PRRC 00-24

FIFTH ANNUAL TECHNICAL PROGRESS REPORT

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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Award Date:	September 25, 1995
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	September 25, 2001 - Budget Period II
Award Amount for Current Fiscal Year:	$2,017,435
Award Amount for Budget Period II:	$5,013,760
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Contracting Officer's Representative:	Dan Ferguson
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US/DOE Patent Clearance is not required prior to the publication of this document.

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ABSTRACT

The Nash Draw Brushy Canyon Pool (NDP) in southeast New Mexico is one of the nine projects selected in 1995 by the U.S. Department of Energy (DOE) for participation in the Class III Reservoir Field Demonstration Program. The goals of the DOE cost-shared Class Program are to: (1) extend economic production, (2) increase ultimate recovery, and (3) broaden information exchange and technology application. Reservoirs in the Class III Program are focused on slope-basin and deep-basin clastic depositional types.

Production at the NDP is from the Brushy Canyon formation, a low-permeability turbidite reservoir in the Delaware Mountain Group of Permian, Guadalupian age. A major challenge in this marginal-quality reservoir is to distinguish oil-productive pay intervals from water-saturated non-pay intervals. Because initial reservoir pressure is only slightly above bubble-point pressure, rapid oil decline rates and high gas/oil ratios are typically observed in the first year of primary production. Limited surface access, caused by the proximity of underground potash mining and surface playa lakes, prohibits development with conventional drilling.

Reservoir characterization results obtained to date at the NDP show that a proposed pilot injection area appears to be compartmentalized. Because reservoir discontinuities will reduce effectiveness of a pressure maintenance project, the pilot area will be relocated to a more continuous part of the reservoir. Most importantly, the advanced characterization results are being used to design extended-reach/horizontal wells to tap into predicted "sweet spots" that are inaccessible with conventional vertical wells.

The activity at the Nash Draw Project during the past year has included the completion of additional zones in four wells, design of the Nash Draw #36 deviated/horizontal well, continued analysis of data, and negotiating a purchase and sale agreement with non-consenting partners.

EXECUTIVE SUMMARY

The use of the Advanced Log Analysis techniques developed from the Nash Draw Project have proven useful in defining additional productive zones and refined completion techniques. The Advanced Log Analysis program proved to be especially helpful in locating and evaluating potential recompletion intervals, which has resulted in low development costs with only small incremental increases in lifting costs. To develop additional reserves at lower costs, zones behind-pipe in existing wells were evaluated using techniques developed for the Brushy Canyon interval. Log analysis techniques developed in Phase I were used to complete a total of eight of the NDP wells in uphole zones. Four wells were recompleted last year which allowed the development of economical reserves during a period of low crude oil prices. An additional four wells were recompleted during this year of the project which resulted in 123,462 BO and 453,424 MCFG reserves being added at a development cost of $1.57 per B.O.E. Based on the technical and economic success of the eight workovers, other project wells are being evaluated for completions in shallower zones.

In order to enhance the ultimate recovery from the NDP project, the plan submitted and approved for Phase II includes directional/horizontal drilling and early pressure maintenance that is designed to develop reserves under surface-restricted areas and potash mines. A major working interest owner has agreed to sell its interest in the Nash Draw Unit to Strata. This consolidation of interests by Strata will greatly simplify and expedite the drilling of deviated/horizontal wells and pressure maintenance. Strata plans to initiate the drilling of the first directional/horizontal data well in the first quarter of 2001.

Continued interpretation of the original 3-D seismic survey using geostatistics and neural networks has resulted in a more complete characterization of the Brushy Canyon reservoir. A new seismic survey is being designed for the north end of the NDP. This new survey will overlap the original survey in an attempt to determine areas of high gas saturation and depletion. Results of the new survey will be instrumental in identifying regions of the reservoir that will be targeted with deviated/horizontal wells in Phase II.

INTRODUCTION

The Nash Draw Pool (NDP) in Eddy County, New Mexico produces oil and associated gas from the Permian (Guadalupian) Brushy Canyon Formation. The Brushy Canyon is a relatively new producer in the Delaware Basin of West Texas, with most drilling having occurred since the late 1980s and many discoveries occurring in the 1990s. Regionally, the fine-grained sandstones of the Brushy Canyon contain as much as 400-800 MMbbls of oil-in-place; thus this formation represents a significant reservoir interval in the Permian Basin. However, low permeability and petrophysical heterogeneity limit primary recovery to only 10-16%.

The NDP is one of the project sites in the Department of Energy (DOE) Class III field demonstration program for slope-basin clastic reservoirs. The objective of the NDP Class III project is to demonstrate that an advanced development drilling and pressure maintenance program can significantly improve oil recovery compared to existing technology applications. A further goal of the project is to transfer these advanced methodologies to oil and gas producers in the Permian Basin and elsewhere throughout the U.S. oil and gas industry.

In the first phase of the NDP project, an integrated reservoir characterization study was performed to better understand the nature of Brushy Canyon production and to explore options for enhanced recovery. Results obtained in the NDP project indicate that a combination of early pressure maintenance (gas injection) and secondary carbon dioxide flooding may maximize production in these complex, laterally variable reservoirs. Because of low permeabilities involved and high water-to-oil relative permeabilities, the use of gas instead of water is suggested as preferable for an oil-mobilizing agent.

The plan submitted and approved for Phase II is to include directional/horizontal drilling and early pressure maintenance to develop reserves under surface-restricted areas and potash mines in order to enhance the ultimate recovery from the project.

RESULTS AND DISCUSSION

This is the fifth annual progress report on the project. Results obtained in the first four years of the project are discussed in previous annual reports[1-4] and in technical papers.[5-11] Results obtained during this reporting period are summarized in this progress report.

Project Management

Reporting

Early in the current project year, the Fourth Annual Technical Progress Report was prepared and submitted to the DOE. Four quarterly reports have been prepared and submitted.

Well Drilling Plans

With the return of higher oil prices and the buyout of non-consenting working interest owners, Strata plans to initiate the drilling of Nash Draw #36 directional/horizontal data well in the first quarter of 2001. In conjunction with the drilling, Strata plans to complete a supplemental 3-D seismic survey over the north end of the Nash Draw Unit.

As technology has advanced, the drilling risk has been reduced and horizontal displacement distance has increased. An attempt will be made to deviate the #36 well 1000 feet northwest of the surface location and then drill 3000 to 4000+ feet horizontally into the middle of Section 11. This will fully develop the seismic amplitude anomaly covering most of Section 11. The original plan was to deviate 930 feet from the surface location and then drill 1120 feet horizontally.

The major consideration now is how to complete the horizontal section. Two options are available, 1) cement casing in the horizontal section and perform multiple stimulation treatments at optimum spacing or, 2) run a ported liner and perform one large stimulation treatment that will induce multiple fractures. Research and modeling will continue to resolve the issue of the best completion practices.

Data and Databases

The NDP production database was updated through August 2000. These data were added to the history of each well to update the decline curves and to project ultimate recoveries as well as to assess the effects of interference and production strategies.

Using an Advanced Log Analysis Procedure for Recompletions

To develop additional reserves at lower costs, behind pipe zones in existing wells were evaluated using techniques developed for the Brushy Canyon interval. The Advanced Log Analysis program proved to be especially helpful in locating and evaluating potential recompletion intervals. This resulted in a low development cost and a small incremental increase in lifting costs. The wells that were completed, as well as treatment costs and incremental reserves, are shown in Table 1 and the individual well decline curves are presented in Figure 1.

The workovers on NDP Wells No. 5, 6, 9 and 11 resulted in 123,462 BO and 453,424 MCFG reserves being added at a cost of $264,251 for a development cost of $1.57 per B.O.E.

Based on the technical and economic success of the eight workovers, other project wells are being evaluated as workover candidates.

Geophysics

Dr. Bob Hardage is designing the seismic survey for the north end of the NDP. It is anticipated that this survey will overlap the original survey in an attempt to determine areas of high gas saturation and depletion. Cost estimates to shoot the survey that have been obtained from seismic contractors range from $15,000 to $18,000 per square mile.

Seismic Analysis

Early in the project, due to a thick high-velocity salt section overlying the Delaware zones in Nash Draw, vertical seismic profiling was used to develop a time-to-depth transform based on the Bone Springs Zone as a definitive marker. The Well #25 VSP was used to create a depth map of the L horizon. Two other depth maps also were created: one used a static adjustment to the better defined Bone Springs Horizon and the other used average velocities calculated at each well. Because the majority of the wells are located in the central part of the field, a possible problem with these maps is that extrapolation of velocity, and thus depth to undrilled parts of the field, may be less useful. Three new time-to-depth transforms were compared during the fourth quarter.

Well log and 3-D seismic data were used to construct three depth maps for the top of the target L horizon of the NDP. The first two depth maps were made using Landmark™ software packages TDQ and Z-map. The third depth map was made using a multilayer perceptron (MLP) neural network to regress for velocity at each seismic bin. At Nash Draw the wells are confined to the central region of the seismic survey, and conventional geostatistics reliably interpolated depths only in the region defined by well control. The MLP approach used the best three of 28 statistically ranked seismic attributes to predict the average velocity field from the surface to the L horizon. Each map was constructed using 15 wells as control points with three wells excluded for testing. Test wells one and two were located away from the control wells and have anomalous average velocities/depths.

The three test wells were used to compare the robustness of the computed depth maps, and all depth predictions were compared to the true depths determined from gamma ray logs for each well. TDQ, Z-map and MLP predicted values within 229.4, 104.7 and 7.6 feet, respectively, at test-well-1; 129.4, 47.7 and 43.7 feet, respectively, at test-well-2; and 12.4, 4.1 and 16.5 feet, respectively, for test-well-3.

Geostatistical methods underestimate the depths to the top of the L for the test wells lying outside the central clustering of control wells, while the MLP solution calculates a relationship that should be valid in each seismic bin in the field. Further refinements in the data and improved methodology are expected to yield a higher degree of accuracy between the real and predicted depths using MLP.

Log Analysis

The usefulness of a Web-based neural network software as a solution to the thin-bed problems associated with resistivity logs was evaluated. The neural network initially was trained and optimized for porosity prediction using full core data and the well logs from the Nash Draw #23 well. Training and optimization of the neural network for S_w, S_o and $S_o*\Phi$ from core measurements was performed to make predictions (validation tests) of other Brushy Canyon wells within the Delaware basin.

Table 2 compiles the neural network results; good correlations were obtained by using the core data as the output data. However the correlation was improved by averaging the core data over 2, 2.5 and 3 ft intervals (approximate interval of logging measurements), The best correlation with core porosity were obtained using a 2 ft interval with 10 input variables (CAL, DPHI, GR, LOG LLD, Log LLS, Log MSFL, NPHI, TNPH, PEF, SP) trained to 0.91 and tested to 0.92.

The neural network provides good correlation between log measurements and core S_w using 2.5-ft interval with 10 input variables trained to 0.79 and tested to 0.82. A poor correlation was obtained between log measurements and core S_o (oil show). The net trained to 0.53 and tested to 0.49 with a 3-ft interval used to average the core measurements. A good correlation was obtained by multiplying core porosity by core oil saturation, S_o. Bulk volume oil, $\Phi*S_o$, averaged over a 2.5 ft interval trained to 0.83 (Fig. 2) and tested to 0.73 as seen in Fig. 3. The predictions are presented in conventional vertical log format.

Since oil shows are a key exploration parameter, this new approach to a direct estimate of a production indicator independent of mud logs or core is significant.

Technology Transfer

Disseminating technical information generated during the course of this project is a prime objective of the project. A summary of technology transfer activities during the current year is outlined below.

Internet Homepage: The address of the Website for the Nash Draw project is: http://baervan.nmt.edu/REACT/Links/nash/strata.html. This site includes an interactive map of logs and production data for the project and the second annual report, including graphics.

Hart's Oil and Gas World
Strata's advanced log analysis program and database management system has won Hart's *Oil and Gas World's* "Best of the Permian Basin – Best New Technology" project award. The project was selected by a panel of judges chosen by the Permian Basin Petroleum Association. The award was presented at the Permian Basin Petroleum Association awards breakfast at the annual meeting held on October 28, 1999 in Midland, TX.

Nash Draw Partners Meeting: A Nash Draw Working Interest Owners meeting was held on May 10, 2000. Members of the technical team presented a comprehensive review of the geological, geophysical, reservoir characterization and simulation results. A plan of development was presented for 2000-2001. This plan included drilling deviated/horizontal wells beneath the potash area to develop high amplitude seismic anomalies and a proposal to convert the Nash #1 to an injection well in order to verify the waterflooding potential. As a result of this meeting, a major working interest owner has agreed to sell its interest in the Nash Draw Unit to Strata. This consolidation of interests by Strata will greatly simplify and expedite the drilling of deviated/horizontal wells and pressure maintenance.

Nash Draw Meeting: In the course of acquiring the 50%+ interest, multiple meetings were held to discuss planning, economics and financing. During these meetings the Nash Draw Project was discussed in detail and the results of the project shown to many different companies and individuals. Some of the companies that were shown the Nash Draw Project were Southern Company, TCW Asset Management Company, Aquila Energy, EnCap Investments, L.C., Duke Energy, Range Resources, Equiva Trading Company, Michael T. Halbouty and Bayless Properties.

SPE Paper #59555
Hart, D.M., Balch, R.S., Tobin, H.J., and Weiss, W.W.: "Time-to-Depth Conversion of Nash Draw "L" Seismic Horizon Using Seismic Attributes and Neural Networks," SPE 59555 was presented at the SPE Permian Basin Oil & Gas Recovery Conference, Midland, Texas, 21-23 March, 2000.

Consortium Meeting: Data from the Nash Draw Project was used for analysis at the meeting, "Reducing Exploration Risk with the Fuzzy Expert Exploration Tool," in Hobbs, New Mexico on November 2, 2000.

CONCLUSIONS

Several conclusions can be drawn from the work done during the fifth year of the NDP project. The use of the Advanced Log Analysis techniques developed from the Nash Draw Project have proven useful in defining additional productive zones and refined completion techniques. The continued interpretation of the 3-D seismic survey using neural networks has resulted in a more complete characterization of the Brushy Canyon reservoir.

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Murphy M.B., et al: "Advanced Oil Recovery Technologies for Improved Recovery from Slope Basin Clastic Reservoirs, Nash Draw Brushy Canyon Pool, Eddy County, New Mexico," Third Annual Report, Cooperative Agreement DE-FC-95BC14941, submitted to the U.S. Department of Energy (October 1998).

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Martin F.D., et al: "Advanced Reservoir Characterization for Improved Oil Recovery in a New Mexico Delaware Basin Project," *Proc.* Fourth International Reservoir Characterization Technical Conference, Houston, (1997) March 2–4, 703-26, and revised in *Reservoir Characterization—Recent Advances*, AAPG Memoir 71, R.A. Schatzinger and J.F. Jordan (eds.), AAPG, Tulsa, (1999) 93-107.

Martin, F.D., et al: "Reservoir Characterization as a Risk Reduction Tool at the Nash Draw Pool," paper SPE 38916 presented at the 1997 SPE Annual Technical Conference & Exhibition, San Antonio, Oct. 5-8, *Proc.*SPE Reservoir Engineering, 751-66, and revised in *SPERE,* **2** (2), (April 1999) 169-79.

Stubbs, B.A., et al: "Using Reservoir Characterization Results at the Nash Draw Pool to Improve Completion Design and Stimulation Treatments," paper SPE 39775 presented at the 1998 SPE Permian Basin Oil and Gas Recovery Conference, Midland, March 23-26.

Martin, F.D., et al: "Implementation of a Virtual Enterprise for Reservoir Management Applications," paper SPE 38868 presented at the 1997 SPE Annual Technical Conference & Exhibition, San Antonio, Oct. 5-8.

Hardage, B.A., et al: "3-D Seismic Imaging and Interpretation of Brushy Canyon Slope and Basin Thin-Bed Reservoirs, Northwest Delaware Basin," *GEOPHYSICS*, Vol. 63 No. 5 (September-October 1998) 1507-19.

Hardage, B.A., et al: "3-D Instantaneous Frequency Used as a Coherency/Continuity Parameter to Interpret Reservoir Compartment Boundaries Across an Area of Complex Turbidite Deposition," *GEOPHYSICS*, Vol. 63 No. 5 (September-October 1998) 1520-31.

Hart, D.M., Balch, R.S., Tobin, H.J., and Weiss, W.W.: "Time-to-Depth Conversion of Nash Draw "L" Seismic Horizon Using Seismic Attributes and Neural Networks," SPE 59555 presented at the SPE Permian Basin Oil & Gas Recovery Conference, Midland, Texas, 21-23 March, 2000.

Table 1. Workover Incremental Increase in Reserves

Table 1

Well	Incremental BO	Incremental MCFG	Actual Cost	Development Cost, $/BOE *
#5	36,912	160,247	$98,978	1.87
#6	62,646	109,809	$109,573	1.49
#9	2,455	67,594	$33,443	3.63
#11	21,449	115,774	$22,257	0.67
Total	**123,462**	**453,424**	**$264,251**	**1.57**

*10 MCFG = 1 BOE

Table 2. Nash Draw #23 Neural Network Training/Test Correlation Coefficients				
Input Variables	Output Var.	Train/Test 2 ft Interval	Train/Test 3 ft Interval	Train/Test 2.5 ft Interval
DPHI, PEF, SP	CoreΦ	0.85/0.84	0.83/0.81	0.83/0.89
Log LLD, Log LLS, PEF, SQRT(PHI)	CoreΦ	0.90/0.85	0.90/0.85	0.91/0.81
Log LLD, Log LLS, SQRT(PHI)	CoreΦ	0.89/0.85	0.90/0.81	0.88/0.91
DPHI, Log, LLD, Log LLS, NPHI	CoreΦ	0.90/0.83	0.89/0.88	0.88/0.94
DPHI, Log LLD, Log LLS, TNPH, PEF	CoreΦ	0.90/0.88	0.90/0.88	0.90/0.82
DPHI, Log LLD, Log LLS, TNPH, PEF, GR	CoreΦ	0.90/0.90	0.92/0.89	0.90/0.88
DPHI, LLD, LLS, PEF, SP	CoreΦ	0.870.87	0.82/0.92	0.84/0.86
DPHI, Log LLD, Log LLS, PEF	CoreΦ	0.89/0.91	0.89/0.89	0.89/0.85
DPHI, Log LLD, Log LLS	CoreΦ	0.90/0.82	0.88/0.91	0.88/0.90
CAL, DPHI, GR, LLD, LLS, MSFL, NPHI, TNPH, PEF, RHOB, SP	CoreΦ	0.88/0.86	0.88/0.85	0.89/0.85
CAL, DPHI, GR, LLD, LLS, MSFL,TNPH, PEF, SP	CoreΦ	0.88/0.86	0.87/0.89	0.87/0.89
CAL, DPHI, GR, LLD, LLS, MSFL, TNPH, NPHI, PEF, SP	CoreΦ	0.88/0.86	0.87/0.86	0.87/0.90
DPHI, LLD, LLS	CoreΦ	0.85/0.85	0.84/0.84	0.84/0.85
DPHI, Log LLD, Log LLS, NPHI, PEF	CoreΦ	0.89/0.88	0.89/0.87	0.90/0.84
DPHI, Log LLD, Log LLS, NPHI, PEF, GR	CoreΦ	0.88/0.89	0.90/0.84	0.90/0.86
DPHI, TNPH, PEF	CoreΦ	0.86/0.83	0..84/0.84	0.84/0.84
DPHI, NPHI, PEF	CoreΦ	0.85/0.85	0.84/0.83	0.84/0.83
CAL, DPHI, GR, Log LLD, Log LLS, Log MSFL, NPHI, TNPH, PEF, SP	CoreΦ	0.91/0.92	0.90/0.87	0.91/0.84
DPHI, PEF, SP	Core S_w	0.73/0.77	0.75/0.74	0.73/0.73
DPHI, LLD, LLS, PEF, SP	Core S_w	0.74/0.65	0.76/0.72	0.76/0.70
GR, LLD, PEF, SP	Core S_w	0.71/0.74	0.74/0.77	0.75/0.77
GR, LLS, PEF, SP	Core S_w	0.72/0.65	0.75/0.77	0.74/0.80
LLD, PEF, SP	Core S_w	0.72/0.73	0.74/0.74	0.74/0.77
GR, Log LLD, PEF, SP	Core S_w	0.71/0.73	0.73/0.79	0.74/0.78
CAL, DPHI, GR, LLD, LLS, MSFL, TNPH, NPHI, PEF, SP	Core S_w	0.75/0.73	0.79/0.71	0.79/0.82
Log LLD, Log LLS, PEF, SQRT(PHI)	Core S_o	0.52/0.50	0.53/0.49	0.52/0.50
DPHI, LLD, LLS, PEF, SP	Core S_o	0.49/0.46	0.52/0.57	0.53/0.59
DPHI, LLD, PEF	Core S_o	0.45/0.47	0.53/0.47	0.53/0.30
GR, LLD, PEF, SP	Core S_o	0.52/0.56	0.54/0.51	0.51/0.51
CAL, DPHI, GR, LLD, LLS, MSFL, TNPH, NPHI, PEF, SP	Core S_o	0.67/0.58	0.68/0.58	0.67/0.45
Log LLD, Log LLS, PEF, SQRT(PHI)	Core S_o*Φ	0.80/0.80	0.82/0.79	0.82/0.76
CAL, DPHI, GR, LLD, LLS, MSFL, TNPH, NPHI, PEF, SP	Core S_o*Φ	0.82/0.63	0.83/0.73	0.81/0.74

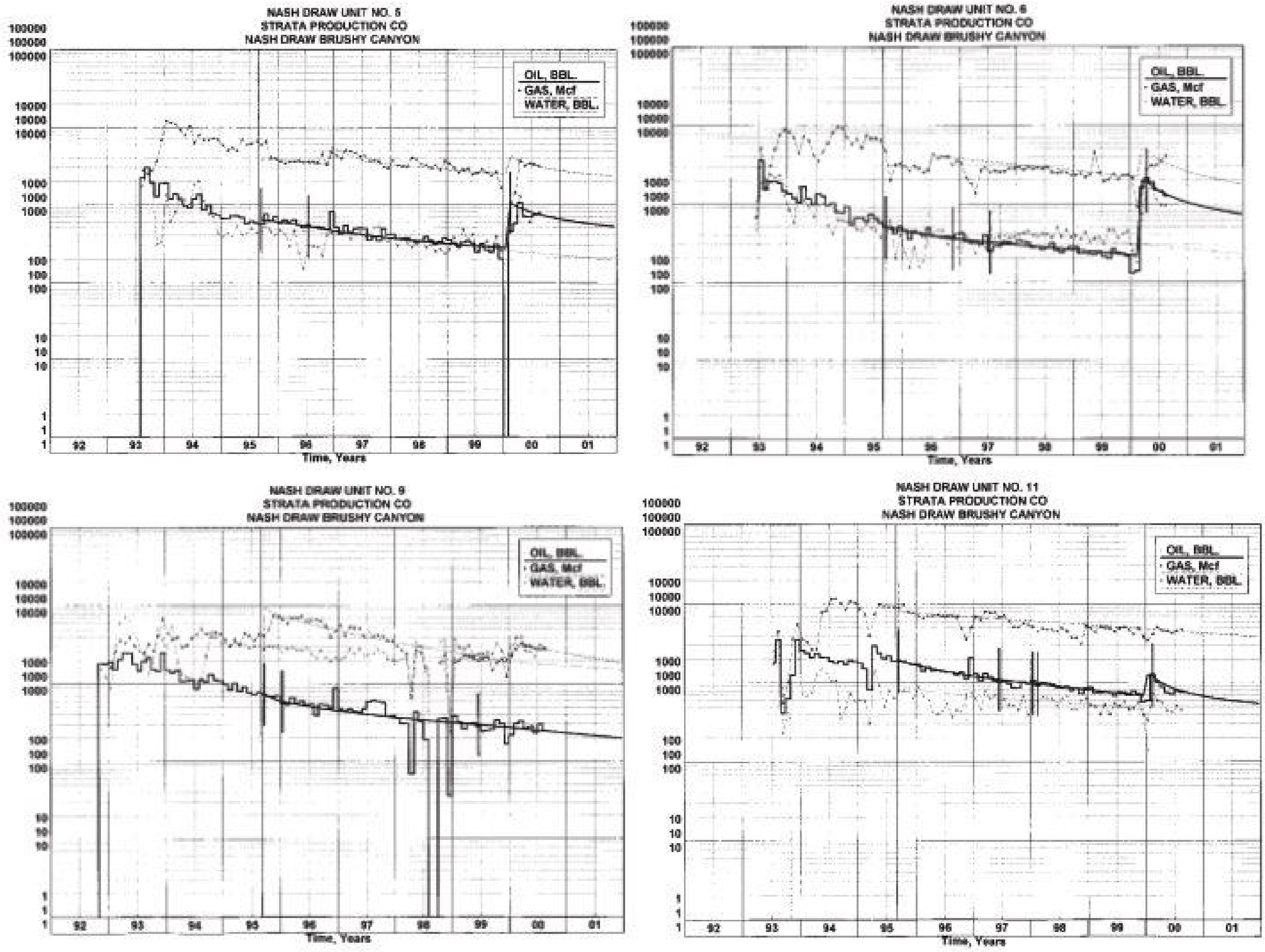

Fig. 1. Decline curves from the four workover wells.

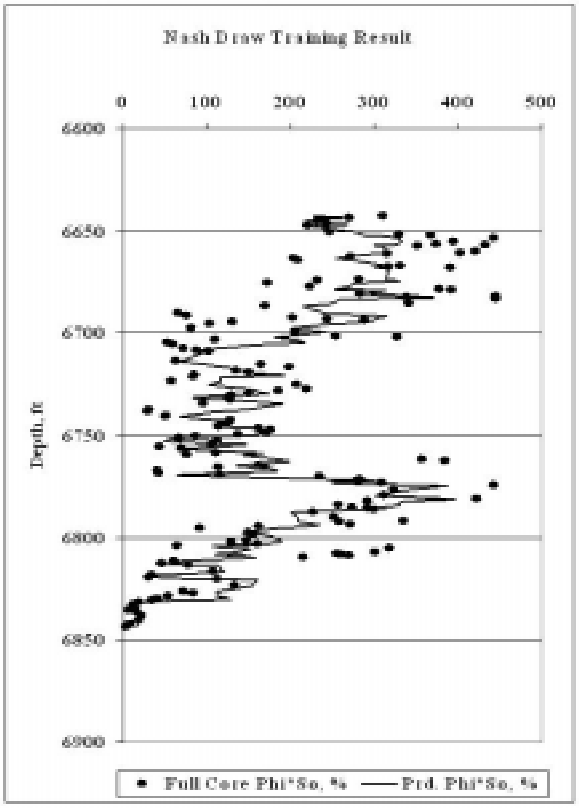

Fig. 2. Training to 83% correlation coefficient.

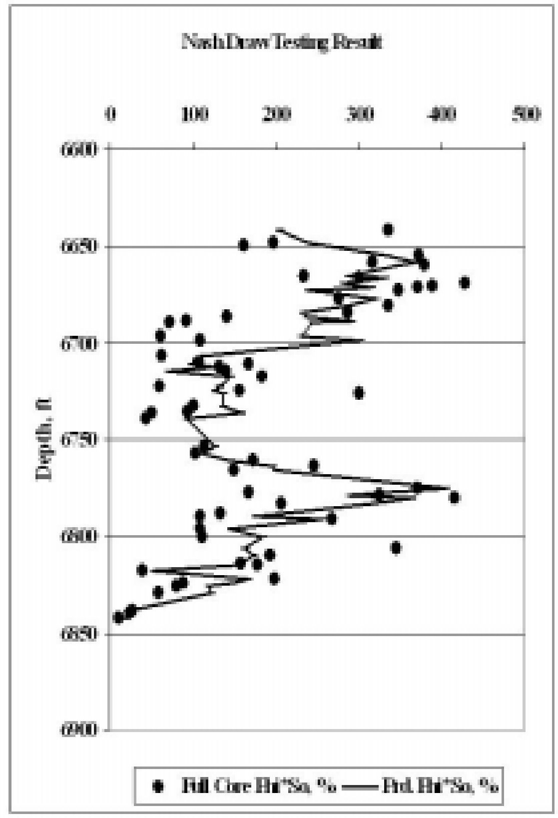

Fig. 3. Training to 73% correlation coefficient.