REVIVING ABANDONED RESERVOIRS WITH HIGH-PRESSURE AIR INJECTION: APPLICATION IN A FRACTURED AND KARSTED DOLOMITE RESERVOIR

Semi-Annual Report

Reporting Period Start Date: November 1, 2003

Reporting Period End Date: May 1, 2004

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Date Report Issued: June 14, 2004

DOE Award Number: DE-FC26-02NT15442

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June 2004

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ABSTRACT

The Bureau of Economic Geology (BEG) and Goldrus Producing Company have assembled a multidisciplinary team of geoscientists and engineers to evaluate the applicability of high-pressure air injection (HPAI) in revitalizing a nearly abandoned carbonate reservoir in the Permian Basin of West Texas. The characterization phase of the project is utilizing geoscientists and petroleum engineers from the Bureau of Economic Geology (BEG) and the Department of Petroleum and Geosystems Engineering (both at The University of Texas at Austin) to define the controls on fluid flow in the reservoir as a basis for developing a reservoir model. This model will be used to define a field deployment plan that Goldrus, a small independent oil company, will implement by drilling both vertical and horizontal wells during the demonstration phase of the project. Additional reservoir data were to be generated during the demonstration phase to improve the accuracy of the reservoir model.

The demonstration phase has been delayed by Goldrus because of funding problems. Since the first of the year, Goldrus has been active in searching for partners to help finance the project. To this end it has commissioned several small consulting studies to technically support its effort to secure a partner. After financial support is obtained, the demonstration phase of the project will proceed. Since just after the beginning of the year, BEG has curtailed project activities and spending of DOE funds except for the continued support of one engineering student. This student has now completed his work and has written a thesis describing his research (titled “Stimulating enhanced oil recovery (EOR) by high-pressure air injection (HPAI) in west Texas light oil reservoir”).

We plan to recommence our work on the project as soon as the operator obtains necessary funding to carry out the demonstration phase of the project. In order to complete all activities specified in the proposal, it will be necessary to request an extension of the project from the originally defined completion date. We are confident that Goldrus will obtain the necessary funding to continue and that we can complete the project if an extension is granted. We strongly believe that the results of this study will provide the impetus for a new approach to enhanced oil recovery in the Permian Basin and elsewhere in the United States.

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I. INTRODUCTION

Despite declining production rates, existing reservoirs in the United States contain large volumes of remaining oil that is not being effectively recovered. This oil resource constitutes a huge target for the development and application of modern, cost-effective technologies for producing oil. Chief among the barriers to the recovery of this oil are the high costs of designing and implementing conventional advanced recovery technologies in these mature, in many cases pressure-depleted, reservoirs. An additional, increasingly significant barrier is the lack of vital technical expertise that is necessary for the application of these technologies. This lack of expertise is especially notable among the small operators and independents that operate many of these mature, yet oil-rich reservoirs. We are addressing these barriers to more effective oil recovery by developing, testing, applying, and documenting an innovative technology that, when proven, can be used by even the smallest operator to significantly increase the flow of oil from mature U.S. reservoirs.

The Bureau of Economic Geology and Goldrus Producing Company have assembled a multidisciplinary team of geoscientists and engineers to evaluate the applicability of high-pressure air injection (HPAI) in revitalizing a nearly abandoned carbonate reservoir in the Permian Basin of West Texas. We have already demonstrated the potential of HPAI for oil recovery improvement in preliminary laboratory tests and a reservoir pilot project. To test the technology more completely, workers on this project are combining a detailed characterization of reservoir properties with a field demonstration and monitoring program to fully access the effectiveness and economics of HPAI.

The characterization phase of the project is utilizing geoscientists and petroleum engineers from the Bureau of Economic Geology and the Department of Petroleum and Geosystems Engineering (both at The University of Texas at Austin) to define controls on fluid flow in the reservoir as a basis for developing a reservoir model. This model will be used to define a field deployment plan that Goldrus, a small independent oil company, will implement by drilling both vertical and horizontal wells during the demonstration phase of the project. Additional reservoir data will be gathered during the demonstration phase to improve the accuracy of the reservoir model. The results of the demonstration will be closely monitored to provide a basis for improving the design of the HPAI field deployment plan. All results will be documented and widely disseminated to facilitate adoption of this technology by oil operators in the Permian Basin and elsewhere in the U.S.

We still think that the successful development of high-pressure air-injection technology has tremendous potential for increasing the flow of oil from deep carbonate reservoirs in the Permian Basin, a target resource that can be conservatively estimated at more than 1.5 billion barrels. Successful implementation in the field chosen for demonstration, for example, could result in the recovery of more than 34 million barrels of oil that would not otherwise be recovered.

II. EXECUTIVE SUMMARY

The Bureau of Economic Geology and Goldrus Producing Company have assembled a multidisciplinary team of geoscientists and engineers to evaluate the applicability of high-pressure air injection (HPAI) in revitalizing a nearly abandoned carbonate reservoir in the Permian Basin of West Texas. The characterization phase of the project is utilizing geoscientists and petroleum engineers from the Bureau of Economic Geology and the Department of Petroleum and Geosystems Engineering (both at The University of Texas at Austin) to define the controls on fluid flow in the reservoir as a basis for developing a reservoir model. This model will be used to define a field deployment plan that Goldrus, a small independent oil company, will implement by drilling both vertical and horizontal wells during the demonstration phase of the project.

Continued laboratory testing has been carried out to quantitatively assess mechanical alterations of reservoir material by the elevated temperatures near the combustion front. Simulation studies were completed using two types of injection fluids, water and air. A summary of results for a homogeneous reservoir and a reservoir with discrete fractures with relevant plots is discussed in this semiannual review.

The reservoir characterization phase (Phase 1) of the project is on schedule, but additional progress will depend on our obtaining new core and log data. New cores are scheduled to be acquired by Goldrus, but data collection and other field activities have been postponed.

The demonstration phase of the project (Phase II) has been delayed because of funding problems being experienced by the operator. Since the first of the year, Goldrus has postponed further field development activity to concentrate on finding new partners to help finance the project. To this end it has commissioned several small studies to technically support its effort to secure a partner. At this point, Goldrus is holding discussions with several interested parties As soon as financial support is obtained, the demonstration phase of the project will proceed. Because of this delay, we will request an extension of the project from DOE so that we can finish the work as Goldrus completes its demonstration phase of the project.

The technology transfer phase (Phase III) is on schedule. We are continuing to present results in oral presentations and papers.

III. OBJECTIVES

The primary objectives of the project are to develop, test, and document optimal methods for deploying high-pressure air injection (HPAI) technology to recover remaining hydrocarbons from an abandoned carbonate reservoir. Each of these will be accomplished in three phases of activity. The reservoir characterization phase (Phase 1) consists of (1) analysis of reservoir stratigraphy and facies, (2) characterization and modeling of reservoir matrix petrophysical properties, (3) characterization and modeling of reservoir fractures, and (4) characterization and modeling of the effects of HPAI on reservoir mechanical properties (deformation, strength, and fluid transport behavior) for both matrix and fractures. The demonstration phase (Phase 2) includes (1) deployment of vertical HPAI injector wells and horizontal oil-producing wells on the basis of stratigraphic, petrophysical, fracture, and rock mechanical models developed in Phase 1; (2) collection of additional reservoir data to further constrain and revise existing models; (3) field monitoring of the progress of HPAI using well tests; and (4) postmortem analysis and synthesis of the best strategies for deployment of HPAI well patterns. The third and final phase of the project (Phase 3, Technology Transfer) is devoted to compiling, reporting, and distributing the results of the completed project to industry.

IV. PHASE 1: RESERVOIR CHARACTERIZATION

Objectives of the reservoir characterization phase of the project are to provide the basic data for defining the distribution of key reservoir properties that control the distribution of remaining oil and the movement of injected air. Among the key issues that must be addressed in this phase are (1) distribution of karst features and their impact on flow; (2) distribution, abundance, and orientation of fractures and their impact on flow; and (3) rock mechanics response of the Ellenburger to HPAI.

IV-1. Summary of Geological and Petrophysical Progress (Tasks 1 to 4)

Since the November 1, 2003, semiannual report, only minor effort has been relegated to the reservoir characterization phase in order to preserve funds that can be used after Goldrus resumes its field demonstration phase. Steve Ruppel, Bob Loucks, and Jeff Kane prepared a summary report (36 pages and 30 figures) on the geology and petrophysics of the reservoir for Goldrus to use in its fund-raising negotiations entitled “Report on the geology and petrophysics of the Ellenburger reservoir at Barnhart field, Reagan County, Texas.”

Several important conclusions can be reached from the available core and wireline-log data for the Ellenburger reservoir at Barnhart field. These are documented in the report. First, like most Ellenburger reservoirs in the Permian Basin, the reservoir section at Barnhart is dominated by peritidal dolomudstones to dolopackstones that were deposited in a restricted, inner platform setting. Like most carbonate mud-rich fabrics, these rocks exhibit low to moderate matrix porosity and permeability. Second, like most Ellenburger reservoirs in the region, the section at Barnhart displays a strong overprint of karst-related diagenesis, including a wide variety of cave fill deposits, fractures, and correlation discontinuities. This karst overprint at the same time adds to the heterogeneity of the reservoir and contributes additional porosity and permeability to the basic matrix properties of the succession.

Correlations using resistivity logs have been locally successful in establishing the reservoir architecture in many parts of the field, especially the area of the Goldrus pilot injection program. An exception is the area of the BEU #3 well, which is shown from core to be highly affected by karst cave formation, infill, and collapse processes. Correlation discontinuities elsewhere in the field may similarly reflect the presence of karsting.

Analysis of available core data clearly documents the dual porosity and permeability system that has been created in the Ellenburger by the interplay of depositional processes (matrix pore systems) and karst processes (fracture- and paleocave-related pore systems) and defines some important trends in porosity and permeability. Specifically, this study shows that porosity and permeability are lowest in matrix-dominated intervals in the upper part of the reservoir section and higher in the lower, karst-overprinted part of the section.

The analysis of wireline-log data from the three modern well log suites in the field performed in this study strongly indicates that the true oil-water contact in the field may be as much as 125 ft lower than previously reported. This finding has a potentially enormous impact on calculations of the original oil in place and estimations of recoverable hydrocarbon volume.

Finally, a review of the production history of the field strongly indicates that despite any heterogeneities that may exist, the reservoir has behaved like most matrix-dominated, solution-gas drive reservoirs in the Permian Basin. In other words, the reservoir should respond to advanced oil recovery technologies as favorably as it did the high-pressure air injection program outlined for the field by Goldrus Producing Company.

IV-2. Task 5.0 – Experimental Characterization of Thermal Alteration

A research study, funded by this project, was completed by Dhiraj Dembla under the supervision of Dr. Jon Olson of The University of Texas at Austin Petroleum and Geosystems Engineering Department entitled "Stimulating enhanced oil recovery (EOR) by high-pressure air injection (HPAI) in west Texas light oil reservoir." This study was undertaken to investigate the potential of HPAI in a naturally fractured, light-oil reservoir. A simulation model was developed on the basis of available laboratory and field data. The model was utilized to perform waterflood and air-injection simulation runs in stratified and fractured reservoir environments. Application of horizontal wells was also investigated. The results obtained after an extensive history matching exercise using combustion tube data indicate that the Barnhart reservoir is a good candidate for high-pressure air injection.

The study also provided insight into implementation of a high-pressure air-injection recovery program in the Barnhart reservoir. The model used to test this concept consisted of an injector-producer pair of one-quarter of a 5-spot pattern about 930 ft apart. Three architectural models were employed: a homogeneous reservoir, a layered reservoir, and a naturally fractured reservoir. Two well arrangements were employed: vertical injector-producer and vertical injector-horizontal producer. Two types of injection fluids were used: water and air. A total of seven fluid components and one solid component were utilized in the combustion model. Oil and rock properties were obtained from laboratory tests and well logs. Relative permeability data were obtained by matching the available laboratory combustion tube data. Chemical reaction kinetics data were obtained from available accelerated rate calorimetry (ARC) tests and adjusted by matching laboratory combustion tube data.

In the homogeneous reservoir case, a small amount of water gravity segregation was observed, whereas in the air-injection case gas override was evident. However, gas override was not observed in the layered reservoir or fractured reservoir models perhaps because the reservoir model has high-permeability layers separated by low-permeability layers. Of all cases studied, good reservoir sweep for waterflood and air injection was observed in the high-permeability zones. However, waterflood studies in the fractured reservoir having these high-permeability zones resulted in low oil recoveries (as low as 11%) owing to severe channeling in the fractures, rendering waterfloods ineffective. *It should be pointed out, however, that air injection in the fractured reservoir model resulted in stable combustion front propagation through the reservoir, yielding high ultimate oil recoveries (as high as 80%).*

To further improve understanding of the air-injection process in the field, various sensitivity analyses, such as use of different vertical to horizontal permeability ratios, use of different types of well arrangements, injection of enriched oxygen air, and cyclic water and air injection (wet combustion), are suggested.

This simulation study showed that the Barnhart reservoir is a good candidate for high-pressure air injection. Application of horizontal well technology can improve ultimate resource recovery from the reservoir. However, incorporating accurate reservoir characterization studies and detailed combustion kinetics into the simulation model will ultimately decide the applicability and profitability of the HPAI process on a large scale.

V. PHASE 2: FIELD DEMONSTRATION

As discussed earlier, the detailed field demonstration has been delayed.

VI. PHASE 3: TECHNOLOGY TRANSFER

An update on geological characterization activities was presented in March at the Southwest Section meeting of the American Association of Petroleum Geologists in El Paso, Texas. The title of the talk, which was co-authored by Deanna Combs, Robert Loucks, and Stephen Ruppel, was “Lower Ordovician Ellenburger Group collapsed paleocave facies, associated pore networks, and stratigraphy at Barnhart field, Reagan County, Texas.” A copy of the abstract of this paper is attached. As described earlier, Ruppel, Loucks, and Kane prepared and delivered a summary report in April on the geology and petrophysics of the field, entitled “Report on the geology and petrophysics of the Ellenburger reservoir at Barnhart field, Reagan County, Texas” to the field operator.

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VII. RESULTS AND DISCUSSION

Continuation of the project depends on Goldrus acquiring a partner to help finance the enhanced oil recovery project. According to Goldrus, several parties are interested, and the enhanced oil recovery program will be able to resume in Barnhart field later this year.

VIII. CONCLUSION

We are confident that Goldrus will be able to resume the detailed field demonstration later this year. Accordingly, we will request an extension of the project from DOE so that we can finish work as Goldrus completes its demonstration phase of the project.

An important new conclusion that was produced from our recent analysis of the newer wireline-log data in the field is that the true oil-water contact in the field may be as much as 125 ft lower than previously reported. This finding has a potentially enormous impact on calculations of original oil in place and estimations of recoverable hydrocarbon volume.

Analysis of experimental data has provided information on the effect of high-temperature processes on the rocks, especially fracturing of the rocks. This information is an important contribution because it allows us to better understand the sweep efficiency in this relatively low-quality reservoir. The study also indicates that the high-pressure air-injection method can increase ultimate oil recovery as much as 80%.

IX. REFERENCES

Dhiraj, Dembla, 2004, Stimulating enhanced oil recovery (EOR) by high-pressure air injection (HPAI) in west Texas light oil reservoir: The University of Texas at Austin, Master's thesis, 123 p.

Ruppel, S. C., Loucks, R., and Kane, J., 2004, Report on the geology and petrophysics of the Ellenburger reservoir at Barnhart field, Reagan County, Texas: The University of Texas at Austin, Bureau of Economic Geology, Consultant Report prepared for Goldrus, 35 p.

X. APPENDIX

ABSTRACT FROM RECENT TERCHNICAL TRANSFER ACTIVITY: SOUTHWEST SECTION AAPG, EL PASO, TEXAS, MARCH 2004.

Lower Ordovician Ellenburger Group Collapsed Paleocave Facies, Associated Pore Networks, and Stratigraphy at Barnhart Field, Reagan County, Texas

COMBS, D.M., R.G. LOUCKS, and S.C. RUPPEL, Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, Austin, Texas, 78713

The Barnhart Ellenburger field, located in the southeast corner of Reagan County, Texas, is an excellent example of a carbonate reservoir that contains a complex stratigraphy and a pore network that is a function of collapsed paleocave facies. Barnhart field is a Lower Ordovician dolomite reservoir, which covers an area of approximately 36 square miles and is overlain by Wolfcampian shale. The contact between the Ellenburger dolomite and the overlying shale is a composite unconformity. As is evident from the Goldrus Unit #3 core, the Ellenburger at Barnhart field has undergone a complex history of fracturing and karsting associated with several unconformities. Through the use of SP and resistivity wireline logs, zones of porosity, karst and collapse, and fault offset have been correlated throughout the field.

Paleocave facies in the Unit #3 core include zones of collapsed slabs and blocks, transported chaotic breccias, debris flow and suspension cave-fill deposits, and speleothems. The collapsed slabs, blocks, and clasts show a strong overprint of crackle brecciation. The pore network in the collapsed paleocave facies consists of several pore types: (1) fine interclast pores, (2) large solution vugs, (3) crackle breccia fractures in blocks, slabs, and smaller clasts, (4) interparticle pores in the detrital carbonate matrix, and (5) possible fracture pores. The study of Barnhart field is an excellent example of how the creative use of old wireline logs can be a valuable tool in determining karst/collapse and fault features.