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QUARTERLY TECHNICAL PROGRESS REPORT
(Third Quarter)

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

Summary of Technical Progress

This is the third quarterly progress report on the project. Results obtained to date will be summarized.

Description of Project Work

Management and Project Planning

Geology and engineering teams worked together in compiling and interpreting the data that is continually being submitted to the reservoir characterization/simulation team. A planning session of the entire geological, engineering, simulation, and management project teams was held during this quarter to review progress in developing the Nash Draw geological model. Final organization of the Liaison Committee and Technical Committee has been completed. A meeting of the Liaison/Technical Committees has been tentatively scheduled for August 16, 1996.

Geology

Reservoir Characterization

In conjunction with the team engineer, a method for estimating net pay from well logs was developed for the wells in the Nash Draw Unit. The method was based on taking the known core-derived porosity and permeability values and developing transforms for each of the three main pay zones (the "K," the "K-2," and the "L" zones). A profile of water saturation for each zone in each well was determined. Net pay was calculated for each zone and mapped across the field. The log-derived net pay maps are more accurate and comprehensive given that the data encompasses the whole interval, not just specific points here and there. The water saturation and capillary pressure data, provided

by the team engineer, is also being integrated into the mapping procedure.

Reservoir Mapping

The geological and engineering data are beginning to support our initial concept that there are at least two, and possibly three, depositional lobes for the "K" and the "L" sands. Interpretive mapping that incorporates the more detailed net pay, capillary pressure, and water saturation data is proceeding, particularly in the proposed pilot area. Isopach mapping of the sub-unit of the "K," the "K-2," and "L" sands is almost complete and will be high-graded using new, more-detailed information.

Based on the discussions with the reservoir simulation team in June, the original structure maps (tops of the units) were re-mapped to be more conformable and eliminate the intersections detected in the original 3-D model. The base of each of the units was also mapped, and the isopach maps of the inter-unit zones will be completed shortly. This will provide a more uniform geologic framework for the studies that will be done by the simulation team.

Analog Field Study

Data gathering continued on the Production Analog Area in the Loving East Field. This field was chosen because the geologic and reservoir characteristics are similar to the Brushy Canyon interval in the Nash Draw Unit.

Oklahoma RB Operating has provided core analysis on five wells in and around the area that is being used as the production analog for the Nash Draw Unit.

Offsetting Well Data

Texaco, Inc. has provided well data and core analyses on five of their wells drilled adjacent to the Nash Draw Unit. The data from the wells have been integrated into the structure and gross isopach maps. Strata has supplied Texaco with like data in return for their contribution.

Engineering

Completion of the third data well, the Nash Draw #25 located in Section 14, was completed in April. Initial production rates were 65 BOPD, 340 BWPD and 100 MCFG. The high water cut can be attributed to the ratio of oil to water transmissibility (which is 0.2); this ratio correlates very well with the actual oil-water ratio of 0.19 BO/BW.

The "engineering database" has been brought up-to-date with the addition of production and decline curves updated through April 1, 1996. Preliminary allocation of the production volumes between zones has been completed. The third generation of the database has been sent to the simulation team for processing of the data into the reservoir

simulator.

By using the full-core analysis to calibrate log calculations, a procedure was developed to identify the zones that are oil-productive. The procedure is based on the premise that zones with residual oil saturation have a high probability of being productive and zones with no residual oil saturation have a low probability of being productive. By calibrating the Micro Lateral Log to calculate a S_{xo} value for each one-half foot interval from the digitized log, potential pay zones were identified.

By applying porosity correction transforms, setting gamma ray and porosity limits, and calibration of R_t values, a more accurate determination of the productive intervals was made. With corrected porosity values, water saturations, and net heights, a volumetric calculation was performed to estimate the original-oil-in-place. The preliminary analysis that compares decline-curve analysis and volumetric analysis is in close agreement. Continued study should determine the drainage radius, define anomalies, and reduce the margin of error.

A corresponding calculation was performed to determine the zones that are water productive and the volume of water present. The "L" zone has minor amounts of interbedded water, the "K-2" has many water zones, and the "K" has highly interbedded oil and water zones. The "L" has high oil saturation (greater than 50%), and the "K-2" has high oil saturations when productive zones are present. The "K" zone has lower average permeability which corresponds to higher capillary pressure and higher water saturations, with S_w in the range of 50% to 60%.

After identifying net pay intervals in each zone, relative permeability was calculated using the relative permeability data derived from the full-core analysis. By summing the transmissibility (kh/μ) values for each oil and water zone, an estimate of the oil-water cut could be calculated for each interval. These values were used to allocate production from each of the three zones.

Capillary pressure data and height above the 100% water saturation have been calculated for each well. Mapping these values versus structure indicates there may be multiple sand pods with different characteristics. These data, coupled with the 3-D seismic interpretation, should help identify depositional pods and their orientation.

A BHP test was performed on the Nash Draw #23 well. These data, and previously-acquired data, were analyzed to determine permeability, skin, and frac geometry. One conclusion derived from this analysis is that the original small frac treatments were not large enough to adequately prop the productive interval. Further, it appears one well was not stimulated, probably because that treatment did not include enough sand to generate a sufficient propped frac height.

Preliminary work has been initiated on the design of a pilot injection area surrounding the Nash Draw #1 well. Various injectants are being considered, including water, dry natural gas, nitrogen, and CO_2 . Determination of the injectant will be dependent on the

results of swelling tests from the laboratory and reservoir simulation studies that will be conducted.

Work on the Analog Area continued with the integration of acquired core data. Calculations to determine OOIP and recoveries are being performed for comparison to the Nash Draw project.

3-D Seismic Data Acquisition

A high-quality 3-D seismic survey was completed across the Nash Draw Unit. Based on competitive bidding, this seismic work was awarded to Dawson Geophysical of Midland, Texas. Considerable pre-survey planning was done with Dawson to ensure that optimum fold coverage and an efficient field operation would result. Of particular concern was the fact that local potash mines had flooded a shallow basin in the north-central part of the survey area for many years. The resulting salt lake complicated the 3-D design because no source or receiver stations could be located in these shallow, but caustic, waters.

In the 3-D survey design developed by the Nash Draw team and Dawson Geophysical, receiver lines were oriented north-south, spaced 880 ft apart, and the receiver stations along each line were 110 ft apart. Source lines were oriented east-west, spaced 1320 ft apart, and had source stations at intervals of 220 ft. Additional source lines were added immediately around the lake to ensure that a high stacking fold would occur in as much of the no-access area as possible.

Before potash mining began, the lake area was evidently a source of fresh water and a popular camp site for ancient people. To ensure that the 3-D seismic field activity would not jeopardize the historical value of the area, a thorough archeological investigation was completed along 100-ft wide corridors centered on each source line and each receiver line. The archeological team found a number of areas that they declared off-limits to vehicular traffic. These archeological sites caused the 3-D seismic grid to be altered, with the final source and receiver station configuration being that described in Figure 1. Several source stations were moved or deleted to prevent vibrators from traversing the indicated archeological areas. No receiver stations were moved or deleted because the recording cables and geophone strings were deployed across archeological sites by personnel walking through these restricted areas, which was permissible. Consequently, no design-altering archeological sites are indicated on any of the receiver lines.

Dawson Geophysical used excellent, state-of-the-art equipment for this 3-D seismic program. All of the equipment mobilized at the Nash Draw Unit had been in use less than one year. The seismic recorder was a new I/O System 2 with new cables and geophone strings, which allowed the data to be recorded with a high dynamic range of 24 bits. Equally important, nine Mertz 18HD623 vibrators were on-site. These vibrators are robust and were operated at an 80-percent drive level to produce 42,000 lbs of ground force per vibrator. Because nine vibrators were supplied, two sets of 4-

vibrator arrays were deployed with one vibrator standing by as a backup unit. By using two vibrator arrays, there was no lost recording time because mechanical or electronic problems were avoided and long drive-around times were not required to reach the source stations.

These Mertz vibrators were equipped with Pelton Advance II electronics which allowed precise quality control of each vibrator unit. An example of the fidelity with which the vibrators phase-locked to the specified ground-force sweep function is illustrated in Figure 2. The ground-force reference signal used at Nash Draw was a linear, 6-120 Hz sweep spanning 14 seconds. The top display shows that all eight active vibrators were generating acceptable ground-force magnitudes throughout the desired 6-120 Hz sweep range. More importantly, the bottom display shows that the ground-force output generated by each vibrator was phase-locked to the reference ground-force signal to a tolerance of 5 degrees or less throughout the 6-120 Hz sweep. Most seismic quality-control people allow vibrators to have a phase error of 10 degrees relative to the reference ground-force signal. In the calibration test shown in Figure 2, the 5-degree tolerance across the 6-120 Hz sweep indicates excellent vibrator performance which ensured that consistent wavefields were generated at each source station.

As a result of the effort expended in pre-survey planning and the use of new, state-of-the-art seismic equipment, excellent 3-D data were recorded. These data are now being processed, and examples will be provided in the next quarterly report.

Reservoir Characterization/Reservoir Simulation

Current activities of the Reservoir Characterization/Simulation Team are focused on the development of a geological model as the precursor to numerical simulation of the pilot test for the Nash Draw Unit. The majority of the effort for this quarter was devoted to the completion of the geological model for the Unit begun during the last quarter. At the end of the last quarter, the following maps had been digitized for each of the five main zones of the reservoir: (1) top of structure, (2) gross isopach, (3) porosity-thickness, and (4) net porosity. The resulting files were imported into SGM (Stratigraphic Geocellular Model) to build a 3-D representation of the Unit. Figure 3 illustrates the relationship between the five major producing horizons.

The next step was the development of a Well Attribute model. This activity was supported by the engineering database created and maintained by the team engineer. For each of the following Nash Draw Unit wells (Nash #1, #5, #6, #9, #10, #11, #13, #14, #15, #19, #20, #23, #24, #25), the following attributes were imported into the model:

- neutron porosity, gamma ray
- interpreted porosity, interpreted permeability
- perforated interval, fractured interval
- net pay
- water saturation

In some instances, these attributes were available on a foot-by-foot basis for one or more of the producing zones. Not all of the attributes were available for each well. The distribution of reservoir attributes like conductivity and storage capacity within the producing zones of the Nash Draw Brushy Canyon Unit will be based on the well attribute model. Within SGM these distributions are interpolated deterministically, that is, weighted by the reciprocal of the square of the distance between the location of interest and nearby wells within the reservoir model. The distributions of porosity, net pay, and water saturation were calculated in this manner. As an example, Figure 4 illustrates the distribution of net pay. Discontinuities in the distributions of porosity, net pay, and water saturations (see Figure 5) near wells Nash #1 and Nash #5, for example, demonstrate the need to re-examine the data in these locations.

The simulation team expects to investigate other methods for distributing porosity and permeability, principally *kriging*, in a future version of the geological model. It is not clear whether there are enough well measurements to support statistical methods like kriging.

From the point of view of reservoir simulation, the geological characterization is complete if it characterizes:

- zone structure
- hydraulic conductivity and continuity
- storage capacity

All of these requirements were satisfied with the exception that the distribution of the aqueous phase from the engineering database could not be supported by the structural framework. In particular the "K" and "L" zones require subdivision. This had already been anticipated in a new set of maps received during the quarter from the team geologist. Figure 5 illustrates the preliminary distribution of water based on well log data.

During the course of generating the 3-D model, it was discovered that the interpretation of the top of the "K" layer resulted in a surface that truncated zones below it. It was decided that in addition to mapping subzones in the "K" and "L" sands, all of the zones would be re-interpreted to avoid truncation. This effort will be the basis for a second version of the geological model. The target date for the completion of this model is the end of July 1996.

The future availability of 3-D seismic data will permit the development of a second generation geological model. Such data may support the use of sophisticated linear estimation methods like co-kriging and stochastic simulation. It is anticipated that the pilot simulations will be based on a geological model incorporating kriging to estimate reservoir properties.

Technology Transfer

Mr. Bruce Stubbs presented a Poster Session on May 15 and 16, 1996 at the Shallow Shelf Carbonate Workshop held in Midland, Texas. The workshop was coordinated by DOE, BDM, and the Center for Energy and Economic Diversification.

Preparations are being made for a Technical Committee meeting and a Liaison Committee meeting to be held in Albuquerque, NM on August 16, 1996.

Strata will participate in a workshop on "The Integration of Advanced Reservoir Characterization Techniques," to be held in Roswell, New Mexico on August 22 and 23, 1996.

An Internet Homepage is being designed and should be accessible by early fall.

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Fig. 1. Final 3-D seismic geometry used at Nash Draw.

Fig. 2. One of the calibration tests for the Nash Draw 3-D seismic program.

Nash Draw Project

Significant Pay Zones in the
Stratigraphic Framework Model

Figure 3

Nash Draw Project

Fence Diagram Illustrating
Distribution of Net Pay in the
Stratigraphic Geocellular Model

Figure 4

Nash Draw Project

Fence Diagram Illustrating
Distribution of Water Saturation
in the
Stratigraphic Geocellular Model

Figure 5