IMPROVED RECOVERY DEMONSTRATION FOR WILLISTON BASIN CARBONATES

Cooperative Agreement DE-FC22-94BC14984

Luff Exploration Company
Denver, Colorado

Award Date: June 10, 1994
Completion Date: June 9, 1997

Government Award for Budget Period 1 - June 10, 1994 through June 9, 1995
$483,284

Project Manager: Larry A. Carrell (Luff Exploration Company)
DOE Project Officer: Chandra Nautiyal

Reporting Period: January 1, 1995 through March 31, 1995

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TABLE OF CONTENTS

Objectives ........................................................................... 1

Executive Summary ............................................................. 1

Summary of Technical Progress ............................................. 2

   Reservoir Analysis and Characterization ............................. 2
   Producibility Problem Characterization and Analysis ............. 5
   Recovery Technology Evaluations .................................... 8
   Associated Technology Transfer Activities ......................... 10

Plans and Schedule for Next Quarter ..................................... 10

Administrative ................................................................... 10

References ........................................................................ 10

Figures ........................................................................... 11

   Figure 1: Red River Study Area with Cores ....................... 11
   Figure 2: Red River Type Log, Stearns A-19 ..................... 12
   Figure 3: Ratcliffe Study Area with Well and Seismic Activity . 13
   Figure 4: Red River Study Area with Well and Seismic Activity . 14
   Figure 5: Ratcliffe Type Log, Trudell M-17 ....................... 15
   Figure 6: Production Signature Plots, Trudell M-17 ............. 16
   Figure 7: Production Type Curve, Trudell M-17 ................. 17
   Figure 8: Pressure Buildup Plots, Trudell M-17 .................. 18
   Figure 9: Red River Porosity Log, Hansen 1-21 ................. 19
   Figure 10: Production Signature Plots, Hansen 1-21 .......... 20
   Figure 11: Production Type Curve, Hansen 1-21 ............... 21
   Figure 12: Pressure Buildup Plots, Hansen 1-21 ............... 22
   Figure 13: Pressure Buildup Plots, Stearns A-19 ............... 23

Management Summary Report Form 4600.5 .......................... 24
IMPROVED RECOVERY DEMONSTRATION FOR
WILLISTON BASIN CARBONATES

Objectives

The purpose of this project is to demonstrate targeted infill and extension drilling opportunities, better determinations of oil-in-place, methods for improved completion efficiency and the suitability of waterflooding in certain shallow-shelf carbonate reservoirs in the Williston Basin, Montana, North Dakota and South Dakota.

Executive Summary

- Cores from five Red River wells in the Bowman-Harding study area have been examined and described in detail.
- Contracts have been awarded for a 3-D survey in Bowman Co., ND and a 2-D, multi-component survey in Richland Co., MT. Acquisition will begin when the ground dries and surface conditions improve.
- Extended-time pressure buildup data have been analyzed from two wells which are candidates for jetting-lance completion workovers.
- A 20-day injectivity test has been completed in the Red River (upper member).
- A jetting-lance completion program has commenced with one job completed and three more scheduled during April.
- Reservoir data from three key Red River fields in the Bowman-Harding study area has been researched and accumulated for inclusion in the TORIS database and technology transfer activities.
- Delays in seismic acquisition and jetting-lance well-completions have prompted a request for a 90-day, no-cost extension of Budget Period 1.
Core Studies

Five Key Ordovician Red River Formation slabbed cores from Bowman Co., ND and Harding Co., SD have been examined and described in detail at the U.S. Geological Survey Core Research Center, Lakewood, CO. Documentation of all important rock facies, sedimentary structures and diagenetic fabrics has been completed via numerous close-up photos and 35 mm slides. The core work to-date consists of approximately 380 linear ft (116 m) of slabs that provide excellent coverage of the lower porosity member of the Red River in the study area (see Table 1 and Figure 1). A small amount of upper and middle Red River porosity member core has been examined, but additional material currently at the North Dakota Geological Survey Core Depository (Grand Forks, ND) and the South Dakota Geological Survey (Vermillion, SD) is being identified for detailed study of the upper two Red River zones. Thirty-eight standard thin sections from four wells in the area have been borrowed from the U.S. Geological Survey for petrographic description under polarized and blue-light epi-fluorescence techniques as well as photo-documentation. A few additional thin sections may be prepared in order to microscopically examine key facies and diagenetic features in the cores studied to date. In addition, the U.S. Geological Survey records have been searched to obtain the results of previous core descriptions, core analysis and other geological work for the Red River study area. Finally, published literature, previous core studies and Luff Exploration Company data on the Red River have been reviewed in order to integrate earlier work into the current Red River reservoir characterization.

A preliminary depositional and early diagenetic model has been developed for the lower porosity member of the Red River formation (see Figure 2) because it is the best represented within the core work to date. Many of the burrow-mottled rocks of the lower member are believed to be the result of storm-wave pumping on a storm-dominated shelf of shallow to moderate water depth. The modified "tempestites" that result in the best quality dolomite reservoirs were originally carbonate sands (grainstones and packstones) that were introduced into open burrow systems within shelf muds during major storm events. Dolomitization, differential compaction and stylolite formation were largely controlled by the distribution of probable linear bands of "tempestite" burrow fills. Subsequent fracturing with solution-enlargement develop orientations largely controlled by stylolite formation. This new integrated depositional and diagenetic model for the lower Red River zone for the project area should assist in determining the best
reservoir development strategies.

Efforts have been made to locate cores for the Mississippian Ratcliffe member of the Charles formation in Richland Co., MT and McKenzie Co., ND. Core material is very limited for the study area, but two or three key cores may be available within the collections of the North Dakota Geological Survey and the Montana Board of Oil and Gas (Billings). These cores will be examined, described and photo-documented in the near future. Appropriate samples will be selected for thin section analysis. The limited number of pertinent cores may be supplemented with examinations of drill cuttings from key wells.

Table 1: Red River Cores Processed

<table>
<thead>
<tr>
<th>Core</th>
<th>Location</th>
<th>Red River Lower Member</th>
<th>Red River Upper Member</th>
<th>Red River Middle Member</th>
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<tr>
<td>Luff 1-6 Travers</td>
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<td>9,957-9,022 ft (gross 65 ft)</td>
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<td>Tenneco 1-6 Schaaf</td>
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<td>9,275-9,303 ft (gross 28 ft)</td>
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<td>Amarillo 1-24 Ernest Fossum</td>
<td>(NWNE Sec. 24, T130N-R104W)</td>
<td>9,419-9,4780 ft</td>
<td>9,504-9,557 ft (gross 53 ft)</td>
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3-Component Seismic Acquisition

A contract has been awarded to Reliable Exploration for acquisition of a 2.5 mile, 2-D 3-component test line. This test is expected to aid in determination of the application of shear waves for fracture detection in the North Sioux Pass (Ratcliffe) T26N, R57-58E, Richland Co., MT study area (see Figure 3). Permit and weather problems have delayed acquisition. It became necessary to relocate the line to avoid skipped shots for water wells and additional delays occurred. The line has
been surveyed and should be drilled by late April or early May. The special three-component geophone strings were rented from the Colorado School of Mines and have been shipped to Billings, MT for testing in Reliable's field office prior to being sent to Sidney for operations. The area is still experiencing some late spring snowfall which might delay shot hole drilling, but is not expected to hamper recording once the source holes are drilled and loaded.

Seismic Interpretation

Three additional sets of 1970's vintage 2-D data were selected for reprocessing and interpretation. Two lines for a total of 7.0 miles in the Mrnak area (T130N-R102W) and three lines (9.51 miles) in the Haley area in T129N-R101W have been reprocessed with radon stack and refraction statics. Two lines (6.33 miles) have also been added in the Stateline (T129N-R103W) area (see Figure 4). These data have been interpreted and are incorporated into a series of detailed study area seismic maps for Bowman County, ND. The Haley area shows two large faults with some suggestion of lateral displacement along them. The Stateline area is complex and has a significant number of mid-size faults. The Mrnak area is a northwest extension of the Cold Turkey Creek area and has a similar structural trend.

3-D Seismic Acquisition

Reliable Exploration Inc. has been contracted for the acquisition of a 4.35 square mile 3-D seismic survey in the Cold Turkey Creek (Red River) area (T130N-R102W, Bowman Co., ND). The area was permitted and surveyed in anticipation of acquisition in March. Approximately one-third of the 378 source holes were drilled and loaded with dynamite. The unusually warm winter has resulted in periodic snowfall followed by brief warm periods. Muddy conditions have prevented the use of heavy drilling equipment in the area and the remaining source holes have not been drilled. Where other crews have attempted operations in the northern part of the basin, environmental surface damage has been severe. Reliable continues to attempt to make progress on the project and expects to complete it rapidly when the area becomes dry. It is anticipated that acquisition will not commence before May 1.

Geological Evaluations

Regional structure and isopach interpretations have been completed in the four-township Richland-Ratcliffe study area. Depth structure of the Ratcliffe with isopachs of the Last Charles Salt, Ratcliffe, and Midale-Bakken intervals have been completed using well-log data.
Regional mapping of structure and isopachs is near completion in the Bowman-Harding Red River study area. Red River depth-structure has been completed. Isopachs of the Greenhorn-Mission Canyon, Mission Canyon-Interlake, Interlake-Red River and Red River are near completion for the 40 by 24 mile regional study area.

Project Related Field Data for Selected Fields

Preliminary engineering and geological descriptions of four of six key Red River fields in the Bowman-Harding area have been completed for the following:

- Medicine Pole Hills
- West Buffalo Red River "B" Unit
- North Buffalo
- South West Amor

These Red River fields have been under or are candidates for secondary recovery. Data have been tabulated per guidelines from the DOE Project Manager (Coop Agreement Attachment C-6 through C-13) for inclusion in the Project Data Set.

PRODUCIBILITY PROBLEM CHARACTERIZATION

Extended-time pressure buildup data were obtained from the Trudell M-17 (Ratcliffe) and Hansen 1-21 (Red River) to provide base-line data for permeability-thickness (kh) and stimulation factor (S). These base-line data are part of the reservoir-characterization attributes being collected for each reservoir study area and also will be used for purposes of comparison after jetting-lance stimulation work.

Trudell M-17 (Ratcliffe) Pressure Buildup Evaluation
North Sioux Pass Field Area, API No. 25-083-200932
Sec 17, T26N-R58E, Richland Co., MT

The Trudell M-17 well was completed in the Ratcliffe reservoir in March 1993 after an unsuccessful completion in the Red River. The well was perforated from 8,701 to 8,759 ft and fracture stimulated with 105,000 gal gel-water and 204,000 lb sand. The neutron-density porosity log of the completion interval is shown in Figure 5. Net productive thickness of the Ratcliffe member is indicated to be about 10 ft with average porosity of 10 percent. Porosity development based on log data is better than average for the Ratcliffe member in the immediate area. The well had an initial rate of 77 bopd with 65 bwpd and has cumulative oil production of 15,430 bbl as of March 31, 1995. Production history is displayed in Figure 6.

The production rate versus time and cumulative plots show a sharp initial decline and shallow decline rate after a period of six months. The water-cut has
been relatively constant at 55 percent of fluid production. Similarly, the gas-oil ratio is also constant from 500 to 700 scf/bbl. Fetkovich production type-curve analysis indicates a small Rd ratio of 10 and that production is still in the transient-flow regime even after two years (see Figure 7). The expected ultimate recovery from the type-curve analysis is 57,000 stb or 12 percent of OOIP in the 129 acre drainage area. The apparent drainage-area of 129 acres is based on certain assumptions of fluid and reservoir properties. The primary properties affecting this calculation are system compressibility of 25E-6 vol/vol/psi and 10 ft of net pay with 12 percent porosity (see Figure 7 for all parameters).

A pressure buildup test was performed in November and December 1994 with a total shut-in time of 332 hrs. The producing rate at the time of the buildup test was 20 bopd and 20 bwpd (pumping). An automated acoustic recorder with computer software was used to convert echo travel-time and casing pressure to bottomhole pressure. A significant characteristic of the pressure data is exhibited by a semi-log MDH plot which is shown on Figure 8. The pressure trend with the logarithm of time is upwardly curving throughout the test indicating a large negative skin in a low-permeability matrix. Indeed, significant negative skin is expected from the large-volume fracture stimulation which was applied to the Ratcliffe.

The transmissibility (kh/UB) to oil is about 7 md-ft/cp and the transmissibility to total fluid (oil and water) is about 10 md-ft/cp. Permeability to oil (Kro) is calculated to be 0.5 md. At late-time on the Miller-Dyes-Hutchinson (MDH) plot, it is observed that there is an upwardly break in slope. This suggests a linear boundary such as a fault. Distance to this possible linear boundary is indicated to be 140 ft. The presence of a linear boundary and well-bore storage make it difficult to confidently determine the skin factor "S" and effective fracture length. Semi-log and radial type-curve analysis indicate a "S" of -4 to -5. Analysis using Greengarten infinite-conductivity fracture curves also indicate a kh/UB to oil of 4 md-ft/cp, Kro of 0.3 md and a fracture half-length of about 150 ft. The radius of investigation for the buildup test is determined to be from 290 to 370 ft using Kro of 0.3 md.

The Ratcliffe member was drill-stem tested when it was penetrated during drilling operations. The test recovery was only drilling mud at a calculated flow rate of 8 bpd. Type-curve and semi-log analysis of the drill-stem test data indicate a transmissibility (kh/UB) of 3 to 4 md-ft/cp and an initial reservoir pressure of about 3,800 psi. The results from this DST are considered a poor show since most drill-stem tests of the Ratcliffe yield some frothy oil with oil-cut mud.

Analysis of the production data using the type-curve method of Fetkovich indicates small Rd ratio of 10, a permeability to oil (Kro) of about 0.1 md and a skin factor "S" of -5.8 (see Figure 7). This method yields a permeability to oil which is
about 20 to 33 percent of the values determined from pressure-transient analysis methods and greater negative skin. It is postulated that a reason for the indications of lesser permeability and greater negative skin factor is the presence of a linear boundary which is suggested from the pressure buildup analysis. The presence of a linear flow barrier (a possible fault) would change the drainage shape factor from radial and result in under-estimation of permeability and over-estimation of the stimulation effect. The presence of a flow barrier can explain why the well performance has been less than expected using the criteria of favorable porosity development based on log character.

The Trudell M-17 well is scheduled for workover using jetting-lance technology. Following this work, the well will be produced for four to six weeks and shut-in for a pressure buildup test.

Hansen 1-21 (Red River) Pressure Buildup Evaluation
Haley Field Area, API No. 33-011-31900
Sec 21, T129N-R101 W, Bowman Co., ND

The buildup test data from October 18 through November 1, 1994 indicate non-radial drainage for the Hansen 1-21 well. The final bottomhole pressure was about 1,550 psi and still building after 329 hours of shut-in time. A possible cause for the non-radial flow is a nearby fault or series of parallel faults.

The Hansen 1-21 well was drillstem tested in the Red River upper member on August 6, 1980. The test has a calculated flow rate of about 177 bopd with no water reported for the pipe or sample chamber recovery. The transmissibility (kh/UB) from the test data is calculated to be 38 md-ft/cp and is near the mean value from the many DST data of the Red River upper member in the Bowman-Harding area. The initial extrapolated pressure (P*) was calculated in 1980 to be 3,930 psi which was slightly less than the original pressure (P*) of 4,200 psi at the Jett 1-28 well (offset well located about one-half mile toward the southwest, see Figure 4). It is noted that the difference between the initial and final extrapolated (P*) pressures of the DST is 91 psi. This pressure drop may suggest a limited or bounded reservoir. It was reasoned at the time of completion of the Hansen 1-21 well that the reservoir surrounding the Hansen 1-21 should not be limited if the Hansen 1-21 DST indicated communication (drawdown) with the Jett 1-28 well. It is also noted that the productivity or transmissibility of the upper Red River member in the Hansen 1-21 is about twice that of the Jett 1-28 well based on the DST data.

The Hansen well was perforated in the Red River upper member and stimulated with 2,000 gal of 15% HCl. A copy of the porosity log from the Hansen well is shown in Figure 9. The peak production rate was 80 bopd with 23 bwpd on the second day of production. Production quickly declined to 25 bopd with 15 bwpd
after two weeks. Cumulative production is 33,961 bbl of oil as of March 1995.

Production signature plots for the Hansen 1-21 well are shown in Figures 10 and 11. Type-curve analysis of the production data indicate a low permeability to oil (kro) of 0.06 md with an apparent large negative skin "S" of -5.6. The ultimate recovery from the Red River upper member is projected to be 8.9 percent of the OOIP (375,000 bbl) and the apparent drainage area is 85 acres. The primary properties affecting this calculation are system compressibility of 25E-6 vol/vol/psi and 6 ft of net pay with 20 percent porosity (see Figure 11 for all parameters).

The pressure data exhibit an upward-curving trend with the logarithm of time and do not bend-over (see Figure 12). Conventional MDH semi-log analysis of the late-time trend indicates a transmissibility of 1.6 md-ft/cp and a skin of -4.3. However, a better analysis is achieved by analytical simulation methods of the well between two parallel faults. A good history-match of the pressure data can be achieved with this reservoir model and also using the transmissibility from the DST (36 md-ft/cp). Using the parallel-fault reservoir model in simulation of the DST pressure data also produces a better history-match than a radial reservoir model. With the parallel-fault model, the initial pressure of the Red River upper member in the Hansen well is determined to be nearly 4,200 psi and closely matches the original pressure of the Jett 1-28 well in March 1974. Acceptance of this reservoir model leads to the conclusion that the two wells are not in good hydraulic communication.

Re-interpretation of 2-D seismic data in the Haley area indicates probable subtle faulting very near the Hansen 1-21 well. This fault trend runs northwest-southeast. The presence of a fault or series of parallel faults can explain the poor performance of the Hansen 1-21 well compared to the results from the drill-stem test.

The Hansen well will be re-stimulated using jetting-lance technology. Following this work, the well will be produced for four to six weeks and shut-in for a pressure buildup test.

RECOVERY TECHNOLOGY EVALUATIONS

Stearns A-19 (Red River) Injectivity Test
North Buffalo Field Area, API No. 40-063-20368
Sec. 19, T22N-R4E, Harding Co., SD

A 20-day water injection test commenced on March 23 in the Stearns A-19 well (Figure 2 shows Red River porosity development in the well and Figure 4 shows the well location in the study area). Water was injected at 100 bpd into the
15-foot Red River upper member at 8,774 ft with pressure gauges on bottom for the duration of the test. The pressure data do not exhibit anomalies which would suggest nearby flow barriers or transmissibility changes (see Figure 13). The reservoir characteristics from the pressure transient analysis are as follows:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Static reservoir pressure at start</td>
<td>2,273 psi</td>
</tr>
<tr>
<td>Water transmissibility (kh/UB)</td>
<td>45.5 md-ft/cp</td>
</tr>
<tr>
<td>Water permeability (Krw)</td>
<td>0.88 md</td>
</tr>
<tr>
<td>Skin factor &quot;S&quot;</td>
<td>-3.2</td>
</tr>
<tr>
<td>Final injection pressure at end</td>
<td>3,625 psi</td>
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</table>

The results from this test indicate that the maximum stabilized injection rate would be about 150 bwpd at a parting pressure of 5,500 psi. This injectivity can be equated to about 10 bwpd per foot of net pay.

A jetting-lance completion will be performed on the Red River upper member followed by a repeat of the injectivity test. Pressure transient data from both tests will be compared to determine if the jetting-lance workover produces a change in apparent transmissibility (Kh/UB) or skin "S".

Hansen 1-21 (Red River) Jetting Lance Stimulation
Haley Field Area, API No. 33-011-31900
SWSE Section 21, T129N-R101W, Bowman Co., ND

Jetting-lance perforations were made into the Red River upper and middle members using a commercially available service (Penetrators, Inc.). Four holes were made to a penetration depth of 10 ft in each porosity member (see Figure 9). The penetration of 10 ft is the maximum capability from this tool design. If there is an increase in oil rate, the zones will be isolated by a bridge plug to determine the production from each zone. The well has been recently placed back on production but there are no production figures to report at this time. There should be 60 days of production data to present for the next quarterly report.

Ratcliffe Hydraulic Fracture Stimulations

Fracture stimulation-type and volume have been tabulated for 14 key wells in the Richland-Ratcliffe study area. These unique wells had been initially completed with only an acid break-down treatment and were produced for a short of several months to a year before being hydraulically fractured. The production and decline characteristics of these wells provide an opportunity to quantify kh, S and reserves before and after hydraulic fracture stimulation treatments. These data will be included in base-line data for comparison of jetting-lance completion efficiency and cost.
ASSOCIATED TECHNOLOGY TRANSFER ACTIVITIES

Project Related Field Data for Selected Fields

Preliminary engineering and geological descriptions of four of six key Red River fields in the Bowman-Harding area have been completed for the following:

Medicine Pole Hills  West Buffalo Red River "B" Unit
North Buffalo        South West Amor

These Red River fields have been under or are candidates for secondary recovery. Data have been tabulated per guidelines from the DOE Project Manager (Coop Agreement Attachment C-6 through C-13) for inclusion in the Project Data Set.

Plans for Next Quarter

Acquisition of 3-D seismic at Cold Turkey Creek (Red River) and 2-D 3-C seismic at Cattails (Ratcliffe) should proceed promptly when weather and ground conditions improve. Jetting-lance completions are in progress. Four to six completions with a lance tool are planned for the next quarter using a new design (not commercially available) which should have greater penetration capability than the tool design used on the Hansen 1-21 well. A post jetting-lance injectivity test will be performed in the Red River upper member at the Stearns A-19 well. Data collection and reservoir characterization studies of key Red River and Ratcliffe fields will be completed.

ADMINISTRATIVE

A letter was sent to David Hunter (Contract Officer, PETC) on April 11, which requested a no-cost extension of Budget Period 1 until September 1, 1995. The primary reasons for requesting the extension are delays in securing field services and adverse weather conditions.

References


Figure 1. Bowman-Harding Red River study area map showing locations of Red River cores which have been examined and described for the project.
Figure 2. Red River type-log showing development of the Upper, Middle and Lower porosity members. Log is from the A-19 Stearns, North Buffalo field area, Sec. 19, T22N-R4E, Harding Co., SD.
Figure 3. Richland-Ratcliffe study area map showing location of Trudell M-17 well. This well has been utilized for pressure transient testing prior to jetting-lance stimulation workovers.
Figure 4 Bowman-Harding Red River study area map showing locations of the Hansen 1-21 and Stearns A-19 wells. These wells have been utilized for pressure transient testing prior to jetting-lance stimulation workovers.
Figure 5. Gamma ray with density-neutron porosity log from the Trudell M-17 well, Sec 17, T26n, R58E, Richland Co., MT.
Figure 6. Production signature plots from the Trudell M-17 (Ratcliffe) Sec. 17, T26N, R58E, Richland co., MT.
Figure 7. Fetkovich production type-curve match of data from the Trudell M-17 (Ratcliffe). A small Rd of 10 indicates a large negative skin or a non-radial shape factor. The apparent drainage area is 129 acres.
Figure 8. Pressure buildup plots from the Trudell M-17 (Ratcliffe). A slope change during late-time on the MDH plot suggests a linear barrier.
Figure 9. Gamma ray with density-neutron log from the Hansen 1-21 (Haley) well. Four holes were made each in the Upper and Middle Red River porosity members with jetting-lance tools.
Figure 10. Production signature plots from the Hansen 1-21 (Red River), Sec. 21, T129N, R101W, Bowman Co., ND.
Figure 11. Fetkovich production type-curve match of data from the Hansen 1-21 well. A recovery factor of 8.9 percent is indicated from a drainage area of 85 acres.
Figure 12. Pressure buildup plots from the Hansen 1-21 well. Analytical simulation methods indicate a narrow drainage shape as a possible reservoir model for this well.
Figure 13. Water injectivity and pressure buildup test results from the Red River upper member in the Stearns A-19 located in Sec. 19, T22N, R4E, Harding Co., SD. The 20 day test indicates the maximum stabilized injection rate would be 150 bwpd at fracture pressure.
**U.S. DEPARTMENT OF ENERGY**

**FEDERAL ASSISTANCE MANAGEMENT SUMMARY REPORT**

OMB Control No. 1910-0400

**OMB Burden Disclosure Statement**

Public reporting burden for this collection of information is estimated to average 3.38 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Office of Information Resources Management, AD-244-GTN, Paperwork Reduction Project (1910-0400), U.S. Department of Energy, 1000 Independence Avenue, S.W., Washington, DC 20585, and to the Office of Management and Budget (OMB), Paperwork Reduction Project (1910-0400), Washington, DC 20503.

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**1. Program/Project Identification No.**
DE-FC22-94BC14984

**2. Program/Project Title**
Improved Recovery Demonstration for Williston Basin Carbonates

**3. Reporting Period**

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1994: $966,568
Total Project: $3,556,028

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**4. Name and Address**
Luff Exploration Company
1580 Lincoln Street, Suite 850
Denver, Colorado 80203

**5. Program/Project Start Date**
10 June 1994

**6. Completion Date**
9 June 1997

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**7 FY 8. Months or Quarters**

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**9. Cost Status a Dollars Expressed in**

- Dollars Scale

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**10. Cost Chart**

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**11. Major Milestone Status**

1) Reservoir Character - P 1128 C 1461
2) Productivity Problems - P 208 C 7
3) Recovery Technology - P 208 C 52
4) Technology Transfer (1) - P 304 C 23
5) Continuation Activities - P 96 C 45
6) Project Management - P 0 C
7) NEPA Compliance - P 3104 C
8) Field Demonstrations - P 1216 C
9) Technology Transfer (2) - P

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**12. Remarks**

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

[Signature]

4/28/95