10/97 7-11-97
Integrated Approach Towards the Application of Horizontal Wells to Improve
Waterflooding Performance

DOE/BC/14951-20
QUARTERLY REPORT

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SEP 25 1997

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Reporting Period: January 1 – March 31, 1997
Work Performed Under Contract No. DE-FC22-93BC14951

Prepared for
U.S. Department of Energy
Assistant Secretary for Fossil Energy

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1. OBJECTIVES

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

The project is divided into two stages. In Stage I of the project, we selected part of the Glenn Pool Field - Self Unit. We conducted cross borehole tomography surveys and formation micro scanner logs through a newly drilled well. By combining the state-of-the-art data with conventional core and log data, we developed a detailed reservoir description based on an integrated approach. After conducting extensive reservoir simulation studies, we evaluated alternate reservoir management strategies to improve the reservoir performance including drilling of a horizontal injection well. We observed that selective completion of many wells followed by an increase in the injection rate was the most feasible option to improve the performance of the Self Unit. This management plan is currently being implemented and the performance is being monitored.

Stage II 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 an appropriate reservoir management plan, and implementation of the plan 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 optimum reservoir management plan in improving secondary recovery performance of marginal oil fields.

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.

2. STAGE I PROJECT MONITORING

During the summer of 1995, we started implementing the reservoir management plan in the Self Unit. Last quarter, after evaluating each individual well, we decided to install electrical submersible pumps to produce three wells. The other three wells required the use of rod pumps. Production from the field improved significantly once the pumps were installed. Over the last twelve months, an average daily production has been approximately 45 bbls/day. Compared to a base line production of 13 bbls/day before the implementation, this is more than a 200% increase in production. Based on our current evaluation of the flow simulation results, we expect that the production from the unit should reach between 80 to 100 bbls/day once the implementation is complete.

Part of the reservoir management plan is to increase the water injection rate. We have installed the injection pump and have started injecting water over the last four months.

3. GEOLOGICAL DESCRIPTION (By Dennis R. Kerr and Liangmiao Ye)

In the first quarter of 1997, geology activities of the Glenn Pool project focused on refinement of Chevron Polymer Flooding acreage study and Tract 9 study, and technology transfer.

3.1 Refinement of Chevron Polymer Flooding Acreage Study

Refinement of ^{the} Chevron Polymer Flooding Acreage study basically refers to the analysis of core data and well logs collected during the trip to Hyperion Oil Company in Dallas conducted last December, 1996.

A question was raised regarding the characters of the oil saturation profiles for the unit right before the polymer flooding project started, in comparison to the current oil saturation profile in our target areas. Oil saturation measurements collected for all 23 cores in the unit were plotted

*inconsistent cooping of Upper & Middle
use upper core in formation name*

verse depth. As an example shown in Figure 1, all these plots illustrate a simple oil saturation profile: the upper and middle Glenn Sand had a evidently higher oil saturation than lower Glenn Sand, which is similar to the current oil saturation profiles observed in the recent TDT logs in Tract 7.

Core data ^{from} of Crow 9-43 in Section 5-17N-12E, about 2 miles north of the polymer flooding acreage, was also analyzed, indicating oil saturation for DGI E can be as high as 85% in contrast to 20-40% for DGI F and G, as shown in Figure 2.

Plots of porosity and permeability measurements verse depth (Figure 3 and 4, as an example) indicate that ^{the} Glenn Sand in this unit is good quality reservoir. Porosity ranges from 15-20% for ~~the~~ Lower Sand and from 17-23% for ^{the} Upper and Middle Glenn Sand; permeability varies from 30 to 500 md for ^{the} Upper and Middle Glenn Sand and 10-70 md for lower sand. Lower porosity and permeability for Lower Glenn Sand is probably due to its poorer grain sorting and higher content of shale rip-up clasts, based on the core observation. Similar trends of variations are observed in Tract 7 and Tract 9 areas.

Through well log correlation, ^{the} relationship between our DGI division and ^{the} previously used "Upper-Middle-Lower" divisions of Glenn Sand is investigated. It is found that the "U-M-L" divisions among different geologists ^{do not match well} are not matching well, as shown in Table 1. ^{on} In average, their Upper Glenn Sand is equivalent to DGI A to D (proposed in this project), and ^{the} Middle Glenn Sand is equivalent to DGI E to F. Moreover, the ^{the} Lower Glenn Sand is always equivalent to DGI G.

3.2 Tract 9 Study

Tract 9 ^{study} in the past quarter mainly focused on shale mapping, that is, describing the separation condition between sandstones of different DGI's. Only 13 logs ^{were} available for geological study in this unit. Thus, the area of "sand-on-sand" contact rather than detailed shale thickness contouring ^{was} is emphasized. The area of "sand-on-sand" is delimited by combined analysis of log response and thickness pattern of overlying channels.

As shown in Figure 5 as an example, four "sand-on-sand" windows between DGI B and C are predicted with confidence. Similar work ^{was} is done for all DGI's and then provided to engineers for reservoir simulation purposes.

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Core Oil Saturation (%) Profile
(Chevron's polymer flooding acreage, NE/4, 17-12N-12E)

Figure 1

Permeability, Porosity, and Oil Saturation Profile, Crow 9-43

Figure 2

Porosity Profile, Well 74, Chevron Polymer Flooding Area

Permeability Profile, Well 74, Chevron Polymer Flooding Area

Figure 4

Table 1 Relationship Between "U-M-L" Division and DGI Division

Well Name

	Tract	U-M-L	DGI	Remarks
7-113	Tract 7	Upper (1398-1461)	A-D	Kuykendal and Matson
		Middle(1463-1522)	E-F	
		Lower (1522-1572)	G	
9-60	Tract 9	Upper (1418-1447)	C-D	Welch
		Middle(1449-1492)	E-F	
		Lower (?)	G	
74	Chevron	Upper (1468-1516)	B-D	Hyperion data
		Middle(1516-1577)	D-F	
		Lower (1577-1632)	G	
119	Chevron	Upper (1444-1478)	B-C	Hyperion data
		Middle(1478-1546)	D-F	
		Lower (1546-1615)	G	
127	Chevron	Upper (1423-1481)	A-D	Hyperion data
		Middle(1481-1535)	D-F	
		Lower (1535-1581)	F-G	
129	Chevron	Upper (1424-1469)	B-D	Hyperion data
		Middle(1469-1525)	D-F	
		Lower (1525-1567)	G	
131	Chevron	Upper (1426-1462)	B-C	Hyperion data
		Middle(1462-1543)	D-F	
		Lower (1543-1575)	G	
137	Chevron	Upper (1424-1468)	A-C	Hyperion data
		Middle(1468-1534)	C-F	
		Lower (1534-1573)	F-G	
139	Chevron	Upper (1504-1562)	B-E	Hyperion data
		Middle(1562-1620)	F	
		Lower (1620-?)	G	-

Shale Thickness Between DGI B and C Sandstones (Tract 9, 17-17N-12E)

Figure 5

3.3 Technology Transfer

As part of technology transfer, two presentations were given in professional meetings. "Reservoir characterization and improved water-flood performance in Glenn Pool Field: DOE class I project" was presented at the 1997 AAPG Annual Meeting in Dallas, April 6-9, 1997. "Application of Borehole Imaging for reconstruction of meandering fluvial architecture: examples from the Bartlesville Sandstone, Oklahoma" was presented at the Fourth International Reservoir Characterization Technical Conference in Houston, March 2-4, 1997. Both presentations received great deal of interest from members of independent and major operators.

As most important part of the technology transfer program, a workshop regarding this DOE Glenn Pool project was offered in Dallas, April 4, 1997 as a continuation of workshops we offered last year in Tulsa, Denver and Houston. This workshop preparation mainly involved reorganizing the poster exhibit. More than 20 geologists and engineers attended our workshop and responded with positive comments on our work.

4. ENGINEERING DESCRIPTION (by Sanjay Paranjy and Mohan Kelkar)

4.1 Introduction

This section presents the work completed in the first quarter of the year 1997. The area of analysis was the Chevron Wm. Berryhill unit which is north of Tract 9 (Figure 6). Chevron implemented a Micellar/Polymer flood pilot from 1979-1983, which was based on selective isolation of the upper zones. Chevron initiated field-wide implementation in 1983-1984 that resulted in a remarkable increase in oil production, which will be discussed later in more detail. The obvious success of the Chevron Micellar/Polymer flood prompted us to analyze the unit in more detail. Further, the performance and the completion strategies in this unit will be used as a focal point to compare and contrast it against Tract 9 which is a geologically similar unit with comparable oil saturation profiles.

4.2 Perforation Strategies

Chevron used the prevalent Upper Glenn, Middle Glenn and Lower Glenn divisions of the Bartlesville sandstone to describe the reservoir. Chevron believed that the Upper and Middle

Figure 6 - Index map showing the location of Chevron unit

Glenn layers were separated by a continuous shale barrier and implemented the pilot flood by isolating the perforations in the upper zones. This was later proved to be untrue. The strategy during the field-wide implementation was to complete the wells both in the Upper and Middle Glenn layers. Figure 7.a shows the contrast in completion strategies during the Pilot and Field implementation. The Lower Glenn was avoided since it is known to be water-bearing. This is in sharp contrast to the completion practices in Section 16 and Tract 9 wherein the completion density is increasing as we progress down to the lower intervals. Figure 7.b shows this in graphical form.

4.3 Effects Of The Micellar/Polymer Flood

The Micellar/Polymer flood implementation resulted in 52 times increase in oil production and a WOR decrease of almost 10 times as shown in Figure 8. Chevron increased the number of completions dramatically in 1982-83 prior to Micellar/Polymer flood field implementation. We believe that at least part of the additional oil response could be attributed to better completion practices. Hence it was decided to conduct a flow simulation to study the effect of additional completions by waterflooding the reservoir as opposed to a Micellar/Polymer flooding effort. This enables us to quantify the additional recovery that could be expected out of a similar program in Tract 9.

4.4 Chevron Unit Flow Simulation

The following data

- a. Core and log data
- b. Production data as a function of time
- c. Perforation/completion data

were collected for the area courtesy of Hyperion Energy Resources, the current operator for the lease. In general the porosity in the Chevron area is higher as compared to Section 16 although this is not true for permeability.

4.4.1 Petrophysical Properties

Figure 7.a - Completion practices in the Chevron unit

Figure 7.b - Completion practices in Section 16 & Tract 9

Figure 8 - WOR and oil production response of the Chevron unit

The core data at each well location was averaged for each DGI. The average values were then interpolated at interwell locations to create areal maps of porosity and permeability (Figure 9) for each DGI. The shale barriers between the DGI's have been assumed to be continuous since the vertical permeability is observed to be negligible as compared to the horizontal permeability.

4.4.2 PVT Properties

The PVT properties input requires oil and gas properties as a function of pressure. The minimum bottom hole pressure is known to be around 20 psi and the initial pressure of the reservoir was around 900 psi. Therefore the working range of pressure is 20-900 psi. All the properties were generated using standard Black Oil model correlations for the above working range in discrete increments of pressure.

4.4.3 Relative Permeabilities

The parametrisation of the relative permeabilities was done using the power law model with reasonable end point permeabilities suggested by the Kuykendall paper (Reference 2). The exponents of the oil and water curves were varied as a function of time.

4.4.4 Constraints

The primary depletion stage simulation was carried out so as to approximate the field oil production response by standard hyperbolic decline with a reasonable guess value of initial oil production. The secondary recovery stages of the simulation were constrained to match the oil rates. The relative permeabilities were fine tuned as a function of time to get the observed water cuts. Every effort has been made to closely monitor the number of active wells and the average reservoir pressure at any time to get a reasonable forecast.

4.4.5 Tool

The simulation was done using the "ECLIPSE" software package.

4.4.6 Gridblock System

The areal expanse of the Chevron unit is 160 acres. It was decided to divide the area into 132 ft x 132 ft gridblocks so that any layer is split in 400 gridblocks. The thickness of each gridblock

Porosity Map/DGI B

Permeability Map/DGI C

Figure 9 - Sample Porosity and Permeability areal profiles

is assigned to be the thickness of the layer itself, which is obtained by interpolating at interwell locations. The system has 11 layers, which is the sum of all DGI's B through G and the intermediate shale layers between any two DGIs.

4.4.6 Results

The results are as shown in Figure 10. The simulated water flooding response shows a much lower kick in the field oil production (FOPR) as compared to the actual Micellar/Polymer flood response. Similarly the WOR plot shows decrease by a larger factor for the actual Micellar/Polymer flood response as compared to the simulated water flooding response. The table quantifies the responses observed.

Response	Micellar/Polymer	Waterflood
Field Oil Production (bls/d)	51 Times Increase	15 Times Increase
WOR (bbl/bbl)	10 Times Decrease	4 Times Decrease

4.5 Summary

A strategic recompletion program will be proposed as part of a detailed reservoir management plan with plausible locations for the drilling of new horizontal/vertical wells. A flow simulation study will be conducted in Tract 9 to investigate the effect of water flooding.

Figure 10 - WOR and Field Oil production charts for the Chevron unit

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