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QUARTERLY TECHNICAL PROGRESS REPORT
(Fifth Quarter)

DOE/BC/14941--5

**ADVANCED OIL RECOVERY TECHNOLOGIES FOR IMPROVED
RECOVERY FROM SLOPE BASIN CLASTIC RESERVOIRS,
NASH DRAW BRUSHY CANYON POOL, EDDY COUNTY, NM**

DOE Cooperative Agreement No. DE-FC-95BC14941

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OBJECTIVE

The overall objective of this project is to demonstrate that a development program—based on advanced reservoir management methods—can significantly improve oil recovery. The plan includes developing a control area using standard reservoir management techniques while comparing its performance to an area developed using advanced reservoir management methods. Specific goals are (1) to demonstrate that an advanced development drilling and pressure maintenance program, can significantly improve oil recovery compared to existing technology applications and (2) to transfer these advanced methodologies to oil and gas producers in the Permian Basin and elsewhere throughout the U.S. oil and gas industry.

SUMMARY OF TECHNICAL PROGRESS

This is the fifth quarterly progress report on the project. Results obtained to date are summarized.

MANAGEMENT AND PROJECT PLANNING

Geological, engineering, geophysical, and simulation teams continue compiling and analyzing data. Data has been entered into the geological model and a preliminary reservoir simulation run has been performed. The 3-D seismic data is being interpreted, and areas have been identified for targeted drilling.

Communication and coordination between the team members located in a diverse geographic areas requires the use of state-of-the-art communication systems. Therefore, to meet our reporting requirements, we use a combination of E-mail, the Internet, and high capacity data transfer to successfully exchange data and conclusions among the groups.

GEOLOGY

Geologic Model: The geologic model has been refined to meet the geological and reservoir engineering constraints necessary to begin the simulation. Much of our time has been spent “fine tuning” the model. The simulation team began the initialization phase and the equilibration of the model in the pilot area. Problems with the volumetrics in the pilot area necessitated modifying the geologic model. The sub-units for the “L” Sand were re-mapped in greater detail as were the individual structure maps. As well, we re-vamped the net pay maps. After completion, the areal extent of the reservoirs was sufficient to accommodate the volume necessary in order to proceed with the simulation.

Geologic Interpretation of Seismic Data: We have shifted our thinking, slightly, regarding the distribution of pay sands in the “K” and “L” sands because of the interpreted 3-D seismic data volume. Though we continue to believe that the overall depositional model and mechanism are the same, the focal points of deposition of the higher quality reservoir facies have shifted to the northern part of the unit. Consequently, the relationship of this distribution to the underlying Bone Spring Limestone needs to be examined more closely. The concentration of better quality reservoir rock may be related to the underlying Bone Spring topography, which is the area currently being investigated.

ENGINEERING

Data Acquisition Well: Nash Draw Well No. 12—located at 918 ft FSL and 2153 ft FEL of Section 12, Township 23S, Range 29E—has been successfully completed. Initial production tests show daily production rates of 75 BO, 250 MCFG and 240 BW. The well is flowing up the annulus and is capable of higher production rates. The majority of the water is producing from the high permeability, wet “K-2” zone.

This well exhibited good “L” zone development and exhibited fair “K” zone development. The correlation of porosity in the “K” and “L” sands with the high intensity seismic reflection amplitudes for the respective intervals in the 3-D seismic data volume, presents positive information that seismic attributes correlate to the best quality reservoir rocks in the Nash Draw Unit.

Decline Curves: Historical production data have been updated through October 1996. The decline curves have been compared to the Delaware Model to evaluate production trends.

Pilot Area: The proposed pilot area around Well No. 1—including Well Nos. 1, 6, 14, 5, 9, and 10—is being reviewed. Detailed flow-unit maps have been prepared. Each of the sub-units of the three main sands has been mapped individually: isopach maps for log-derived net pay and isopach maps for gross sub-units. These maps have been put into the geologic model for the reservoir simulation study in the pilot area.

Comparison of the seismic lines and time slices have shown some evidence of discontinuities in the area surrounding Well No. 1. This indicates the area may be compartmentalized and the lateral continuity between the pilot wells could be reduced. Further study of this discovery is needed to determine the viability of the proposed pilot area. The 3-D seismic indicates other areas may be better suited for the initial pilot area.

E. Loving Analogy: To evaluate the recovery techniques used in this project, an analog area was selected and analyzed to determine the recovery efficiency and producing characteristics of a field completed using standard techniques. An entire 640-acre section in the Loving Brushy Canyon Pool was selected as a typical primary producing model. Section 14, Township 23S, Range 28E was selected because it was fully developed on 40-acre spacing, offered a wide variety of geological conditions, and had sufficient production history to predict recoveries reliably. Section 14 contains the typical components of a Delaware pool:

- It dips from West-northwest to the East.
- The northwest corner is at -3107 ft at the top of the Bone Spring Formation.
- The East edge is at -3261 ft.

This is a change of 254 ft in the structure across the section. Located in the middle-west side of the section is a bench which has a lower dip angle than the steps on either side of the bench. Production associated with sands deposited on the bench is considerably higher than wells located on the steps.

Section 14 has a bench that is approximately one-half mile wide, with steeply dipping steps on either side. The step-bench sequence is a typical depositional characteristic of the Basal Delaware Zones in this area. Wells located on the bench in Section 14 have significantly higher recoveries than

wells located on the updip or downdip step.

Comparison of data from the Nash Unit and the Loving Field helped confirm that reservoir characteristics were similar between areas. Core data was obtained from the wells in the Loving Field and the distribution of porosity versus permeability were compared and found to be very similar. Also, producing characteristics, oil saturations, and rock properties are in close agreement. The single most important difference between the two areas is in the "K-2" zone. The Nash has a highly developed "K-2" zone that is wet and produces large volumes of water if stimulated. The Loving wells do not have a significant "K-2" zone and produce small quantities of water.

To predict the ultimate primary recovery from this section, a production curve was created for each well displaying oil, gas, and water historical production. From this production history, decline curves were described for each phase and projected to the economic limit to calculate the ultimate recovery from each well. The projected primary recovery from each well was estimated from the decline-curve analysis, and the total primary recovery from the 16 wells in Section 14 is projected at 2,084,013 BO, 10,981,608 MCFG, and 976,669 BW.

The OOIP estimate was made by performing a core-calibrated log analysis to determine the actual net pay from a digitized log. The use of digitized logs with 0.5 foot sampling provides the resolution to determine productive zones in the highly laminated Delaware Zones. After the pay zones, saturations, and permeabilities were determined, a volumetric calculation was performed to determine the oil-in-place at each wellbore.

Comparing these two methods of analysis, we find good agreement between the two calculations, as seen in Table 1.

Table 1. Comparison of oil and gas recoveries.

	Volumetric Analysis	Material Balance Calculation
OOIP	12,473,340	12,467,072
Oil Recovery	16.71%	16.77%
OGIP	12,722,807	12,716,413
Gas Recovery	88.04%	

These are the values that will be used to analyze the techniques used at the Nash Draw Unit. With better stimulation, targeted drilling, pressure maintenance, and reservoir characterization, recoveries, at the Loving Pool, should be better than the 16.7% realized.

Delaware Data: Texaco has drilled five wells offsetting the Nash Unit in the southeastern corner of the Nash Draw Unit. Log and core data were obtained for analysis and inclusion into the NDU data base. The "L" zone is the main pay zone in the Texaco wells, similar to the NDU wells, the "K-2" zone is wet and produces large quantities of water, and the "K" zone is lower structurally and is wet. The "L" zone exhibits similar porosity-permeability relationships in both areas. Permeability is slightly lower in the "K-2" zone in the Texaco wells, and the permeability is slightly higher in the "K" zone.

The wells in the Texaco area are deposited on a bench-step surface on top of the Bone Spring zone, similar to other Delaware fields in the area. The top of the Bone Spring zone on the west edge of Section 19 is at a depth of 6830 ft (common datum) and the east edge is at a depth of 6950 ft. This

represents a dip of 120 ft across the north end of the section. The bench is approximately 0.5 miles wide and the steps are approximately 0.25 miles wide.

The Texaco wells were completed in the first half of 1996; therefore, sufficient production history is not available to make an accurate prediction of ultimate recoveries from decline curve analysis.

A volumetric estimate of the OOIP was made by assigning the oil-in-place value for 0.4 acre grid blocks for the 640-acre section. Using this analysis, the section contains 2,954,648 BO, with 493,526 recoverable reserves using a recover factor of 16.7%. The recovery for each well, based on drainage areas, is shown in Table 2.

Table 2. Estimated recoveries, based on drainage areas.

<u>Unit</u>	<u>PRIMARY RECOVERIES, BO</u>	<u>ACRES</u>
"A"	92,151	72.0
"B"	59,182	64.0
"C"	49,942	57.6
"F"	53,152	70.4
"K"	<u>50,209</u>	<u>83.2</u>
TOTAL	305,636	347.2

Because of thinner pays, a narrower bench, and the "L" zone as the only pay, the Texaco wells have approximately half of the primary reserves as the NDU wells. Also, the very wet "K-2" zone contributes large quantities of water if fracture stimulated with the "L" zone.

3-D SEISMIC

A seismic profile, extending across the central part of the Nash Draw 3-D grid, illustrated the conformability relationships between the two reference chrono-stratigraphic surfaces selected for the Nash Draw interpretation (the top of the Bone Spring and the shallower CRS event) and the stratigraphically adjacent "K" and "L" Brushy Canyon reservoirs.

Because the easily interpreted Bone Spring and CRS surfaces are conformable to the difficult-to-interpret "K" and "L" thin-bed reservoirs, thin analysis windows that exactly span the "K" and "L" units can be properly positioned in the 3-D seismic volume by defining sequence boundary surfaces that are offset from the Bone Spring and CRS reference surfaces by a constant (conformable) distance across the complete 3-D image space, that offset distance being determined by the VSP calibration data recorded in the nearby No. 25 well.

Herein lies the importance of establishing a high degree of conformability between a targeted, but poorly imaged, thin bed and a nearby robust chrono-stratigraphic reflection surface; therefore, when conformability does occur, an accurate analysis window, which spans the thin bed, can be defined even if difficult to see. Analysis of East-west crossline profile supports the assumption that the L sequence is conformable to the top of the Bone Spring, and that the K sequence is conformable

to the CRS peak.

VSP calibration data acquired in the Well No. 25 established: (1) the top of the Bone Spring Limestone was a robust reflection peak at 1.0 s (at the 25 well), (2) the "L" sequence that dominates production at Nash Draw field was associated with the first reflection trough immediately above this Bone Spring peak, and (3) the "K" sequence began at, or just above, the first reflection peak above the Bone Spring event. Inspection of the 3-D data volume showed that the "L" reflection trough had a highly variable amplitude and waveshape and was associated with a number of distinct seismic facies across the image space. Regardless of the depositional facies exhibited (concordant, downlap, mounded, or chaotic), the "L" reflection trough never rose higher than 16 ms or 18 ms above the Bone Spring.

Because of this approximate conformability between the L reflection trough and the robust Bone Spring reflection peak, the amplitude of the L reflection trough was defined in every bin of the 3-D volume by determining the maximum negative amplitude value in a data window that was bounded at the base by the Bone Spring reference surface and at the top by an arbitrary surface defined as Bone Spring-18 ms.

A map of these maximum negative reflection amplitudes across the total 3-D seismic image space displayed a strong visual correlation between the areal distribution of the high-amplitude L reflections and the positions of the better producing wells (Well Nos. 19, 11, 15) documents an important principle that should be considered when siting future Nash Draw wells:

As the amplitude of the L reflection trough increases, the productive potential of the L sequence increases.

There is a strong, positive correlation between the amplitude of this reflection trough and the productivity of the Nash Draw wells. Wells 11, 13, 15, 19 and 24 are the best producers in Nash Draw field, and the amplitude of the L reflection trough is a maximum along the trend where these wells are located, although the trend does not quite extend to the 24 well. The amplitude behavior near well 13 should be ignored because this well location is not properly imaged due to surface constraints imposed by the large salt lake in the north central portion of the Nash Draw unit. Wells 9, 23, and 25 are the poorest producers in the field, and the amplitude of the L reflection trough has its minimum values near these well sites. Well Nos. 1, 4, 5, 6, 10, 14, and 20 are modest producers, and the L reflection trough has intermediate amplitudes and a patchy behavior around these wells. Thus, higher amplitudes of the L reflection trough imply better well productivities.

A map of the amplitude of the "K" reflection peak looks much like this "L" reflection trough map, with higher reflection amplitudes again occurring at the better producing locations.

The correlation between well performance and the "L" reflection amplitude can be expressed in a quantitative way that reservoir simulators can use to numerically calculate critical fluid-flow parameters from the 3-D seismic amplitude volume. In particular, statistically significant linear relationships have been established between reflection amplitudes of the "L" sequence and three critical "L" reservoir properties:

- Reflection amplitude and net pay
- Reflection amplitude and porosity feet
- Reflection amplitude and transmissivity to oil and water.

Crossplots of the relationships among these parameter pairs were used to obtain the best-fit straight line developed by linear regression to describe the distribution of the respective data populations. These three equations are repeated here for completeness:

$$NP = 12.18 - 0.37 A \quad (1)$$

$$PF = 1.52 - 0.05 A \quad (2)$$

$$T_{ow} = 5.98 - 0.24 A \quad (3)$$

where NP = net pay, PF = porosity feet, T_{ow} = transmissivity to oil plus water, and A = amplitude of "L" reflection trough.

This suite of equations represents numerical relationships that can be used to convert the "L" reservoir reflection trough amplitudes in the Nash Draw 3-D data volume into estimates of the L reservoir net pay, porosity feet, and fluid transmissivity in areally continuous cells measuring 55 ft x 55 ft, which is the smallest spatial sampling provided by the 3-D seismic volume.

For the L reservoirs, the seismic attribute A in Equations 1 through 3 is the amplitude of the reflection trough associated with the L reservoir system. In each case, the reservoir parameter (net pay, porosity feet, transmissivity) increases as the magnitude of the reflection trough amplitude increases.

RESERVOIR CHARACTERIZATION/RESERVOIR SIMULATION

Activities of the Reservoir Characterization/Simulation Team for the fourth quarter of 1996 were focused on the initialization of a reservoir simulation model of the oil lobe which supports the pilot area wells (Nash #1, Nash #5, Nash #6, Nash #10, and Nash #14).

During the quarter, the Engineering and Geology teams developed a new interpretation of this lobe that incorporates, for the first time, data from the recently acquired 3-D seismic survey. Using seismic amplitude as a guide, the pilot lobe was recontoured. In this interpretation, the pilot lobe occupies about 300 acres. Figure 1 contrasts this new interpretation with the previous one (Fig. 2) for the top of structure of the uppermost horizon, the "J" sand.

Using the Well Attribute model developed last quarter, the following attributes were imported into the stratigraphic framework model for the "L" sand of the pilot lobe: interpreted porosity, interpreted permeability, and water saturation. The "L" sand produces more than 90% of the oil from the pilot area, and the "K-2" sand is responsible for most of the water production.

In some instances, these attributes were available on a foot-by-foot basis for one or more of the producing zones. All of the attributes were available for each well identified above. The distribution of reservoir attributes like conductivity and storage capacity within the producing zones of the Nash Draw Brushy Creek Unit was based on the well attribute model. Within SGM, these distributions are weighted by the reciprocal of the square of the distance between the location of interest and nearby wells within the reservoir model.

The present model is adequate to represent the geology of the Nash Draw Brushy Canyon Pilot for reservoir simulation. A simulation model has been constructed to reflect this latest characterization, which includes a description of the

- Reservoir fluid property data (differential vaporization experiment)
- Special core analysis data (for a sample taken from Nash #19)

- Initial reservoir fluid saturations and datum pressure
- Production and well test data for all of the wells in the pilot area

This model consists of twenty layers. This resolution is the minimum required to capture the thin beds of the "L" sand. The areal dimensions of the grid blocks are approximately one acre. The OOIP for the pilot is in close agreement with engineering estimates:

Engineering value	Geological Model	Simulation Model
3.591 x 106 STB	3.606 x 106 STB	3.572 x 106 STB

The next step in the project is to validate the simulation model against pressure test data. This may require adjustment of transmissibility and/or relative permeabilities.

TECHNOLOGY TRANSFER

Transferring technical information generated during the course of this project is a prime objective of the project. Toward this objective, Strata has participated in several meetings and workshops to promote the dissemination of information generated during this quarter. A summary of these activities is outlined.

Technology Transfer Meeting - December 1996: A liaison committee meeting was held on December 18, 1996. The purpose of this meeting was to update Mr. William J. Lemay Director of the New Mexico Oil Conservation Division as to the status of the project and findings to date.

Fourth International Reservoir Characterization Technical Conference - March 1997. Mr. Dave Martin will present a paper entitled "Advanced Reservoir Characterization for Improved Oil Recovery in a New Mexico Delaware Basin Project" at the Fourth International Reservoir Characterization Technical Conference to be held in Houston, Texas on March 2-4, 1997.

AAPG Annual Convention - April 1997. A poster session will be presented at the AAPG Annual Convention to be held in Dallas, Texas on April 7-10. Bruce Uzsinsky will present an update of the status and findings at the Nash Draw Project.

Internet Homepage: One of the pertinent technology transfer objectives was the rapid dissemination of the technology that had a direct influence on the characterization of the Nash Draw field. Towards this objective, the New Mexico Petroleum Recovery Research Center embarked upon creating an Internet homepage specifically dedicated to the Nash Draw project. This homepage may be accessed at the URL (address) <http://baervan.nmt.edu/prrc/resdiv/react/reactnew.html>. This address accesses the REACT (Reservoir Evaluation and Advanced Computational Technologies) homepage. By clicking on REACT PROJECTS section, the NASH DRAW project may be accessed.

The Nash Draw homepage was created using the hypertext markup language (HTML). The homepage uses some of the latest internet technology, including image mapping, available for technology transfer. Clicking on various sections of the homepage links the user directly to different internet locations as well as white papers pertaining to the highlighted topic. Currently, users around the world can directly access the third quarterly report submitted by Strata Production Company that

discusses the state of the affairs pertaining to the Nash Draw project. The Nash Draw plat map may be accessed by clicking on the highlighted "Nash Draw Unit". This fires up a schematic of the Nash Draw plan view map, showing the location of all the wells. At this point, the user is allowed two options - either to view the "Production Data," or the "Well Logs" for all the wells in the field. Choosing one of the above creates an image map which has all the data (production or well logs) embedded in it. Clicking on any of the wells creates a new window with a color display of the requested data set.

The Nash Draw homepage is updated frequently and thus all the pertinent information is easily accessible to simultaneous multiple users all over the world. This homepage is best viewed using an internet browser such as Netscape 2.0+.

Figure 1. New Interpretation of Structure in the Nash Draw Pilot Area.

Figure 2. Interpretation of Structure in the Pilot Area Prior to Availability of 3D Seismic Data.