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**ASSIST IN THE RECOVERY OF BYPASSED OIL
FROM RESERVOIRS IN THE GULF OF MEXICO**

Contract Number: DE-AC22-92BC14831

**Louisiana State University
Department of Petroleum Engineering
Baton Rouge, LA 70803-6417**

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**Project Manager: Gene Pauling
Metairie Project Office**

Principal Investigator: Philip A. Schenewerk

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Abstract

The objective of this research is to assist the recovery of non-contacted oil from known reservoirs on the Outer Continental Shelf in the Gulf of Mexico. Thus far, research has consisted of data collection from Minerals Management Service (MMS); literature and operators; screening of reservoirs for detailed studies; modification of two public domain simulators; development of a predictive model; and design of several laboratory experiments for studying attic oil recovery.

The methodology for data collection from MMS, literature and operators is keyed on 208 sands containing 1,289 reservoirs, representing 60% of the original oil in place (OOIP) in the Gulf of Mexico. This data collection is presently in progress after several delays concerning confidentiality agreements between MMS, DOE, and LSU and its subcontractors.

Modifications on two public domain computer reservoir simulators, BOAST II and MASTER, is underway. Modifications will consist of developing a code to handle steeply dipping oil reservoirs and a radial grid format for near wellbore studies. Modifications for steeply dipping reservoirs have been successfully implemented. At present, modifications to BOAST II for radial grid systems are producing acceptable results in a reasonable, though long, period of time.

Research of all phases listed above are in progress; therefore, no results or conclusions can be reported at this time.

Executive Summary

The objective of this research is to assist in the recovery of non-contacted oil from known reservoirs on the Outer Continental Shelf in the Gulf of Mexico. Mature offshore reservoirs, declining oil reserves, declining production, and other natural forces currently are accelerating the abandonment of offshore oil resources and production platforms. As these offshore wells are plugged and the platforms are abandoned, an enormous volume of remaining oil is permanently abandoned. Significant quantities of this oil could be recovered using advanced technologies now available if the resource can be identified.

The methodology for data collection from Minerals Management Service (MMS), literature and operators is keyed on 208 sands containing 1,289 reservoirs. These sands contain 60% of the original oil in place (OOIP) in the Gulf of Mexico. This data collection presently is in progress after several delays concerning confidentiality agreements between MMS, DOE, and LSU and its subcontractors. MMS data are outdated for the most part, a majority being 20 to 25 years old. Older fields are not a priority with MMS; and because of lack of manpower, substantial work is not performed on fields or reservoirs after initial mapping and reserve estimates have been completed. MMS rarely remaps fields. Field extensions are remapped based on priority and whatever can be handled by available manpower. Most reserve updates are based primarily on decline curves with new studies performed only on special cases. Data collection protocol from MMS is stringent. MMS will transfer all data through DOE. ICF Resources, Inc. (ICF), a subcontractor and LSU together will gather information by searching maps and other hard-copy data. Because of proprietary data reasons (MMS data older than 2 years are public information) MMS wants to limit the study to older fields where no new wells have been drilled in the last two years.

Other sources of information are being pursued through literature searches conducted on the GEOREF database at the U.S. Geological Survey Library in Reston, VA.; Petroleum Abstracts at the LSU library in Baton Rouge, LA.; the MMS library in New Orleans, LA.; and various geological societies in the Gulf of Mexico area.

From these sources, a list of high-priority fields/reservoirs was compiled, and additional information has been perused on these fields/reservoirs.

Operators of these fields/reservoirs are being contacted to determine their interest in providing data or other assistance. To date, ARCO Oil and Gas Company and Taylor Energy Company have provided data. Amoco, Mobil and Texaco have agreed to provide data that they are presently collecting. Chevron has also shown interest in providing data.

Modifications on two public domain computer reservoir simulators, BOAST II and MASTER, are underway. Modifications will consist of developing a code to handle steeply dipping oil reservoirs as well as constructing a radial grid for use on near wellbore studies. Modifications for steeply dipping reservoirs have been successfully implemented. At present, modifications to BOAST II for radial grid systems are producing believable results in a reasonable, though long, period of time. Attempts to reproduce the results of small-scale experiments produced in the Department of Petroleum Engineering are currently underway. The results appear to compare favorably with the experimental data, but more rigorous comparisons will need to be performed. Also, difficulties are being experienced with the inclusion of gravity in the model, however the problems are minor, and several ideas have been considered to resolve the difficulties.

BDM has modified the MASTER reservoir simulation model for use in simulating miscible gas injection processes in steeply dipping reservoirs. The simulation code has been modified to include the dip feature, and the program has been successfully installed and operated on in-house PCs. BDM began the process of verifying the model through comparison of model output to published model results for an attic gas injection process in a steeply dipping reservoir.

Laboratory investigations have been designed to develop three phase-relative permeability relationships, define minimum miscibility pressures for various injectants, define critical velocities of gas movement in gravity stable miscible displacement processes, and determine the impact of the use of various injectant gases in miscible and immiscible processes. Much of the design and laboratory techniques are based upon previous work by Combs and Knezek¹,

Strickland², and Harvey³. The results from these experiments will be used to assist in the simulation work and to substantiate the results of simulation. Materials for the building of the apparatus have been ordered, and its construction has begun.

Introduction

The objective of this research is to assist in the recovery of non-contacted oil from known reservoirs on the Outer Continental Shelf in the Gulf of Mexico. Mature offshore reservoirs, declining oil reserves, declining production, and other natural forces are currently accelerating the abandonment of offshore oil resources and production platforms. As these offshore wells are plugged and the platforms are abandoned, an enormous volume of remaining oil is permanently abandoned. Significant quantities of this oil could be recovered using advanced technologies now available if the resource can be identified.

Much of the remaining oil offshore is trapped in formations that are extremely complex due to intrusions of salt domes. Conventional seismic processing techniques cannot clearly image these traps or the full extent of oil-bearing segments near the salt domes; therefore, substantial volumes of oil may have remained un-contacted by previous drilling. Recently, however, significant innovations have been made in seismic processing and mathematical migration of seismic signal. In addition, significant advances have been made in deviated and horizontal drilling technologies and applications. These technological advances make it possible to reprocess existing seismic data to identify non-contacted portions of the reservoirs, which can then be contacted using advanced drilling technologies to kick out new wells from existing wells. Effective application of these technologies, along with improved recovery methods, offers opportunities to increase significantly Gulf of Mexico production, delay platform abandonments, and preserve access to a substantial remaining oil target for enhanced recovery and other advanced recovery processes.

This project will proceed under three broad phases: analysis, supporting research, and technology transfer.

In the analysis phase, TORIS-level data will be collected on the major fields located in the piercement salt dome province of the Gulf of Mexico Outer Continental Shelf. Representative reservoirs will be studied in detail in order to evaluate undeveloped and attic oil reserve potential. These detailed

investigations will be used to calibrate the TORIS level predictive models. The recovery potential of advanced secondary and enhanced oil recovery processes and the exploitation of undeveloped and attic oil zones for salt dome reservoirs in the Gulf of Mexico will be assessed.

Supporting research will focus on the modification of public domain reservoir simulation models to accurately simulate the conditions encountered in the piercement salt dome province of the Gulf of Mexico. Laboratory research will focus on the development of fluid relationships that will be used in the simulation of miscible and immiscible processes in the project area.

During the final phase of the project a significant effort is planned to transfer the results of this project to potential users of the technology. Technology transfer activities will also provide feedback channels that will help keep the analysis and supporting research focused on the most important problems associated with this project.

Project Description and Objectives

The objective of the project is to estimate the potential reserve additions that could result from the application of advanced secondary and enhanced oil recovery technologies and the exploitation of undeveloped and attic oil zones in Gulf of Mexico oil fields that are related to piercement salt domes. A task list follows.

1. Develop a detailed work plan. This plan will include detailed task assignments, scheduled outlines of data collection and field assessment methodologies, and integration of the laboratory work into reservoir simulation as well as TORIS model development efforts. This task will include the selection and orientation of a peer review committee and planning for the integration of the data collection efforts with the work being performed by the Texas Bureau of Economic Geology to develop a Gulf of Mexico oil and gas atlas.

2. Collect TORIS-level data. TORIS level reservoir data will be collected on the

major oil fields in the piercement salt dome province offshore of Louisiana. This data will be generated or extracted from data available through the Department of Interior Minerals Management Service, Louisiana Geological Survey, published operator case studies, and other available sources. It will be necessary to negotiate an interagency agreement to protect the confidentiality of the MMS data.

3. Modify public reservoir models. Readily available public reservoir simulation models (BOAST II and/or MASTER) will be modified to simulate accurately the conditions encountered in steeply dipping high permeability reservoirs. The modifications will also involve the development and integration of radial grid systems suitable for the investigations proposed in the project. The existing models will be evaluated, modified, and validated against commercial reservoir models.

4. Perform laboratory research. A program of laboratory research will be undertaken to study and develop fluid relationships that will be utilized in the reservoir simulation of miscible and immiscible processes in steeply dipping reservoirs. The investigations will focus on developing three phase-relative permeability relationships, defining minimum miscibility pressures for various injectants, defining critical velocities of gas front movement in gravity stable miscible displacement processes, and determining the impact of the various injectant gases on miscible and immiscible processes.

5. Develop TORIS predictive models. TORIS-level predictive models for miscible and immiscible processes and for undeveloped and attic oil zones in steeply dipping reservoirs will be developed. These models will be calibrated using the modified reservoir simulation models developed in Task 3 and the results of the laboratory investigations of Task 4. The methodology used in the modeling will be subject to peer review.

6. Characterize representative reservoirs. Selected representative reservoirs

will be studied in detail in order to evaluate undeveloped and attic reserve potential. A detailed geological and reservoir characterization of these reservoirs will be performed using available geological, geophysical, and reservoir data, some of which will be provided by operators, will be performed.

7. Define production potential. The production potential for undeveloped and attic oil zones in representative fields will be determined using material balance and reservoir simulation studies. The modified reservoir simulation models from Task 3 will be utilized in the reservoir simulation efforts.

8. Integrate and complete regional assessment of production potential. The results of the detailed geological and reservoir engineering studies of Task 6 and 7 will be integrated with the TORIS models developed in Task 5 for calibration purposes. Cost and economic data will also be integrated in the models.

9. Install TORIS models at BPO. The TORIS models developed by this research program will be installed at the Bartlesville project office. Economic parameters developed in Task 8 will be utilized to assess the recovery potential for the application of advanced secondary recovery and enhanced oil recovery processes and the exploitation of undeveloped and attic oil zones for salt dome reservoirs in the Gulf of Mexico. Documentation of the database development task, laboratory and simulation tasks, the detailed field analysis tasks, and the TORIS models will be prepared and presented as a summary report of the project.

10. Conduct technology transfer. This technology will be transferred to the industry through publications and a workshop.

Project Status

Data Collection

It was originally proposed that the data collection be on a fieldwide basis. However, MMS felt this was too large of an endeavor and suggested starting with the 87 reservoirs identified by an original screen of >5 MMSTB of recoverable oil. MMS stated that they could provide general fieldwide data for background on particular reservoirs. They also suggested going to the operator for maps and other pertinent accurate information. Much MMS data are outdated, a majority being 20 to 25 years old. Older fields are not a priority with MMS; and because of lack of manpower, substantial work is not performed on fields or reservoirs after initial mapping and reserve estimates have been completed. MMS rarely remaps fields. Field extensions are remapped based on priority and whatever can be handled by available manpower. Most reserve updates are based primarily on decline curves with new studies performed only on special cases.

MMS stated that many reservoirs are either poorly understood or improperly mapped, as indicated by the fact that current recovery from many reservoirs is well in excess of 60% of the MMS value for original in-place oil. Because of this, it was decided another computer search should be performed for all reservoirs with a >2.5 MMSTB recoverable and >60% recovery factor to date. This search identified 127 reservoirs from 30 fields.

However, because of the MMS data format and time requirements, it was decided that a data collection effort keying in on sands would be the most efficient way to collect data. Therefore, efforts were shifted from keying on the 127 reservoirs that had >2.5 MMBBLS reserves and >60% produced to date (i.e. large, incorrectly mapped reservoirs) to keying on the 208 sands in 46 fields that contained 1,289 reservoirs. This represents 60% of the original oil in place (OOIP) for the entire offshore Gulf of Mexico. If time and resources permit, additional reservoirs will be included to increase the coverage to 70% (plus) OOIP. The most efficient target for an accurate description of the bypassed oil

in the Gulf of Mexico is in the 208 sands and 60% OOIP.

A list of information that was felt would be necessary for the database studies was provided to MMS (A copy of this list has been attached to this report.). MMS and ICF believed that much of the information could be obtained from computer retrieval off of their database (FRRE). The remaining requested information would have to come from seismic and other available maps, from either MMS or operators. MMS also offered to check into the more aggressive attic oil projects presently being performed by active operators.

Data collection protocol from MMS is stringent. MMS will transfer all data through DOE. ICF Resources, Inc. (ICF), a subcontractor and LSU together will gather information by searching maps and other hard-copy data. Because of proprietary data reasons (MMS data older than 2 years are public information) MMS wants to limit the study to older fields where no new wells have been drilled in the last two years.

MMS will provide, through DOE, the content of FRRE Database for the 1,289 reservoirs. For the purpose of cross-checking the FRRE Database, ICF's on-site personnel will compile measurements of fault blocks from maps, data elements from MER and other hard-copy files, and key reservoir properties from hard-copy files.

To date, other data sources include the following:

- 1) Salt Domes, Gulf Region, United States and Mexico, by Michel T. Halbouty (1979);
- 2) MMS OCS Operations Field Names Master List (1992) and EIA Oil and Gas Field Code Master List (1991);
- 3) MMS Platform Inspection Database (1992); and
- 4) Petroleum Information Production Data.

A database was compiled by BDM with data from the aforementioned sources. It includes a detailed summary table of the information, a listing of the data

from the platform database, operator listings, production plots on each field, and detailed production data summary tables.

Other sources of information are being pursued through literature searches conducted on the GEOREF database at the U.S. Geological Survey Library in Reston, VA., Petroleum Abstracts at the LSU library in Baton Rouge, LA.; the MMS library in New Orleans, LA.; and various geological societies in the Gulf of Mexico area. From these sources, a list of high-priority fields/reservoirs was compiled, and additional information was perused on these fields/reservoirs.

Operators of these fields/reservoirs are being contacted to determine their interest in providing data or other assistance. To date, ARCO Oil and Gas Company and Taylor Energy Company have provided data. Amoco, Mobil and Texaco have agreed to provide data that they are presently collecting. Chevron has also shown interest in providing data.

Predictive Modeling Phase

The determination of the methodology for the predictive modeling phase of the project is about 50% complete. The design of the blueprint began in February 1993, and the computer coding began in March 1993.

Modification of BOAST II

Personnel from the LSU computer science department worked on the simulation of two-phase flow of slightly compressible fluids in a three-dimensional porous medium. Progress to date has included the construction of a FORTRAN program that uses 3-D finite elements to approximate the governing equations. Although the solutions show numerical stability, minor oscillations inherent in the transient finite element methods were discovered. The fact that the equations are highly nonlinear, along with the fact that the model typically contains a sharp front (or discontinuity), magnifies these problems so that the resultant solutions are sometimes unsatisfactory. These problems of oscillations are traditionally resolved by refining the mesh, as in finite difference methods. However, in order

to obtain acceptable answers, the refinement would have to be to such a degree that it would result in unacceptable memory and time requirements. Through further investigation, it is believed that the use of a better time integration scheme such as Crank-Nicholson, Pade Approximate, or Predictor-Corrector should significantly reduce the oscillations. This is the current focus of efforts.

To determine the source of the oscillation problem, considerable improvements were added to the program, and the code was scrutinized so that confidence of its correctness could be achieved. In addition, extensive information was gathered concerning Darcy-flow simulations when they are discretized with finite element techniques. It is believed that an acceptable solution with the model is obtainable and will be reached with one of these time integration schemes. There is a high degree of confidence that these techniques will be easily extended to a large collection of simulation problems.

The existing finite element code was adapted so that virtually any type of element may be easily incorporated into the solution scheme. This gives increased flexibility and makes it possible to utilize the mesh refinement techniques.

Additionally, code was created that will refine and unrefine arbitrary elements in a mesh of bilinear quadrilateral elements. This code has been tested and appears to be robust. The next step was to incorporate this mesh refinement code into the finite element program to provide a tool that dynamically constructs small elements in regions of activity and coarse elements elsewhere.

At present, the software is producing "believable" results in a reasonable, though long, period of time. Attempts to reproduce the results of small-scale experiments produced in the Department of Petroleum Engineering are currently underway. The results appear to compare favorably with the experimental data, but more rigorous comparisons will need to be performed. Also, difficulties with the inclusion of gravity in the model are being experienced; however, the problems are minor, and several ideas have been considered to resolve the difficulties.

Future work will include the resolution of our problem with the gravity term, followed by a quantitative comparison of our results with the experimental data. This will be followed by the construction of an adaptive finite element program for full three-dimensional modeling. Although the solution methods will

be similar to those used in two-dimensional problems, emphasis will be placed on producing efficient code to reduce the computational resources needed for a simulation.

MASTER Modification

BDM has modified the MASTER reservoir simulation model for use in simulating miscible gas injection processes in steeply dipping reservoirs. The simulation code has been modified to include the dip feature, and the program has been successfully installed and operated on in-house PCs. BDM began the process of verifying the model through comparison of model output to published model results for an attic gas injection process in a steeply dipping reservoir. In addition, BDM is in the process of installing a post-processing package on the MASTER model that will greatly enhance the capability for plotting and mapping simulation output data.

Attic Oil Critical Parameters

Many times, within producing or produced oil reservoirs, existing wells will not have penetrated the uppermost structure of the reservoir. This situation is amplified in steeply dipping reservoirs, such as those found trapping out against piercement salt domes. One way to produce this "attic oil" is to drill new wells upstructure. Many times, however, this is inefficient and uneconomical. Another way to produce the oil is to simulate a natural gas cap by injecting gas into the reservoir through existing well(s) and letting it migrate to the uppermost portions of the reservoir. This, in turn, displaces the oil downward to existing well(s).

In order to study and develop fluid relationships that will be utilized in the reservoir simulation of miscible and immiscible processes in steeply dipping reservoirs, critical attic oil parameters are being identified. Two variables that need to be considered are the maximum gas injected volume and the rate of the gas injection. Through reservoir simulation, Strickland¹ showed that "for

reservoirs where free gas exists at the end of the production cycle, the upstructure migration of gas is independent of injection rate. However, this does not hold for reservoirs produced at pressures above the original bubble-point." So reservoirs at or below the bubble-point pressure at the beginning of an injection cycle are rate independent, and reservoirs above the bubble-point pressure at the beginning of an injection cycle are rate dependent. Strickland also states that the maximum volume of gas that can be injected is equal to the reservoir volume of water that can be moved from the watered-out zone back into the water zone. Anything greater than this will displace some of the remaining oil below the original oil/water contact, causing some of this once mobile oil to become residual and immobile within the water zone.

Based on these primary observations and parameters, laboratory investigations were designed to develop three phase-relative permeability relationships, define minimum miscibility pressures for various injectants, define critical velocities of gas movement in gravity stable miscible displacement processes, and determine the impact of the use of various injectant gases in miscible and immiscible processes. Much of the design and laboratory techniques are being based upon previous work by Combs and Knezek², Strickland, and Harvey³. The results from these experiments will be used to assist in the simulation work and to substantiate the results of simulation. Materials for the building of the apparatus have been ordered, and its construction has begun.

Planned Activities

Planned activities for the 1993 year are to complete collection of data; complete modifications to reservoir simulators as well as testing these simulators against commercial models; complete laboratory studies of attic oil recovery; complete detailed studies of selected reservoirs; complete collection of TORIS level data; complete development and installation of TORIS predictive models; complete regional assessments of recovery potential; and transfer results and conclusions of research through publications and workshops.

Summary

During April 1992, the contract management process was set up and negotiations were begun with the two subcontractors for the project, BDM Federal Inc. (BDM) and ICF Resources Inc. (ICF). Minerals Management Service (MMS) was also contacted to begin negotiations to access the MMS OCS Database.

During May 1992, a meeting was held between LSU, BDM, and ICF to evaluate the revised statement of work and assign specific tasks to each organization. The Detailed Work Plan for Task 1 also began at this meeting.

During June 1992, a meeting was held between LSU, BDM, ICF, and MMS in Metairie, Louisiana, to determine the types of data that might be available to the project and the security requirements of MMS. Negotiations began between DOE and MMS to allow the project research staff access to the MMS database. Negotiations also began with DOE to determine the minimum size offshore reservoir for inclusion in the TORIS database. Project staff also began collecting and evaluating the public domain reservoir simulation software for use during the project. The evaluation of parameters that are important to the recovery of attic oil was also started during this period.

During July 1992, a meeting was held between LSU, DOE, BDM, and ICF to finalize the data request from MMS. DOE developed a data collection protocol for submission to MMS. Also during July, the public domain simulation software (BOAST II and MASTER) were obtained for use on the LSU Department of Petroleum Engineering computer network. Additionally, parameters critical to the recovery of attic oil continued to be evaluated.

During August 1992, the subcontract with ICF was finalized and signed. DOE submitted a proposed data protocol to MMS for approval. Data collection could not begin without this approval due to the sensitive nature of the MMS data. Additionally, the process of modifying BOAST II for radial grid systems began and parameters critical to the recovery of attic oil continued to be evaluated.

During September 1992, data compilation and analysis for identifying and screening piercement salt dome fields in the Gulf of Mexico began. Modification of BOAST II for radial grid systems and evaluation of the critical parameters to

the recovery of attic oil continued.

During the October 1992, data compilation and analysis for identifying and screening piercement salt dome fields in the Gulf of Mexico continued by BDM and LSU. Also, the modification of BOAST II for radial grid systems and evaluation of the critical parameters to the recovery of attic oil continued.

During the November 1992 reporting period, two meetings were held between LSU and BDM to discuss project status and planning. LSU continued the modifications on BOAST II for the integration of radial grid systems. Also, the experimental apparatus to be used in the critical process parameter experiments for recovery of attic oil was being designed during this reporting period.

During the December 1992, personnel from ICF, BDM, LSU, DOE, and MMS met in New Orleans to discuss data collection protocol and to begin collection and screening of reservoirs. Also, BDM sent follow-up letters to several service companies showing interest in the project. LSU continued the modifications on BOAST II for the integration of radial grid systems. In addition, the experimental apparatus design to be used in the critical process parameter experiments for recovery of attic oil was completed and materials were ordered.

During January 1993, ICF continued data collection from MMS. LSU also continued collecting data from several operators and modifying BOAST II for the integration of radial grid systems and the building of the experimental apparatus designed for studying the recovery of attic oil. BDM began modifying the MASTER reservoir simulation model.

During February 1993, ICF continued its data collection efforts at MMS. BDM continued its efforts to modify MASTER for use in simulating miscible gas injection processes in steeply dipping reservoirs. LSU made contact with Taylor Energy Company, the operator of several fields in the Gulf of Mexico, namely South Marsh 73. Taylor was and is being very cooperative by providing much needed detailed data.

Report Distribution List

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Publications

There have been no publications during this reporting period.

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