("fans"). For fans I through III, the maximum and the minimum depth of source were 1520 and 704 ft, respectively. The source is pulled up at a constant speed activating eight times in a 2 ft interval. The mid-point of every eight source defines an eight-fold vertical stack location. The consecutive vertical stacks are 16 ft apart which yields 52 stacked source locations for each fan, I through III. Fan IV has lower areal coverage compared to the first three. However, 51 stacked source locations exist due to the 4 ft spacing. In the test survey a total of 207 stacked source locations exist, each shooting into 3 receivers. This results in 621 rays. Over 4000 rays from unstacked sources were acquired in approximately five hours.

Figure 2 shows the raw data from the four fans as common receiver (receiver 1) gathers. A first processing attempt on the data is in progress.

Geological Description

Stratigraphic framework of the Glenn Sand reservoir in the Self Unit (160 acres) has been established through a series of northeast to southwest stratigraphic cross sections. Some cross sections extend on southwestward into the adjacent Burrows Unit.

A thin interval (1-2 ft), expressed as high gamma ray and conductivity log response, is used as a marker bed about 12 ft. above the Glenn Sand (figure 3); two thin intervals, expressed as high conductivity log response, are also used as markers in those wells that penetrate up to 50 ft. below the Glenn Sand. In these stratigraphic cross sections, the Glenn Sand has been subdivided into 7 units (A descending through G), each of which is a discrete genetic interval (contiguous facies deposited during a brief, discrete increment of time). The superpositional relationship among discrete genetic intervals is established by the elevation of the top of channel-fill deposits relative to the marker beds.

A combination facies and facies-biased, net-sand isopach maps have been constructed for each of the seven discrete genetic intervals. Units A through E are characterized by channel-fill and splay facies as reservoir rock and floodplain and levee facies as barrier or baffle rock. Within the channel-fill facies, localized isopach closures of the 10-ft isogram typically encompasses 15 acres, and the centers of these closures are separated by 1,000 ft along a channel-fill facies trend. The channel-fill facies sandstone obtains a maximum thickness of about 30 ft. In the A Unit, splay facies reaches a maximum thickness of 15 ft in locations proximal to the channel-fill facies and diminishes to zero feet thick up to 2,200 ft away; in the other units, splay facies is more restricted in thickness and lateral extent. Units F and G include a channel-mouth-bar facies as reservoir rock. The channel-mouth-bar facies acquires a maximum thickness of 40 ft at a channel terminus, and extends laterally beyond the limits of the Shelf Unit.

Work in progress includes mapping the thickness and lateral extent of nonreservoir rock facies. This will determine the potential for vertical isolation or baffling between each discrete genetic interval.

Shallow stratigraphic correlations were completed in the vicinity of the cross well tomography test in order to evaluate possible acoustic reflections observed in the test results. Wells included in the cross section are Self Nos. 72, 62, 55, 66, and 57. Stratigraphic zones identified between top of Glenn Sand (about 1,470 ft drill depth) up to the top of the logged interval (about 500 ft) include, in ascending order: upper Boggy Formation to top of the Inola Lime (at 1,370 ft); Red Fork to top of Pink Lime (at 1,210 ft); Senora Formation, including Skinner Sands to top of Verdigris Lime (at 930 ft); lower Marmaton Formation, including Pure Sands to top of the Big Lime (at 750 ft); and Mowata Shale up to the top of the logged interval. All stratigraphic units are continuous between the test source well (No. 72) and receiver well (No. 62), except the Skinner Sands which clearly terminate between these two wells.

Engineering Description and Simulation

To construct the spatial description of the reservoir properties, a two step procedure is used. In the first step, geological description was created using a geostatistical program SISIMPDF.² This program allows the different geological units to be described by numerical quantities. For example, sand A was described by number 1,

sand B was described by number 2, and so on. After assigning numbers to individual sands, vertical and horizontal variograms were constructed and the sands were simulated at inter well locations. To validate our results, the sands description was compared with the geological maps. Although not identical, the simulated descriptions show resemblance to the geological units. For example, see figure 5 where an areal map at a particular depth is compared with geological map for sand A. In the same figure, an areal map of simulated values for sand C is compared with the geological map of sand C.

Once the simulated sands distribution is constructed, the next step was to assign the petrophysical properties to individual grid blocks. To ensure that we assign the permeability and porosity values consistent with individual sands, we first used all the core information and divided the core data for individual sands based on the sand description at that particular location. As a result, we had limited permeability and porosity data for individual sands. The lower sands had much higher permeability compared to the upper sands. Using this limited data, porosity variograms for individual sands in both vertical and horizontal directions were constructed. For horizontal direction, due to pure nugget effect, we had to make assumptions with respect to ranges of the variograms. With the help of these variograms, using the method of simulated annealing,³ spatial distribution for porosities for all the sands was constructed at every grid point. That is, for eight sands we had eight porosity values at each grid block. We filtered the simulated porosity values through the simulated sand maps to assign a porosity value at an individual grid block. For example, if sand A is present at a particular grid block, we assign the porosity value corresponding to sand A porosity simulation. This way, our porosity distribution was consistent with the observed core values. By using a cross plot between log of permeability and porosity for each sand, permeability values at individual grid block were assigned.

For conducting flow simulation, we also need PVT properties. In the absence of any reliable data, we assumed that the bubble point pressure of the oil was the same as initial reservoir pressure. As to the relative permeability data, we used a single curve published by ARCO for the entire Glenn Pool field. We realize that it does create significant uncertainty in our reservoir description. However, our goal is not necessarily to match the historical performance; instead, to observe how close we come to the historical performance by simply using a forward modeling. Figure 6 shows a comparison between the historical performance and the simulated performance. For early years, the match simulated performance underpredicts the actual performance. Several reasons may explain the discrepancy. First, we do not have yearly production data till year 1935. What we have is one single number in 1945 which indicates cumulative production till that time. How reliable that number is, it is not known. Second, during the early years, all the wells were drilled at the boundary of the Self Unit to protect the drainage of the reserves. As a result, some of the wells may have drained oil from nearby leases. We, however, assumed that the Self Unit is bounded. Overall, considering the uncertainties involved in many of the reservoir parameters, the match is deemed satisfactory.

We will continue to investigate the simulation results more carefully. One goal is to use more grid blocks to investigate the sensitivity of flow performance on smaller scale heterogeneities. Another goal is vary vertical permeability in the simulation. Vertical permeability is one of the unknowns in the simulation results. We would like to investigate the sensitivity of flow performance on this parameter as well. Once these studies are completed, we will investigate the applicability of horizontal injection well in improving the reservoir performance. Such study is still in progress.

References

1. Quarterly Report, Integrated Approach Towards the Application of Horizontal Wells to Improve Waterflooding Performance (Contract No. DE-FC22-93BC14951), January 1 - April 30, 1993.
2. Deutsch, C.V. and Journel, A.G.: GSLIB, Oxford University Press, New York (1992).
3. Perez, G.: Stochastic Conditional Simulation for Description of Reservoir Properties," Ph.D. Dissertation, University of Tulsa, Tulsa, OK (1991).

Crosswell Test Survey Day1 (receiver 1)

Figure 2. Common Receiver Gathers for Fan I, II, III, IV

Wm B Self No. 59

Figure 3. Discrete Genetic Intervals in Glenn Sand

Simulated

Geological

SAND A

Simulated

Geological

SAND C

Figure 4 Simualted Sands and Geological Model

Figure 5 Field Performance and Simulated Performance

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