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TITLE: ECONOMIC RECOVERY OF OIL TRAPPED AT FAN MARGINS USING
HIGH ANGLE WELLS AND MULTIPLE HYDRAULIC FRACTURES

Cooperative Agreement No.: DE-FC22-95BC14940

Contractor Name and Address: Atlantic Richfield Co., P.O. Box 147, Bakersfield,
California 93302

Date of Report: July 29, 1996

Award Date: September 28, 1995

Anticipated Completion Date: August 28, 1996

Government Award for Current Fiscal Year: \$409,351

Principal Investigators: Bruce L. Niemeyer, ARCO

Project Manager: Edith Allison, Bartlesville Project Office

Reporting Period: Apr. 1-Jun. 30, 1996

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Objective

This project attempts to demonstrate the effectiveness of exploiting thin-layered, low-energy deposits at the distal margin of a prograding turbidite complex through the use of hydraulically-fractured, horizontal or high-angle wells. The combination of a horizontal or high-angle well and hydraulic fracturing will allow greater pay exposure than can be achieved with conventional vertical wells while maintaining vertical communication between thin interbedded layers and the wellbore.

A high-angle well will be drilled in the fan margin portion of a slope-basin clastic reservoir and will be completed with multiple hydraulic-fracture treatments. Geologic modeling, reservoir characterization, and fine-grid reservoir simulation will be used to select the well location and orientation. Design parameters for the hydraulic fracture treatments will be determined by fracturing an existing test well. Fracture azimuth will be predicted, in part, by passive seismic monitoring from an offset well during fracture stimulation of the test well.

Summary of Technical Progress

Reservoir simulation has played a significant role in optimizing the depletion strategy for the Yowlumne field. However, the full-field model grid is too coarse to adequately

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predict the performance of the NE fan-margin area of the field. To more accurately represent the fan-margin, a partial-field, fine-grid model was constructed using the detailed geologic description completed as a part of this project during the first quarter of 1996¹. History matching has been completed and several production-forecast scenarios are in progress to determine the most effective options for exploiting the fan-margin.

History Matching

The partial-field model consists of 10 layers and 11,560 cells. Each of the four major flow units are represented by two layers. The remaining two layers are used to represent a minor flow unit at the top, and an unproductive interval at the base (to model possible downward growth of the hydraulic fracture). Each cell has an area of 0.62 ac. For comparison purposes, the Yowlumne full-field model has five layers and 15,750 cells. The 1.75-ac interior cells are approximately three times the area of the partial-field model cells. The partial-field model is more capable of representing the heterogeneous fan-margin area of the field, both vertically and horizontally.

The eastern edge of the partial-field model is represented as a no-flow boundary, consistent with the geologic description and previous full-field simulation and streamtube modeling. No-flow boundaries could not be established for the rest of the model. Thirty-nine pseudo wells were placed along the northern, western, and southern edges of the model to represent flux (Fig. 1). Flux rates were initially based on streamline models and were later adjusted to match the performance of wells near model edges.

Based upon observed pressure differentials between perforated intervals, vertical transmissibility between layers was set at zero. A horizontal to vertical permeability ratio (k_v/k_h) of 0.05 was used to represent the random, discontinuous shales in the fan margin area².

The partial-field model contains 21 producing wells and 10 water injection wells. Water injection rates were explicitly specified for each well. Past injection well profiles were used to allocate water injection rates by layer. For producing wells, oil production rates were explicitly specified and water-oil ratios (WOR), gas-oil ratios (GOR), and pressures were matched. An abundance of pressure data are available from wells throughout the model area. Over 18 years of production and pressure history were matched.

Several producing wells in the Yowlumne field have experienced calcium carbonate scaling of perforations when injection water breaks through. These occurrences have actually been favorable, promoting "natural" water shut-off of high water cut intervals, increased drawdown of producing bottomhole pressures, and greater contribution of low-pressure, high oil cut intervals. In addition, because of the piston-like displacement process in the Stevens reservoir, minor amounts of oil were left behind in the scaled intervals. Remedial workovers such as acidizing or reperforating have typically resulted in high water

cut production. Previous full-field modeling has represented wells with scaling tendencies by using water relative permeability pseudofunctions that were too favorable. The current partial-field model employs higher skin factors for the scaled intervals. This technique allows more reasonable water relative permeability pseudofunctions to be used. In addition, the water cut performance of wells with post-breakthrough remedial workovers was used to calibrate the water relative permeability curves.

Once the history match was nearing completion, local grid refinement was applied in the area of the proposed south-to-north slant well (Fig. 1). The solution method was switched from IMPES to fully implicit, and the history match was completed. Figure 2 is a plot of the production history match for the partial-field model area.

Production Forecasts

The partial-field model as developed has the ability to evaluate dissimilar development options such as vertical wells, slant wells, horizontal wells, and fractured wells. Initial forecasting consisted of the proposed south-to-north slant well as depicted by the nested grid shown in Fig. 1. The slant well is expected to penetrate the formation at an angle of 56° from vertical, or 76° relative to the top of the formation taking into account structural dip (Fig. 3). Although the true gross thickness is 190 ft, the well will be exposed to 1200 ft of formation.

For all production forecast scenarios, the injection-withdrawal ratio will be set and held constant at unity until the year 2000. Field-wide pressure maintenance is expected to end at that time, and only produced water will be injected. All wells are placed on bottomhole pressure control. Since a slant well with three hydraulic fractures will require an electric submersible pump (ESP) to produce the expected high rates, the limiting producing bottomhole pressure is set at 1500 psi for these forecast scenarios. For all other cases, hydraulic jet pump lift is anticipated, and the limiting producing bottomhole pressures are set at 2000 psi.

Figure 4 is a plot of incremental oil production for the slant well without hydraulic fractures. Also shown is the total incremental oil production for three vertical wells spaced along the slant well path. Without hydraulic fracturing, the slant well recovers less oil than three vertical wells. This is attributed to the very low effective vertical permeability that is expected in the fan-margin region as a result of random shales. Three hydraulic fractures are planned for the well, which are expected to act similarly to three vertical wells by providing vertical communication between much of the formation and the slant wellbore.

Additional forecast scenarios are progressing. Some of the scenarios being investigated include sensitivities to the number of hydraulic fractures, frac height, frac length, frac orientation, slant well orientation, and vertical permeability.

References

1. Mattax, C.C. and Dalton, R.L., *Reservoir Simulation*, Monograph Series, SPE, Richardson, Tex. (1990) 13, 44-49.
2. Begg, S.H., Chang, D.M., and Haldorsen, H.H., *A Simple Statistical Method for Calculating the Effective Vertical Permeability of a Reservoir Containing Discontinuous Shales*, paper SPE 14271 presented at the 60th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Las Vegas, Nev., September 22-25, 1985.

Fig. 1 Partial-field model grid showing local grid refinement and NS slant well.

Xowlumne Strip Model (1/77 - 12/95)
 Model History Match of Production Rates
 DOE Class III Project

Fig. 2 History match of production rates for partial - field model.

Fig. 3 Vertical Cross section of partial-field model grid showing NS slant well.

Fig. 4 Comparison of incremental oil production from slant well without fracs and three vertical wells.

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U.S. DEPARTMENT OF ENERGY FEDERAL ASSISTANCE MANAGEMENT SUMMARY REPORT

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1. Program/Project Identification No. DE-FC22-95BC14940	2. Program/Project Title Economic Recovery of Oil Trapped at Fan Margins using High Angle Wells and Multiple Hydraulic Fractures	3. Reporting Period 04/01/96 through 06/30/96
Name and Address Bruce L. Niemeyer ARCO Western Energy, P.O. Box 147, Bakersfield, CA 93302		5. Program/Project Start Date 09/28/95
		6. Completion Date 08/28/96

4. FY 95-96	6. Months or Quarters Quarters	4th Qtr 95	1st Qtr 96	2nd Qtr 96	3rd Qtr 96

7. Cost Status a. Dollars Expressed in
Thousands

b. Dollar
Scale

8. Cost Chart

Fund Source		Quarter				Cum to Date	Tot Plan
		1st 96	2nd 96	3rd 96	4th 95		
ARCO	P	68	51	17	273	392	409
	A	66	165		2	233	
DOE	P	68	51	17	273	392	409
	A	97	226		2	325	
	P						
	A						
	P						
	A						
Total P		136	102	34	546	784	819
Total A		163	391		4	558	
Variance		27	289		(542)	(226)	

P = Planned A = Actual

C Cumulative Accrued Costs

Total Planned Costs for Program Project	Planned	546	682	784	819
818.7	Actual	4	167	558	
	Variance	(542)	(515)	(226)	

1. Major Milestone Status	Units Planned	
	Units Complete	
	P	
	C	
	P	
	C	
	P	
	C	
	P	
	C	
	P	
	C	
	P	
	C	
	P	
	C	
	P	
	C	
	P	
	C	

SEE ATTACHED GANTT CHART

2. Remarks

3. Signature of Recipient and Date

14. Signature of U.S. Department of Energy (DOE) Reviewing Representative and Date

ECONOMIC RECOVERY OF OIL TRAPPED AT FAN MARGINS USING HIGH ANGLE WELLS AND MULTIPLE HYDRAULIC FRACTURES

Project ID No.: DE-FC22-95BC14940
Budget Period One
2nd Qtr 1996

Task
Progress

Milestone
Summary

Rolled Up Task
Rolled Up Milestone

Rolled Up Progress