QUARTERY TECHNICAL PROGRESS REPORT
FOR THE PERIOD ENDING DECEMBER 31, 2000

TITLE: FIELD DEMONSTRATION OF CARBON DIOXIDE MISCIBLE FLOODING IN THE LANSING-KANSAS CITY FORMATION, CENTRAL KANSAS

DOE Contract No. DE-AC26-00BC15124

Contractor:	University of Kansas Center for Research, Inc. 2385 Irving Hill Road Lawrence, KS 66044
DOE Program:	Class II Revisited - Field Demonstrations
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Program Period:	March 8, 2000 – March 8, 2006 (BP1 03/00-03/01, BP2 03/01-03/05, BP3 03/05-03/06)
Reporting Period:	October 1, 2000 – December 31, 2000
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ABSTRACT:

Progress is reported for the period from October 1, 2000 to December 31, 2000. The Carter-Colliver #1 CO2 I was drilled at the end of the last quarter and completed and logged at the beginning of this quarter (Task 2.1). In this quarter analysis was performed on the logs and cores from the Murfin Drilling Company Carter-Colliver #1 CO2 I well. Log and core data from the new Carter-Colliver #1 CO2 I injection well have been collected, formatted and placed on the website (Task 1.1), and analyzed (Tasks 2.1.2, 2.1.3, 2.1.4). Both logs and core have been analyzed to evaluate residual oil saturation in the reservoir (Task 2.2.1). In addition, routine and advanced core analysis has been performed (Tasks 2.2.3, 2.2.5, and 2.2.6). The available core has been described (task 2.2.7) and all data are being integrated into the existing geomodel of the reservoir.

Porosities in the "C" zone are higher than predicted. Permeabilities are similar to predictions in the upper portion of the "C" zone but are lower in the lower portion. Archie cementation exponents are high and increase with increasing porosity. Residual oil saturation to waterflood, a key parameter for project continuation, averages 28% in routine core, 27.4% in coreflood tests, and is measured as ranging from 30-40% in the "C" zone using wireline logs. The high-pressure core exhibits 10% residual saturation but is highly disaggregated and is believed to have been extensively flushed. Regional resource assessment indicates the Lansing-Kansas City may have insufficient resource under certain economic conditions to support a pipeline alone. Resource characterization of the Arbuckle is being performed.

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INTRODUCTION

Objectives - The objective of this Class II Revisited project is to demonstrate the viability of carbon dioxide miscible flooding in the Lansing-Kansas City formation on the Central Kansas Uplift and to obtain data concerning reservoir properties, flood performance, and operating costs and methods to aid operators in future floods. The project addresses the producibility problem that these Class II shallow-shelf carbonate reservoirs have been depleted by effective waterflooding leaving significant trapped oil reserves. The objective is to be addressed by performing a CO_2 miscible flood in a 40-acre pilot in a representative oomoldic limestone reservoir in the Hall-Gurney Field, Russell County, Kansas. At the demonstration site, the Kansas team will characterize the reservoir geologic and engineering properties, model the flood using reservoir simulation, design and construct facilities and remediate existing wells, implement the planned flood, and monitor the flood process. The results of this project will be disseminated through various technology transfer activities.

Project Task Overview -

Activities in Budget Period 1 (03/00-03/01) involve reservoir characterization, modeling, and assessment:

- Task 1.1- Acquisition and consolidation of data into a web-based accessible database
- Task 1.2 - Geologic, petrophysical, and engineering reservoir characterization at the proposed demonstration site to understand the reservoir system
- Task 1.3 - Develop descriptive and numerical models of the reservoir
- Task 1.4 - Multiphase numerical flow simulation of oil recovery and prediction of the optimum location for a new injector well based on the numerical reservoir model
- Task 2.1 - Drilling, sponge coring, logging and testing a new CO2 injection well to obtain better reservoir data
- Task 2.2 - Measurement of residual oil and advanced rock properties for improved reservoir characterization and to address decisions concerning the resource base
- Task 3.1 - Advanced flow simulation based on the data provided by the improved characterization
- Task 3.2 - Assessment of the condition of existing wellbores, and evaluation of the economics of carbon dioxide flooding based on the improved reservoir characterization, advanced flow simulation, and engineering analyses
- Task 4.1 – Review of Budget Period 1 activities and assessment of flood implementation

Activities in Budget Period 2 (03/01-03/05) involve implementation and monitoring of the flood:

- Task 5.1 - Remediate all wells in the flood pattern
- Task 5.2 - Re-pressure the pilot area by water injection
- Task 5.3 - Construct surface facilities
- Task 5.4 - Implement CO_2 flood operations
- Task 5.5 - Analyze CO_2 flooding progress - carbon dioxide injection will be terminated at the end of Budget Period 2 and the project will be converted to continuous water injection.

Activities in Budget Period 3 (03/05-03/06) will involve post-CO2 flood monitoring:

- Task 6.1 – Collection and analysis of post-CO2 production and injection data

Activities that occur over all budget periods include:

- Task 7.0 – Management of geologic, engineering, and operations activities
- Task 8.0 – Technology transfer and fulfillment of reporting requirements

EXECUTIVE SUMMARY:

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Porosities are higher than predicted. Permeabilitiesa re similar to predictions in the upper portion of the "C" zone but are lower in the lower portion. Archie cementation exponents are high and increasing with increasing porosity. Residual oil saturation to waterflood, a key parameter for project continuation, averages 28% in routine core, 27.4% in coreflood tests, and is measured as ranging from 30-40% in the "C" zone using wireline logs. Regional resource assessment indicates the Lansing-Kansas City may have insufficient resource under certain economic conditions to support a pipeline alone. Resource characterization of the Arbuckle is being performed.

RESULTS AND DISCUSSION:

Task 1.1 ACQUISITION OF DATA AND MATERIAL

New data obtained from the Carter-Colliver #1 CO2 I have been placed on the web site: http://www.kgs.ukans.edu/CO2/index.html and data specific to the #1 CO2 I well can be obtained from the site map. A clickable map with links for each well to wireline logs, drillers logs, wellbore schematics, core and cuttings images is available at the CO2 website under: http://www.kgs.ukans.edu/CO2/welldata.html.

TASK 2.1 DRILL, CORE, LOG AND TEST NEW CO2 INJECTION WELL

As reported last quarter, drilling commenced on the Murfin Drilling Company, Inc. #1CO2 I Carter-Colliver well (API# 15-167-23179), located in the S/2 SE/4 of Section 28-14S-13W, Russell County, Kansas, on September 23, 2000 and was completed on October 2, 2000 (fig. 1). Eight and five-eighths inch surface casing was set at 1435 feet (437.4 m) with 650 sacks of cement, a 7-7/8 inch (0.2 m) hole was drilled to a total depth of 3115 feet (949.45 m) and 5.5-inch (0.14 m) production casing was set at 3114 feet (949.15 m), one foot (0.3 m) off bottom, with 360 sacks of cement. Drilling operations were trouble free and the maximum hole deviation was ¾ degrees from vertical. Total cost for drilling and completion was initially estimated to be $146,050. Actual costs were $165,505. A low water loss polymer and starch mud system resulted in excellent hole conditions throughout the operation. Five cores were taken including three conventional cores at depths of 2871-2894 (875.1-882.1 m; L-KC 'B' and 'C' zones), 2949-54 (898.86-900.38 m; L-KC 'G' zone), and 2954-2981 (900.38-908.6 m; L-KC 'G' zone) and two pressure cores at depths of 2894-2904 (882.1-885.14 m; L-KC 'C' zone) and 2904-2914

(885.14-888.19 m; L-KC 'C' and 'D' zones). Schlumberger's Platform Express logging suite was run at total depth, including Compensated Neutron Litho Density, Array Induction Linear Correlation, and Microlog. In addition, a Borehole Compensated Sonic log was run. Schlumberger's Repeat Formation Tester tool was run following the electric logging operation on sixteen intervals to obtain pressure data.

Though recovery of material cored using the high-pressure core barrel was good, a significant portion of material recovered from the good quality reservoir interval was deconsolidated and was primarily carbonate "dust." The cause for the crushing and results obtained from the core must be qualified. Given the unconsolidated nature of the core, the core is believed to have been extensively flushed.

The geologic report log for the Lansing-Kansas City interval is presented at:
http://www.kgs.ukans.edu/CO2/CO2Data/Misc/CO2I-1gr.html.
Wireline logs in the 'C' zone can be viewed at:
http://www.kgs.ukans.edu/CO2/CO2Data/1516723179.html
And complete LAS format logs can be viewed and downloaded from:
http://polaris.kgs.ukans.edu/pls/abyss/qualified.well_page.DisplayWell?f_kid=1020066130

Figure 1. NW view of Murfin Carter Colliver #1 CO2 I in background and the Colliver #13 producing well, in the SE corner of the flood pattern, in the foreground.

Formation Pressures (2.1.4)

Original plans were to perform drill stem testing of the reservoir interval. The pressure cores obtained from the reservoir interval exhibited severe damage either as the result of the use of the pressure-coring tool or as a result of significant reservoir rock fragility. Because of possible significant rock fragility, drill stem testing was not performed so as not to potentially damage the formation. Rather than drill stem test, Schlumberger's Repeat Formation Tester tool was run following the electric logging operation on sixteen intervals to obtain pressure data. Data for these tests are presented in Appendix F. Differences in pressure between the Lansing-Kansas City 'C" zone (~800 psi, 5.9 MPa) and overlying formations (~1250 psi, 8.6 MPa) indicate that these intervals are not in communication which would indicate that wellbore integrity issues and potential loss of fluids into shallower intervals should not present a problem for the demonstration project.

TASK 2.2 PRODUCIBILITY CHARACTERIZATION USING NEW CORE

Routine and Special Core Analysis (2.2.5 & 2.2.6)

Permeabilities decrease with increasing depth below the top of the "C" zone and exhibit properties similar to initial reservoir simulations. Core obtained using the pressure core barrel exhibited significant damage and may have affected the representativeness of data obtained on these cores. Oil saturations measured in the routine core, taken in the top 2 feet (0.61 m) of the "C" zone exhibit an average oil saturation of 28%. The high pressure core, taken over the remainder of the "C" zone exhibit an average oil saturation of 10%. This low saturation is believed to be the result of extension flushing of the crushed and unconsolidated core.

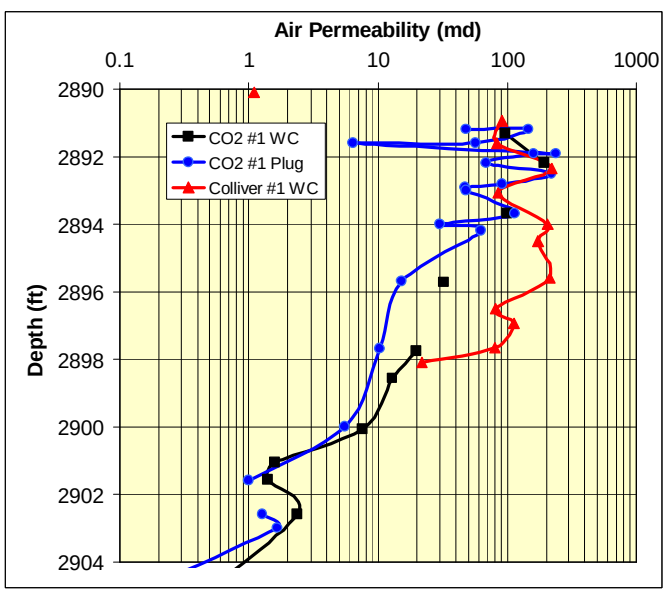

Figure 2. Permeability versus depth for Murfin Carter-Colliver #1 CO2 I well and the Collvier #1 well. (1md = $9.87*10^{-4}$ um^2, 1 ft = 0.3048 m)

Archie cementation exponents, *m*, for Wireline log analysis are significantly greater than the conventional value of 2.0. Cementation exponent values for "C" zone oomoldic limestones ranged from 2.2 to 3.6. Values increase with increasing porosity (fig. 3) and with increasing proximity to the top of the "C" zone.

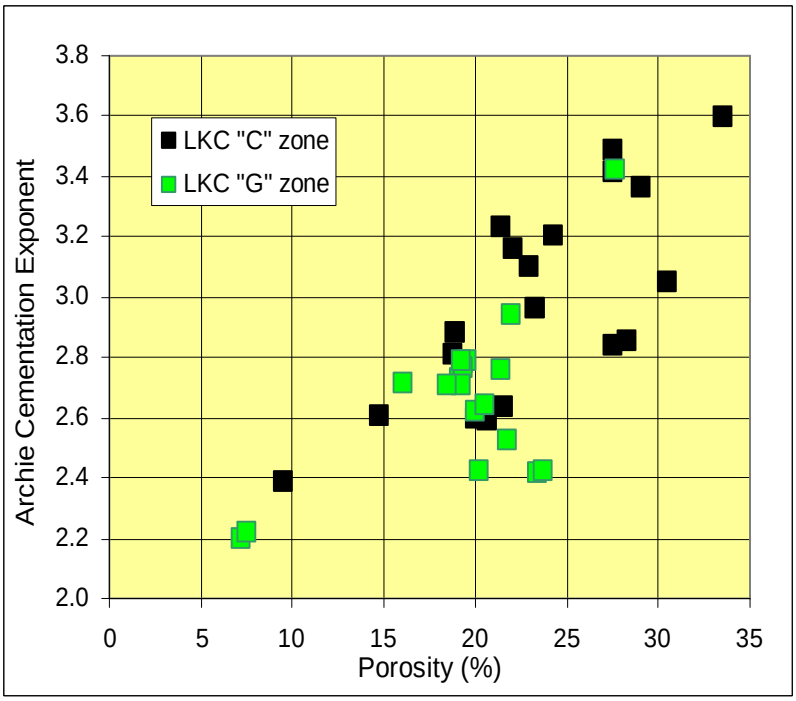

Figure 3. Cross-plot of Archie cementation exponents versus porosity showing increase in *m* with increasing porosity.

Wireline Log Analysis (2.2.7)

To obtain information concerning subsurface rock types, porosity, and fluid saturations Schlumberger's Platform Express logging suite was run from casing to total depth. Logs included in this suite include Caliper, Gamma Ray, Compensated Neutron Litho-Density, Array Induction Linear Correlation, and Microlog. In addition, a Borehole Compensated Sonic log was run. Initial analysis of logs for this interval indicate that remaining oil saturations are near 30-40% (Fig. 4). Saturations of 30%-40% are sufficient for a meaningful test of CO_2 flooding.

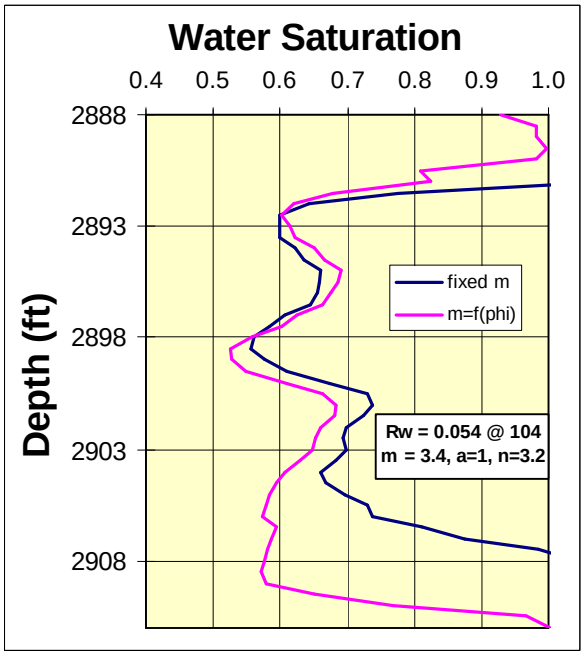

Figure 4. Calculated water saturations in Lansing-Kansas City "C" zone using Wireline log deep induction response and Archie parameters that are both fixed at values measured in the Laboratory or vary with porosity. Water saturations in "C" zone range from 30-40% and are sufficiently high to justify implementation of CO_2 enhanced recovery operations.

Residual Oil Saturation (2.2.1)

Core analysis of residual oil saturation to waterflood indicates that mean residual oil saturation for "C" zone oomoldic limestones measured to date in the Carter-Colliver #1 CO2 I is 27.4% with a minimum and maximum of 14.3% and 36.9%, respectively (fig. 5). These core flood values are consistent with the routine core saturation and the log-measured saturations but are not consistent with the high-pressure core oil saturations.

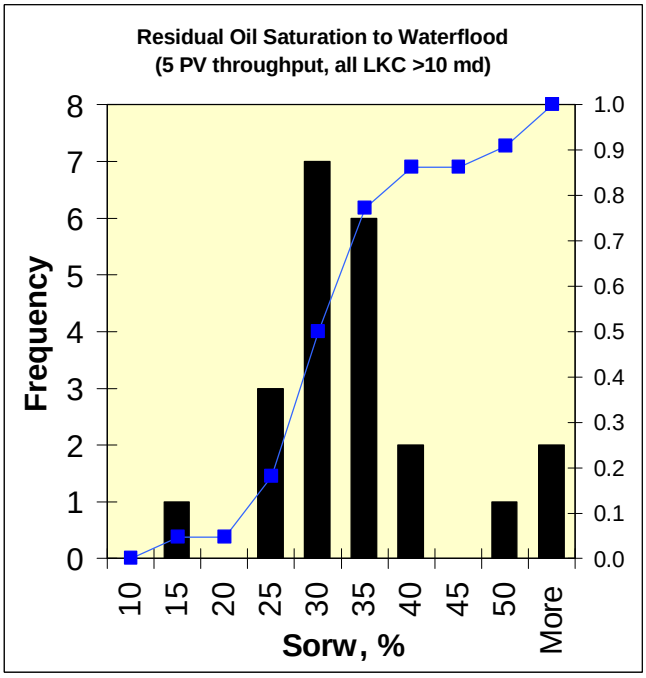

Figure 5. Histogram of residual oil saturation to waterflood for coreplugs from the Carter-Colliver #1 CO2 I oomoldic limestone "C" zone.

TASK 3.2 ECONOMIC AND RECOVERY ANALYSIS OF PILOT

As part of economic forecasting, a regional resource assessment was performed and integrated with the economics of a pipeline from Guymon, Oklahoma and the economics of CO2 flooding Central Kansas Uplift leases, as outlined in the Dubois and others (2000) paper discussed in the September Quarterly Report. Kinder-Morgan indicated that an economic pipeline would require a resource base of approximately ~200 million barrels of primary and secondary recovery. Lease economics indicate that at $1.00/mcf CO2 cost, $20/bbl oil price, and estimated capital costs of $1MM/lease (Dubois and others, 2000), a viable CO2 flood candidate site must have produced greater than 8MBO/acre. Regional assessment of L-KC and Arbuckle potential was performed on a section and lease-basis assuming values for the average lease size. Analysis of the Lansing-Kansas City indicates that for these economics the L-KC does not have sufficient resource base to support a pipeline alone but the Arbuckle does have sufficient resource (Table 1). Based on this assessment, Kinder-Morgan CO2 Company indicated the resource base of the Arbuckle needed to be proven. A list has been compiled of critical variables for delineating the viability of the Arbuckle resource and these will be evaluated.

Table 1. Cumulative Oil Production for L-KC and Arbuckle
Based on DOR Database and Calculated assuming Section and Lease Basis

Calculated MBO/acre	L-KC Cumulative Production (bbls) from 10 County Region by Section	L-KC Cumulative Production (bbls) from 10 County Region by Lease	Arbuckle Cumulative Production (bbls) from 10 County Region by Section	Arbuckle Cumulative Production (bbls) from 10 County Region by Lease	Mississippian Cumulative Production (bbls) from 10 County Region by Lease
>10	49,270,125	118,729,970	242,713,940	335,957,840	27,107,353
9	61,811,405	135,266,247	260,253,625	393,422,559	28,659,833
8	77,838,373	152,823,438	303,246,717	454,630,672	30,037,051
7	92,081,810	177,008,452	415,783,953	521,019,943	33,611,084
6	120,379,742	203,041,866	502,774,338	610,869,878	37,816,051
5	134,642,276	230,641,508	619,055,065	712,170,200	48,535,274

note: Lease basis calculated assuming Lease cum/160acres (APB 11/21/00)

TASK 7.0 PROJECT MANAGEMENT

One organizational meeting were held 11/21 at the offices of the TORP with the following personnel present: MV Energy) Jim Daniels, Larry Jack; TORP) Paul Willhite, Rich Pancake, Don Green; KGS) Alan Byrnes, Marty Dubois; Kinder-Morgan) Lanny Schoeling, Russell Martin, and Bill Flanders; PTTC) Rodney Reynolds. The status of the new injection well, results of well and core testing, regional resource assessment, and future tasks were discussed.

TASK 8.0 TECHNOLOGY TRANSFER

One technology transfer activity was performed in this quarter:

1) A talk was presented at the Sixth Annual CO2 Conference in Midland, Texas, December 5-6, 2000. The talk was jointly presented by Richard Pancake and Alan P. Byrnes and was entitled "Field Demonstration of Carbon Dioxide Miscible Flooding in the Lansing-Kansas City Formation, Central Kansas." The talk is available for viewing and download from the CO2 website: http://www.kgs.ukans.edu/ERC/index.html.

CONCLUSIONS:

Core and log analysis of the Carter-Colliver #1 CO2 I have provide data on reservoir properties. Porosities are higher than anticipated but permeabilities are lower in the lower portion of the "C" zone. The high-pressure cores were highly disaggregated and possibly highly flushed which constrained the ability to perform measurement or draw conclusions from some data. Analysis of wireline logs and core waterflood tests indicate that residual oil saturation should be in the range of 30-40%. The routine core in the top of the "C" zone indicates 28% but the flushed high-pressure core indicates saturations near 10%. The new data will be used to refine the the reservoir flow simulation model. Regional resource and economic analysis indicate the L-KC does not have sufficient resource base to support a pipeline alone but the Arbuckle may. Resource assessment of the Arbuckle is being conducted.