QUARTERY TECHNICAL PROGRESS REPORT
FOR THE PERIOD ENDING MARCH 31, 2001

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
Award Date:	March 8, 2000
Total Project Budget:	$5,388,683
DOE Cost Amount:	$1,892,094
Program Period:	March 8, 2000 – March 8, 2006 (BP1 03/00-06/01, BP2 06/01-03/05, BP3 03/05-03/06)
Reporting Period:	January 1, 2001 – March 31, 2001
DOE Project Manager:	Daniel J. Ferguson, NPTO Tulsa, Oklahoma

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DISCLAIMER:

ABSTRACT:

Progress is reported for the period from January 1, 2001 to March 31, 2001. In this quarter data were obtained for the second high pressure core from the interval 2904-2914 ft (885.14-888.19 m; task 2.2.5) and additional special core analysis was performed to measured “irreducible” water saturation and capillary pressure (2.2.6). Rock thin sections were analyzed to reveal depositional and diagenetic properties for these oomoldic limestones similar to other L-KC oomoldic limestones (2.2.7). Measured reservoir properties data have been incorporated into the geomodel and refined reservoir flow simulation performed to predict oil recovery using CO2 flooding for a variety of flood patterns (Task 3.1).

In February ICM, Inc. announced the construction of an ethanol plant in Russell, Kansas, seven miles from the demonstration site. ICM has agreed to be a partner in the project and is willing to supply CO2 provided that cost details can be worked out. Details concerning their exact role and the business structure of their relationship are being addressed.

Reservoir simulations of 10-acre, 40-acre, and 60-acre flood patterns predict recovery of 21,000 BO, 70,000 BO, and 105,000 BO (BO-barrels of oil), respectively, during the 5-year period of the DOE-demonstration. Preliminary economics for this scenario indicate that the internal rate of return for MV Energy, LLC would be –27%, 0%, and 13% for the three flood patterns respectively. These economics are highly sensitive to uncertainty in the reservoir properties surrounding the Colliver #7. Economics will be resolved in the next quarter. Because of major changes in the CO2 supply plan and unresolved business issues, Budget Period 1 was extended to June 6, 2001.

Aspects of Arbuckle resource assessment addressed in this quarter include: preliminary mapping of Arbuckle reservoir pressure and oil production distribution, generic reservoir geomodel construction, reservoir simulation to determine the feasibility of CO2 flooding the Arbuckle, calculation of the influence of dissolved natural gas in oil on Arbuckle minimum miscibility pressure values, and initial research into identifying Arbuckle fracture pressure gradients. A update talk was provided to the Kansas Geological Society, two talks were given at the TORP Fourteenth Oil Recovery Conference, and a Public Radio interview was given.

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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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RESULTS AND DISCUSSION:

TASK 2.2 PRODUCIBILITY CHARACTERIZATION USING NEW CORE

Routine and Special Core Analysis (2.2.5 & 2.2.6)

The second high-pressure core recovered from the "C" zone interval 2904-2914 ft (885.14-888.19 m) in the Carter-Colliver #1 CO2 I well is well-consolidated and exhibits decreasing porosity with increasing depth from 16% to 1% and permeabilities from 0.73 md to <0.01 md ($7.3*10^{-5}$ to $1*10^{-6}$ um^2). These data indicate that model layers 5 and 6 are thicker and exhibit slightly poorer reservoir properties than predicted. The trend of decreasing permeability with increasing depth below the top of the "C" zone extends into the interval of the second core (fig. 1).

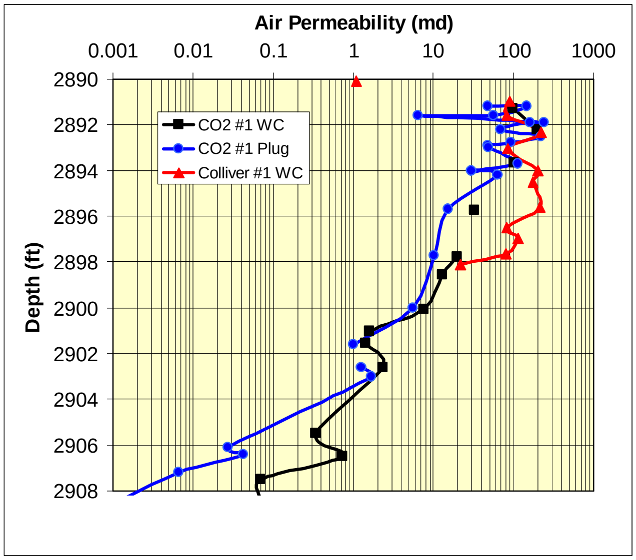

Figure 1. Permeability versus depth for Murfin Carter-Colliver #1 CO2 I well and the Collvier #1 well. (1md = 9.87*10^{-4} *um*^{2}, 1 ft = 0.3048 m)

"Irreducible" water saturations (*Swi*) measured at an air-brine pressure equivalent to a hydrocarbon column height of 50 ft (15 m) above free water level, exhibit a trend similar to that of other L-KC oomoldic limestones (fig. 2) except that cores with permeability greater than 50 md exhibit Swi values as much as 25% greater than the predicted by the general L-KC trends. This represents a limited sample set in the upper-most portion of the core and must be evaluated further.

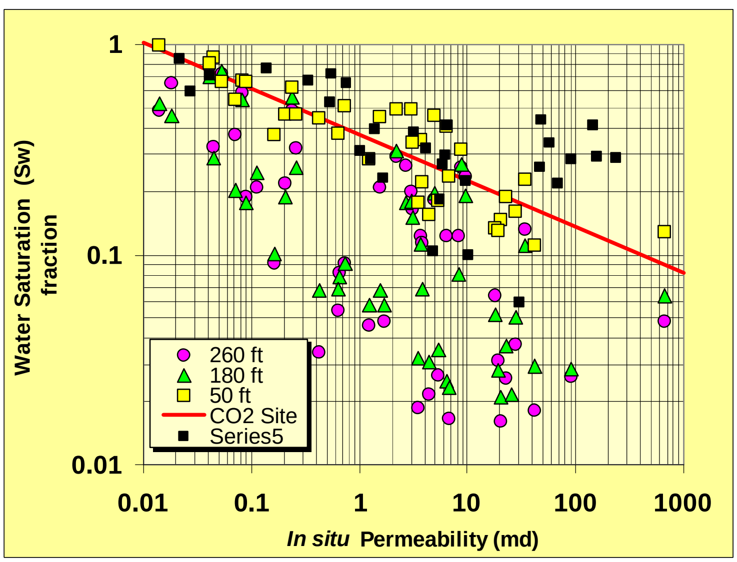

Figure 2. Water saturation versus permeability for L-KC oomoldic rocks and from the Carter-Colliver #1 CO2 I (black squares). High permeability samples exhibit anomalously high Swi values and indicate further testing is warranted. (1md = 9.87*10^{-4} *um*^{2}, 1 ft = 0.3048 m).

Mercury capillary pressure intrusion measurements to 10,000 psi (1,000 kPa) provided capillary pressure curves for selected samples ranging in permeability from 0.027 md to 220 md (2.6*10^{-6} to 2.2*10^{-2} *um*^{2}). Saturation versus capillary pressure curves for these cores are consistent with capillary pressure curves measured on other Central Kansas Uplift oomoldic limestones and with the generalized model curves constructed for the reservoir simulation geomodel (fig. 3).

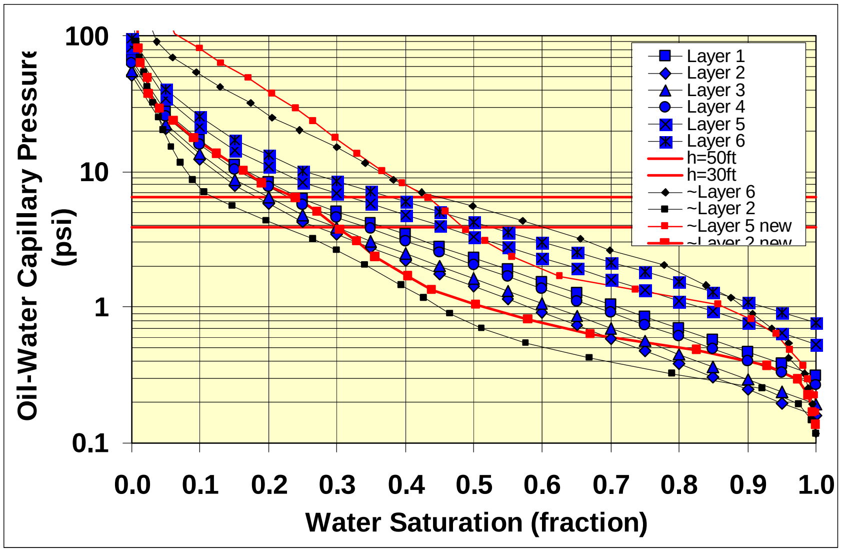

Figure 3. Capillary pressure curves for high and low permeability samples from the Carter-Colliver #1 CO2 I "C" zone (black and red symbols) compared with the generalized model curves developed for the reservoir simulation geomodel (blue curves).

Geologic Characterization (2.2.7)

The "C" zone is composed of coarse grained oomoldic grainstone exhibits a slight decrease in oomold size and deceasing packing with increasing depth below the top of the zone. Minor isopachous rim cementation and micritized ooid cortices are also present. Based on thin-section analysis, the L-KC in this region underwent similar diagenesis to that described by LeBeau (1997) and Byrnes and others (2000) (fig. 4).

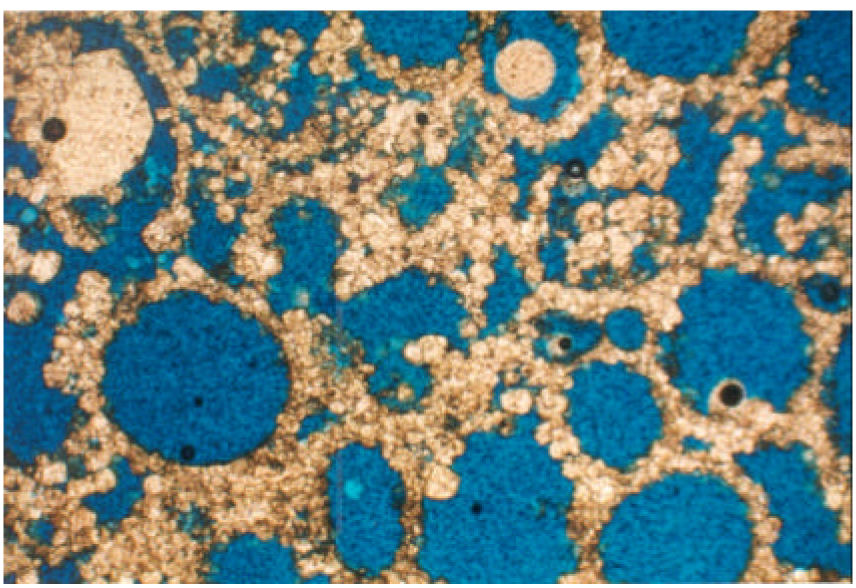

Figure 4. Plane light thin section of L-KC "C" zone 2903 ft (884.8 m) showing blue-dye impregnated oomoldic porosity and recrystallized limestone matrix framework. Crushing of matrix is evident.

TASK 3.1 RESERVOIR SIMULATION

The existing reservoir simulator is installed on a Silicon Graphics Octane MXE workstation and the pilot area is simulated using the six-layer geomodel, with 48x46 gridcells in each layer, and with grid cells 110ftx110ft. The existing model was modified to reflect the rock and reservoir properties measured in the Carter-Colliver #1 CO2 I core and well. Primary changes involved: 1) an increase in “irreducible” water saturation for layers C2 and C3 to 23% for 11% and 14%, resepectively, 2) modification of layer permeabilities within approximately a factor of 2, and 3) an increase in model porosities by approximately 2 porosity percent. The new history match for the Colliver lease (fig. 5) more closely matches the estimated lease oil production history and rates than previous models. Differences between model and estimated rates of production during the pilot waterflood from 1958 to late 1962 are believed to result from either: 1) a different contribution of oil from the L-KC “G” zone than estimated, or 2) reservoir properties in the pilot flood area, and particularly around the Colliver #7 well, that are significantly different than other areas of the lease. Further model refinements are being evaluated. In addition, modeling of lease repressurization and CO2 flood confinement is being performed and the model is being evaluated for sensitivity to areal and vertical grid cell size and the number of pseudo-components in the compositional model.

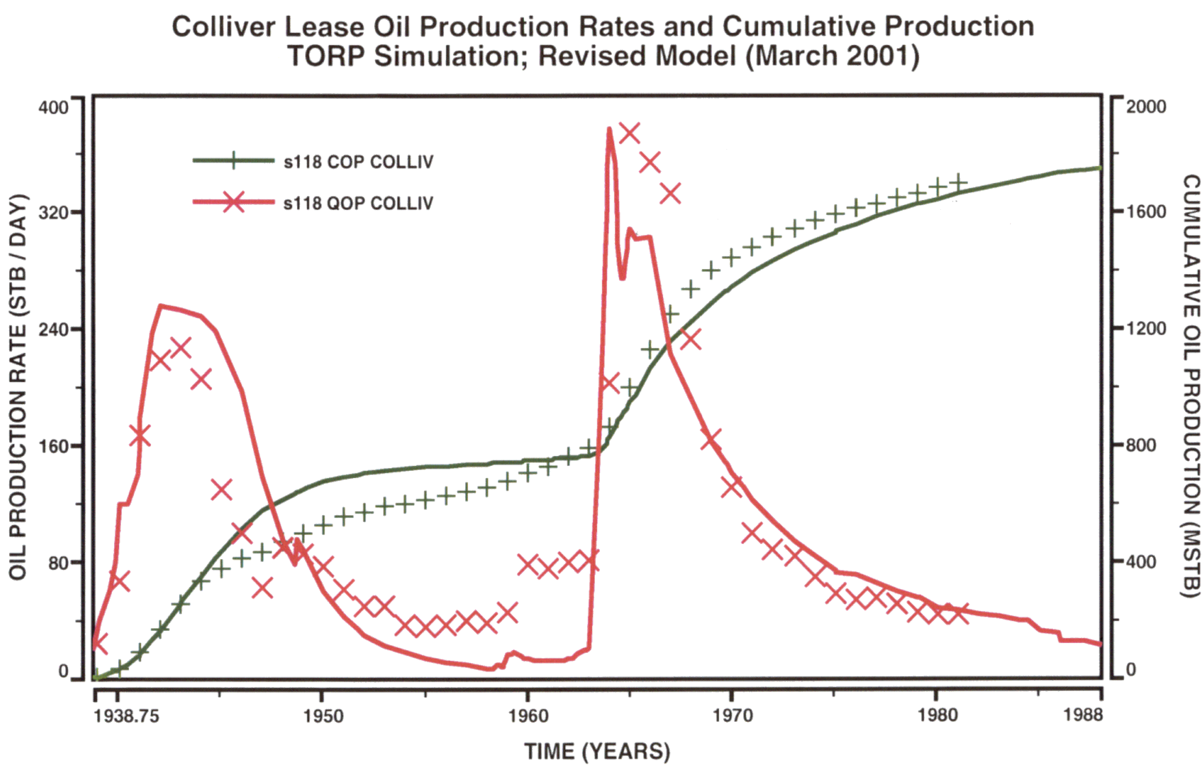

Figure 5. Comparison of model and estimated Colliver lease oil production rates and cumulative production.

The revised reservoir simulator model was used to predict oil recovery using a CO2 WAG (Water- Alternating - Gas) flood. Oil recovery was predicted for 10-acre, 40-acre, and 60-acre flood patterns (fig 6). For these patterns oil recovery within the 5-year period of the DOE demonstration is predicted to be 21,000BO, 70,000 BO, and 105,000 BO (BO-barrels of oil) for each of the patterns respectively.

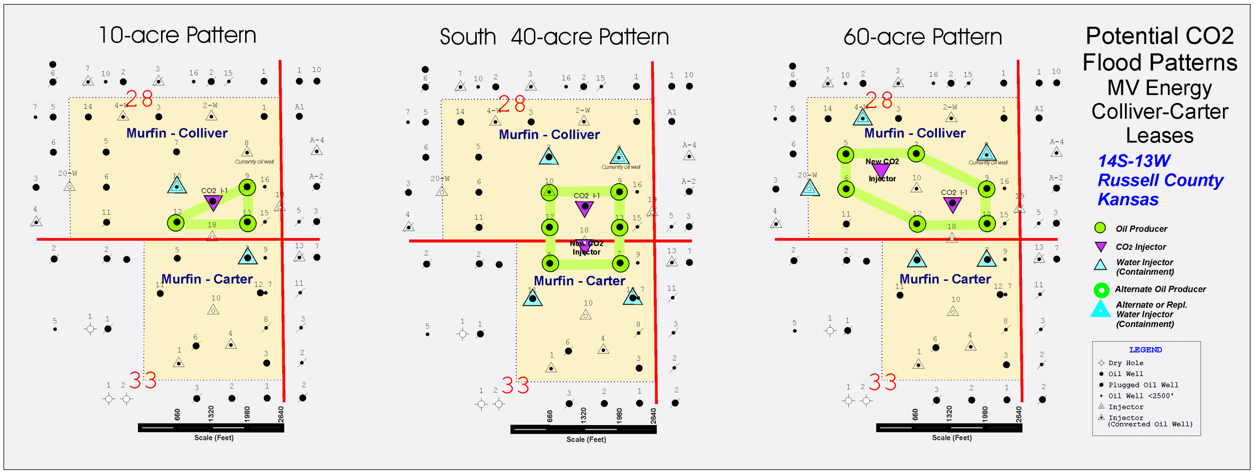

Figure 6. Flood patterns evaluated for CO2 flood recovery using the TORP reservoir simulation model.

TASK 3.2 ECONOMIC AND RECOVERY ANALYSIS OF PILOT

Costs are being evaluated for CO2 supply to the demonstration site from the ethanol plant by truck and high-pressure pipeline. Based on the simulator-predicted recoveries and updated estimates of well remediation costs and other capital and lease operating expenses, the 10-acre pattern flood provides a –27% internal rate of return (IRR) for MV Energy LLC, the 40-acre pattern provide a 0% IRR, and the 60-acre provides a 13% IRR. Predicted recovery for the 60-acre pattern is highly sensitive to model properties near the Colliver #7 well. This well exhibits anomalously high production for predicted reservoir properties based on wireline logs. In addition, to match the estimated production history, model permeabilities in the region near the Colliver #7 are as high as 1.2 darcy (0.1 um^2). The uncertainty of properties near the Colliver #7 and the sensitivity of the economics to those properties result in too much uncertainty in economic forecasting. The model, existing, data, and the allocation of oil production from the "C" and "G" zones are being evaluated to try and reduce uncertainty.

Arbuckle resource assessment is a critical task to justify Kinder-Morgan participation in the project. Aspects of Arbuckle resource assessment addressed in this quarter include: preliminary mapping of Arbuckle reservoir pressure and oil production distribution, generic reservoir geomodel construction, reservoir simulation to determine the feasibility of CO2 flooding the Arbuckle, calculation of the influence of dissolved natural gas in oil on Arbuckle minimum miscibility pressure values, and initial research into identifying Arbuckle fracture pressure gradients.

Preliminary analysis of drillstem tests (DST) in the Arbuckle indicates that the Arbuckle may be divided into three classes of reservoir based on bottom hole pressures (BHP) measured after significant lease production. Low BHPs are interpreted to result from poor connection of the producing Arbuckle interval with the underlying aquifer. Intermediate and high BHPs are interpreted to indicate moderate and good connection with the underlying aquifer. Mapping of reservoir pressures shows that different portions of major Arbuckle fields exhibit different connection to the underlying aquifer, as shown for example in the Bemis South field in figure 7.

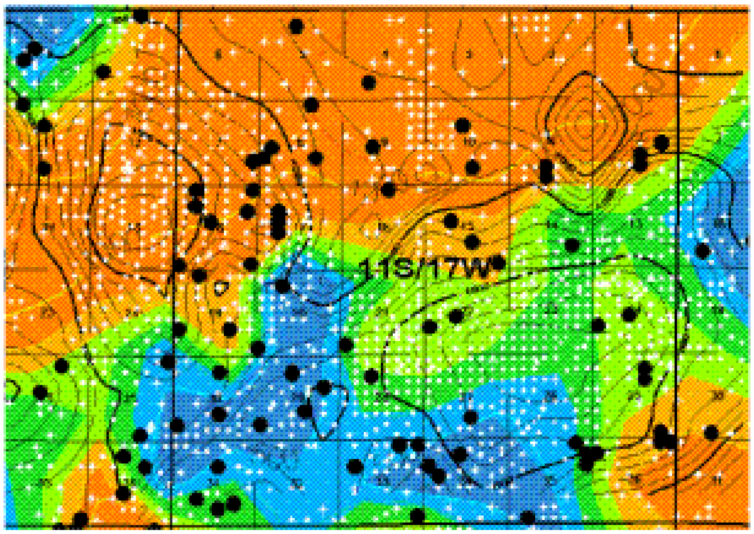

Figure 7. Drillstem test pressure regions in Bemis South showing low (<500 psi, blue), intermediate (green), and high (>1100 psi, orange) pressure regions.

Logs for the Bemis-Shutts were analyzed and integrated with core petrophysics (Byrnes and others, 1999) to construct generized layered reservoir models for the three classes of Arbuckle reservoir in the Beamis South field. Reservoir flow simulations on these generalized models indicate that it is possible to pressurize the Arbuckle productive intervals to pressures greater than minimum miscibility pressure for Arbuckle oil (fig. 8)

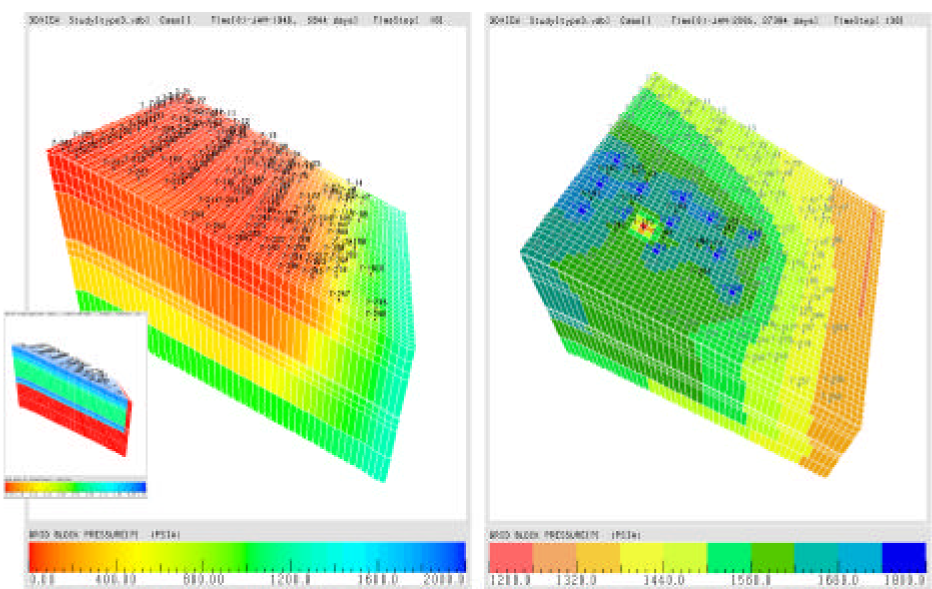

Figure 8. Reservoir simulation of present pressure and post-injection pressure in generalized isolated Arbuckle reservoir showing ability to reach MMP pressures in Arbuckle.

Present data indicate that in the 10-county central Kansas area oil production from known high producing Arbuckle reservoirs, which exhibit pressures indicating isolation from the underlying aquifer and which are capable of being pressured up to MMP, is approximately 150-186 million barrels (MMBO; 23.8-29.6 $*10^6 m^3$). To recover 25% of this oil using CO2, and assuming it required 4mcf/bbl for recovery, then this would require approximately 150-186 billion cubic feet (BCF, 4.2-5.3$*10^9 m^3$) of CO2. Total regional Arbuckle production for leases estimated to produce over 10,000-8,000 bbls/acre is is 337-454 MMBO (53.6-72.2 $*10^6 m^3$), respectively. Approximately 75-112 MMBO (11.9-17.8$*10^6 m^3$) are in areas for which connection to the aquifer has not been determined but based on regional distribution is likely to be floodable. A remaining 112-140 MMBO (17.8-22.3$*10^6$ m^3) were produced from high-pressure reservoirs that are well connected to the aquifer and may or may not be suitable for CO2 flooding. Though more investigation is needed, the present data and results indicate that a significant fraction of the Arbuckle may be a viable resource for CO2 enhanced oil recovery. Lansing-Kansas City (LKC) leases which have produced >10,0000-8,000 bbl/acre are estimated to have produced from 70-120 MMBO (11.1-19.1$*10^6$ m^3), where the range expresses differences due to the method for assessing production. The combined CO2 demand for the Arbuckle (225-298 BCF; 6.4-8.4$*10^9$ m^3) and the L-KC (70-120 BCF; 2.0-3.4 $*10^9$ m^3) indicate there is sufficient resource to require at least 295-320 BCF (8.3-9.1 $*10^9$ m^3) of CO2 which would support an 8- to 10-inch pipeline.

TASK 7.0 PROJECT MANAGEMENT

One organizational meeting was held on March 14 at the offices of Murfin Drilling Company with the following personnel present: MV Energy) Jim Daniels, Larry Jack; TORP) Paul Willhite, Rich Pancake, Don Green, Rajesh Kunjithaya; KGS) Alan Byrnes, Marty Dubois, Tim Carr; Kinder-Morgan) Russell Martin (by phone), Don Schnacke, Bill Flanders; DOE) Dan Ferguson; ICM) Paul Cantrell, Ken Ulrich. Topics covered included: economics of various patterns, project shortfalls, review of partner financial positions, Arbuckle assessment items, Carter-Colliver #1 CO2 I data review, new reservoir simulations, pros/cons for various patterns, and timeline for decision-making.

TASK 8.0 TECHNOLOGY TRANSFER

Four technology transfer activity were performed in this quarter:

1) A talk was presented at the Kansas Geological Society. The talk was jointly presented by Martin K. Dubois and was entitled "Update on the 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.

2) A talk was presented at the TORP Fourteenth Oil Recovery Conference by G. Paul Willhite and Alan P. Byrnes entitled "Status of the Central Kansas CO2 Miscible Flooding Project.“

3) A talk was presented at the TORP Fourteenth Oil Recovery Conference by Don W. Green, G. Paul Willhite, Rajesh Kunjithaya, and Alan P. Byrnes entitled " Computer Modeling of the Central Kansas CO2 Miscible Flooding Project.“

4) A radio interview was given by Alan P. Byrnes concerning CO2 flooding and the oil industry in Kansas for an "in-depth" story by the local affiliate of National Public Radio. The story was picked-up by NPR stations across Kansas.

CONCLUSIONS:

With the construction of an ethanol plant in Russell, Kansas, and with ICM, Inc. willing to partner in the project, a close source of CO_2 is available for the pilot but economic details and business structures need to be finalized. Economics based on reservoir simulations of the demonstration site indicate that a 60-acre flood may be required for MV Energy to avoid financial loss on the demonstration. Though reservoir properties in the Carter-Colliver #1CO2 I well were similar to predicted values, economic forecasts for the demonstration are very sensitive to reservoir properties away from the new well that are not known with sufficient confidence to proceed into Budget Period 2. Additional investigation is being conducted to refine the economics, finalize partner roles in the project, and try to better resolve reservoir properties. To provide time for this investigation Budget Period 1 has been extended to June 7, 2001.