“Small, Geologically Complex Reservoirs Can Benefit from Reservoir Simulation”

Final Report

DOE Grant No. DE-FG26-99BC15242

June 24, 2002

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ABSTRACT

The Cascade Sand zone of the Mission-Visco Lease in the Cascade Oil field of Los Angeles County, California, has been under water flood since 1970. Increasing water injection to increase oil production rates was being considered as an opportunity to improve oil recovery. However, a secondary gas cap had formed in the up-dip portion of the reservoir with very low gas cap pressures, creating concern that oil could be displaced into the gas cap resulting in the loss of recoverable oil. Therefore, injecting gas into the gas cap to keep the gas cap pressurized and restrict the influx of oil during water injection was also being considered. Further, it was recognized that the reservoir geology in the gas cap area is very complex with numerous folding and faulting and thus there are potential pressure barriers in several locations throughout the reservoir. With these conditions in mind, there were concerns regarding well to well continuity in the gas cap, which could interfere with the intended repressurization impact.

Concerns about the pattern of gas flow from well to well, the possibilities of cycling gas without the desired increased pressure, and the possible loss of oil displaced into the gas cap resulted in the decision to conduct a gas tracer survey in an attempt to better define inter-well communication. Following the gas tracer survey, a reservoir model would be developed to integrate the findings of the gas tracer survey, known geologic and reservoir data, and historic production data. The reservoir model would be used to better define the reservoir characteristics and provide information that could help optimize the waterflood-gas injection project under consideration for efficient water and gas injection management to increase oil production. However, due to inadequate gas sampling procedures in the field and insufficiently developed laboratory analytical techniques, the laboratory was unable to detect the tracer in the gas samples taken. At that point, focus on, and an expansion of the scope of the reservoir simulation and modeling effort was initiated, using DOE's BOAST98 (a visual, dynamic, interactive update of BOAST3), 3D, black oil reservoir simulation package as the basis for developing the reservoir model.

Reservoir characterization, modeling, and reservoir simulation resulted in a significant change in the depletion strategy. Information from the reservoir characterization and modeling effort indicate that in-fill drilling and relying on natural water influx from the aquifer could increase remaining reserves by 125,000 barrels of oil per well, and that up to 10 infill wells could be drilled in the field. Through this scenario, field production could be increased two to three times over the current 65 bopd. Based on the results of the study, permits have been applied for to drill a directional infill well to encounter the productive zone at a high angle in order to maximize the amount of pay and reservoirs encountered.

FINAL REPORT

DOE Project Number:DE-FG26-99BC15242

INTRODUCTION

The Cascade zone of the Mission-Visco Lease in the Cascade Oil Field of Los Angeles County, California, produces 65 BOPD, 225 BWPD, and 20 MSCFD, from seven wells with 270 BWPD injection in one down dip injection well. The areal extent of the oil accumulation is approximately 50 acres with OOIP estimated at 14 million STBO. Cumulative oil production as of January 1, 1999, was 2 million BO. It is estimated that there are approximately 12 million stock tank barrels of oil remaining in the Cascade zone, trapped in the faulted anticline.

The Cascade zone, at a depth 2,300-3,000 feet, has been under water flood since 1970 with currently low oil production rates compared to the large volume of remaining OIP. Cumulative fluid volume withdrawals have exceeded cumulative water injection, so increasing water injection to increase oil production rates was being evaluated as an opportunity to improve oil recovery, targeting the large remaining volume of OIP.

A secondary gas cap has formed in the up-dip portion of the reservoir with very low gas cap pressures of 15-25 psig, and there was concern that oil could be displaced into the gas cap. Resaturating the gas cap with oil could result in the loss of recoverable oil rendered immobile at oil saturations below the irreducible oil saturation in the gas cap. Therefore, injecting gas into the gas cap to keep the gas cap pressurized and restrict the influx of oil was considered as a possible option. However, it is recognized that the reservoir geology in the gas cap area is very complex, and thus there are potential pressure barriers in several locations throughout the reservoir. With these conditions in mind, there were concerns regarding well-to-well continuity in the gas cap, which could negate the intended repressurization benefit.

Because of concerns about the pattern of gas flow from well-to-well, the possibilities of just cycling gas without the desired increased pressure, and the possible loss of oil displaced into the gas cap, it was decided that a gas tracer survey should be conducted to better define inter-well communication. Identifying the movement of the gas tracer throughout the reservoir could increase the understanding of the complex nature of the Cascade zone geology. Following the gas tracer survey, a reservoir model would be developed to integrate the findings of the gas tracer survey, known geologic and reservoir data, and historic production data. The reservoir model would be used to better define the reservoir characteristics and provide information that could help optimize the water flood-gas injection project under consideration for efficient water and gas injection management to increase oil production.

GAS TRACER WORK

200 grams of a fluorocarbon tracer and 3,300 MCF of natural gas were injected into a centrally located well, just down dip of the gas cap, over a 22-day period. A casing gas production rate increase was observed at one nearby producer, but due to inadequate gas sampling procedures in the field and insufficiently developed laboratory analytical techniques, the laboratory was unable to detect the tracer in the gas samples taken. The original project scope was directed at the use of gas tracer technology to better define the faulting in the gas cap area. It was intended that the gas tracer data could then be used in conjunction with reservoir modeling to develop an improved reservoir management plan. However, review of the gas tracer technology indicated that the survey analysis may not be accurate enough to obtain conclusive results. The cost associated with improving the accuracy of the tracer analysis and the unavailability of qualified personnel to attempt additional tracer work resulted in termination of the gas tracer survey.

RESERVOIR DESCRIPTION AND MODELING

At that point, focus on, and an expansion of the scope of the reservoir description, simulation and modeling effort was initiated. A detailed review of the well, production performance, and other reservoir data revealed significant additional information that needed to be incorporated in developing the optimum reservoir management plan. 170 MMcf of gas had been injected into the reservoir over a 20-month period during 1991-1992 as a means of storing gas until a market could be developed for new wells producing from a deeper horizon. Production performance and reservoir pressure data indicated that there might have been more edge water influx than originally thought, and poor or no communication between some of the wells. The additional information indicated that injecting increased volumes of water into the reservoir might not be the best approach. It became apparent that a thorough analysis of this data would be quite helpful in understanding the entire reservoir.

The reservoir geology was re-interpreted using an "EarthVision" 3-D visualization model. The Cascade Sand reservoir, shown in gray on Figure 1, was interpreted to be a faulted, steeply dipping homocline, with oil trapped primarily by low angle thrust faults cutting off the sand near the top of the anticline. The primary difference between this geologic interpretation and earlier interpretations (see Figure 2) was the presence of steep dips throughout the oil pay section, instead of more gentle dipping caused by an anticlinal roll-over feature.

This interpretation differed from earlier work due to the use of dip meter data obtained from additional wells drilled in the early 1990's to exploit deeper producing horizons. The Cascade Sand reservoir was originally drilled and developed in the mid 1950's. No dip meter data was acquired at that time, or in association with replacement wells drilled later.

This geologic interpretation supports the observed poor communication between some of the wells near or in the gas cap area as well-to-well communication is restricted by small shale sequences in the stratigraphic section.

Overall, data available for reservoir modeling included,

- 15 wells in 50 surface acres;
- a very consistent initial oil/water level in all wells;
- oil and water monthly rate vs. time data by well over 45 years; however, no gas production data was available—it was known to be small at the present time;
- Gas injection volumes over the 21 month gas injection project with surface casing pressure data measurements taken on all wells at least weekly; overall, reservoir pressure increased from 300 to 500 psig during injection—but individual wells varied widely;
- Static reservoir pressure measurements taken from fluid levels of wells shut-in for mechanical reasons for long periods of time; this data always showed significantly higher pressures in down-dip wells compared to that in up-dip wells;
- Formation Interval Test (FIT) pressure data obtained from open hole logging of wells drilled through the reservoir 35 years after initial production; this data showed a wide variation in reservoir pressure in the vertical section.
- Infill wells drilled in the late 1970's (20+ years after initial production) produced at 3 times the current rate of existing wells (1/2 of the initial rate of existing wells), but will recover approximately the same total oil over life as the pre-existing wells.

A comprehensive analysis of this data required the use of a reservoir simulator. Too many simplifying assumptions had to be made to conduct single cell material balance calculations. It was recognized that the reservoir was too complex to model uniquely, but qualitative assessments about the reservoir might be feasible.

DOE's BOAST98 (a visual, dynamic, interactive update of BOAST III), 3D, black oil reservoir simulation package, using 8x29x41 grid blocks, was selected as the basis for developing a reservoir model (the DOE reservoir simulation package is available for use at no charge).

CONCLUSIONS

A satisfactory history match of the production and pressure data with the model could only be accomplished using 1/3 to 1/2 of the volumetrically determined OOIP. Further analysis indicates that the discrepancy is not due to areal extent or net pay determinations, but rather is due to considerably more faulting within the reservoir than originally thought, and/or the completion of wells in differing stratigraphic intervals due to the steep dips encountered. These factors result in poor inter-well continuity and

connectivity, resulting in large portions of the reservoir being poorly drained by the existing production-water injection well patterns (confirming concerns raised from the beginning, albeit, the impact addresses oil production as well as gas injectivity concerns).

Since the reservoir is a very thick sand, the additional faulting is probably "sand-on-sand" and not detectable by conventional geological methods of analysis. Also, the down-dip aquifer support plays a larger role in pressure maintenance than originally thought, and the original Oil Water Contact may be deeper than originally believed.

As a result of the modeling effort, there has been a significant change in the planned depletion strategy from a process improvement involving increased water injection down-dip with simultaneous gas injection up-dip, to a program of in-fill drilling for further field development while relying on natural water influx from the aquifer for optimum oil recovery. Performance predictions from the simulation model indicate that by implementing infill drilling, remaining reserves can be increased by the rate of 125,000 BO per well and that up to 10 infill wells could be drilled in the field. Through this scenario, the field production rate could be increased two to three times over the current 65 BOPD.

Consensus is that these results could not have been determined via any less of a comprehensive evaluation effort. The reservoir simulator has proven to be the key reservoir management tool to organize the data, unravel this fairly complex reservoir, and give the operators the confidence to conduct further field development.

PROJECT UPDATE

As of this date (May, 2002) we have not tested the results of these studies with infill drilling. We applied for drilling permits in May of 2001 and are hopeful of getting them this year. Permitting used to be a 3 to 6 month process. However, we experienced some opposition this time, and it has become necessary to go through a more involved process. The first well should be drilled in the summer of 2003. We plan to drill the well directionally, encountering the productive zone at a high angle, thus maximizing the amount of pay and reservoirs encountered.

Figure 1
Cascade EarthVision Cross Section and
Wellbore (with dips) Model

Looking East

Surfaces honor dipmeter

Zone Color Key
Display: Cascade_906_hrz.f...

6	1800_foot_sand
5	Cascade_sand
4	Base_Cascade
3	Omelveny_sand
2	Base_Omelveny_sand
1	Top_Miocene

Z exaggeration: 0.5
Azimuth: 301.1
Inclination: 13.7
X Front Cut: 2000.0

Figure 2
Cascade Oil Field