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

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ABSTRACT

The overall objective of this research was to assist in the recovery of this non-contacted oil from known reservoirs on the Outer Continental Shelf in the Gulf of Mexico. This project proceeded under three broad phases: analysis, supporting research, and technology transfer.

This final report has been organized into a description of the overall work plan of this project and five volumes. Because of the wide variation and complex coverage of several topics and disciplines, each volume contains its own table of contents, list of tables, list of figures, abstract, executive summary, introduction, subject sections or chapters, acknowledgements, bibliographies, index and appendices.

EXECUTIVE SUMMARY

The overall objective of this research was to assist in the recovery of this non-contacted oil from known reservoirs on the Outer Continental Shelf in the Gulf of Mexico. The efforts of the project included estimating 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. This project proceeded under three broad phases: analysis, supporting research, and technology transfer. Specific tasks were as follows:

1. Develop a detailed work plan. This plan included 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 included 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 was collected on the major oil fields in the piercement salt dome province offshore of Louisiana. This data was 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 was 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) were modified to simulate accurately the conditions encountered in steeply dipping high permeability reservoirs. The modifications also involved the development and integration of radial grid systems suitable for the investigations proposed in the project. The existing models were evaluated, modified, and validated against commercial reservoir models.
4. Perform laboratory research. A program of laboratory research was undertaken to study and develop fluid relationships that were utilized in the reservoir simulation of miscible and immiscible processes in steeply dipping reservoirs. The investigations focused 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 were developed. These models were 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 was subject to peer review.
6. Characterize representative reservoirs. Selected representative reservoirs were studied in detail in order to evaluate undeveloped and attic reserve potential. A detailed geological and reservoir characterization of these reservoirs were performed using available geological, geophysical, and reservoir data, some of which was provided by operators, was performed.
7. Define production potential. The production potential for undeveloped and attic oil zones in representative fields was determined using material balance and reservoir simulation studies. The modified reservoir simulation models from Task 3 were 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 were integrated with the TORIS models developed in Task 5 for calibration purposes. Cost and economic data was also integrated in the models.
9. Install TORIS models at BPO. The TORIS models developed by this research program were installed at the Bartlesville project office. Economic parameters developed in Task 8 were 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 were prepared and presented as a summary report of the project.
10. Conduct technology transfer. This technology was transferred to the industry through publications, presentations and continuing internet homepage access.

This final report has been organized into a description of the overall work plan of this project and five volumes. Because of the wide variation and complex coverage of several topics and disciplines, each volume contains its own table of contents, list of tables, list of figures, abstract, executive summary, introduction, subject sections or chapters, acknowledgements, bibliographies, index and appendices.

INTRODUCTION

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.

The overall objective of this research was to assist in the recovery of this non-contacted oil from known reservoirs on the Outer Continental Shelf in the Gulf of Mexico. The efforts of the project included estimating 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. This project proceeded under three broad phases: analysis, supporting research, and technology transfer.

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

Supporting research focused 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 focused on the development of fluid relationships that were used in the simulation of miscible and immiscible processes in the project area.

Transfer of the results of this project to potential users of the technology was and is being accomplished through numerous publications, presentations and access to the reports, publications and information through Louisiana State University's internet homepage. 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. Specific tasks have been outlined in a detailed work plan.

This final report has been organized into a description of the overall work plan of this project and five volumes. Because of the wide variation and complex coverage of several topics and disciplines, each volume contains its own table of contents, list of tables, list of figures, abstract, executive summary, introduction, subject sections or chapters, acknowledgements, bibliographies, index and appendices. Volume I covers the modification of public reservoir models. This includes modifications to the mainframe version of the BOAST II simulator, the PC version of BOAST II simulator, and the MASTER simulator. Volume II covers the laboratory research performed at Louisiana State University in support of this project. Volume III covers the characterization of two representative reservoirs, B35K and B-65G, within the Gulf of Mexico, South Marsh Island 73 Field. Volume IV covers the characterization of a representative reservoir, the U-8, in a blind coded Gulf of Mexico Field. Volume V covers the collection of the TORIS level data, the development of the predictive models and a complete regional assessment of potential

DETAILED WORK PLAN

This plan includes detailed task assignments and scheduled, outlines of data collection and field assessment methodologies, and integration of the laboratory work into reservoir simulation and TORIS model development efforts. It also includes 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. The detailed work plan was developed by Louisiana State University and is as follows:

Task 1 - Develop Detailed Work Plan

This plan will include detailed task assignments and scheduled outlines of data collection and field assessment methodologies, and integration of the laboratory work into reservoir simulation and 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. LSU will be responsible for this task.

Sub-Task 1.1 - Prepare and Finalize Subcontracts - Subcontractors consist of BDM International, Inc. and ICF Resources, Incorporated. BDM will focus on the characterization of the representative reservoirs, the definition of production potential both regionally and locally and the regional assessment of potential. ICF will focus on the collection of TORIS-level data, the development of TORIS predictive models, the regional assessment of potential and the installation of the TORIS models at the Bartlesville Project Office.

Sub-Task 1.2 - Kickoff Meeting/Draft Plan - Draft of plan consists of Gantt Chart outline.

Sub-Task 1.3 - Program Reporting/Plan Updates - LSU will collect monthly reports from all sub-contractors and will in turn provide DOE with monthly status reports. Quarterly, annuals, and final reports also will be handled by LSU.

Sub-Task 1.4 - Peer Review Process - LSU will use the Petroleum Engineering Department Industrial Advisory Committee as a peer review committee. The committee will be able to offer suggestions to the research personnel on various ideas and problems as well as being able to critique any potential publications/presentations.

Task 2 - Collect TORIS-Level Data

TORIS level reservoir data will be collected on the major oil fields located in the piercement salt dome province of offshore Louisiana. This data will be generated or extracted from data available through the Department of Interior Minerals Management Service, published operator case studies, and various other published material. It will be necessary to negotiate an interagency agreement between MMS and DOE to protect confidentiality of the MMS data. From the MMS data, candidate reservoirs will be chosen by LSU, ICF and BDM. Once reservoirs have been identified, LSU will make initial contacts with operators in order to obtain updated information or more. ICF will be primarily responsible for this task with assistance from LSU and BDM.

Sub-Task 2.1 - Develop Data Collection Protocol (BEG, MMS) - In order for the information obtained through this research to be used in a Gulf of Mexico Oil and Gas Atlas being prepared by the Texas Bureau of Economic Geology (BEG), a data collection protocol will be developed. It will be necessary to negotiate an interagency agreement between MMS and DOE to protect confidentiality of the MMS data. ICF will screen and choose the necessary information it deems pertinent and will relay this to DOE, who will then make a formal request for transfer to DOE from MMS. BEG will then be provided with this information from DOE, subject to same restrictions as DOE.

Sub-Task 2.2 - Interagency Agreements on Data Confidentiality - In order to safeguard data considered to be confidential by MMS, yet pertinent to the research, agreements between agencies must be prepared. These agreements will allow research personnel to have access to the information. ICF will screen and choose the necessary information it deems pertinent and will relay this to DOE, who will then make a formal request for transfer to DOE from MMS. ICF, LSU and BDM will then be provided with this information by DOE, subject to same restrictions as DOE.

Sub-Task 2.3 - Identify Target Reservoirs/Collect MMS Data - ICF will be primarily responsible for this task with assistance from LSU and BDM. The methodology for screening candidate fields to be studied will be as follows;

- case studies or those fields which have had new technologies successfully utilized in aging fields will be selected,
- fields which new technologies could be applied to in order to extend and enhance the productive life of the field will be selected.

The first screening step would be to isolate only **piercement salt dome fields**. This would be accomplished by use of Michel T. Halbouty's book, "Salt Domes Gulf Region, United States & Mexico", MMS public information, various geological society's publications and any other public domain literature found.

The primary cut-off criteria for piercement salt dome fields is that the depth of at least one producing interval must be equal to or greater than the top of salt. Also, selection criteria will include such parameters as the depth of the productive formations, field size, geologic complexity, salt dome characteristics, water depth, and operator type.

Sub-Task 2.4 - Collect Private Data - Operators of the most favorable reservoirs will be contacted after the initial screening. If a favorable response is obtained from the operator then the reservoir will pass the second screening. If an unfavorable response is obtained from the operator the reservoir will still be included in the report but it will not be a candidate for detailed studies. Input from the operators is imperative for accurate results. Other industry sources, such as seismic service companies, will also be contacted to help identify operators who have recently conducted redevelopment programs to exploit bypassed oil.

Task 3 - Modify Public Reservoir Models

Readily available public reservoir simulation models (BOAST II and/or MASTER) will be modified to accurately simulate 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 this project. The existing models will be evaluated, modified, and validated against commercial reservoir simulation models. LSU will be responsible for this task.

Sub-Task 3.1 - Identify/Evaluate Existing Reservoir Models - Modification will be performed on public domain models. The identification and evaluation of suitable models for modification will emphasize accuracy, versatility, and technical soundness. Commercial simulators will be identified for comparison and uses as a benchmark.

Sub-Task 3.2 - Modify Models for Steeply Dipping Reservoirs - In order for a reservoir simulator to accurately model and predict the behavior of a steeply dipping reservoir, specialized code must be included. These specializations must account for gravity and dip.

Sub-Task 3.3 - Develop and Integrate Radial Grid Systems - It is believed that the integration of a radial grid system into the modified simulator will solve many of the inherent instability problems of reservoir simulation. A radial grid system will be able to more closely match an actual well/reservoir situation.

Sub-Task 3.4 - Validate Modified Public Models Relative to Commercial Simulators - Make benchmark runs of actual and test reservoir simulations on both the modified version(s) and chosen commercial simulators for comparison and validation.

Sub-Task 3.5 - Develop User Documentation - User documentation should include data input formats, example runs, hints and troubleshooting sections.

Task 4 - Perform Laboratory Research

A program of laboratory research will be undertaken to study and develop fluid relationships which will be utilized in the reservoir simulation of miscible and immiscible processes in steeply dipping reservoirs. The investigations will focus on the development of 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 determination of the impact of the use of various injectant gases in miscible and immiscible processes. This task will be LSU's responsibility and research will be conducted in the Petroleum Engineering Department at LSU.

Sub-Task 4.1 - Perform Environmental Assessment - This assessment will be performed by a DOE chosen consultant.

Sub-Task 4.2 - Evaluate Critical Process Parameters - Two variables which are important are the maximum gas injected volume and the rate of the gas injection. Through reservoir simulation Strickland (Strickland, Richard F.: "Numerical Simulation of Gas Injection for Upstructure Drainage," Dissertation- Texas A & M University. (December, 1976) 49-51) 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. Strickland followed up on previous work performed by Combs and Knezek (Combs, George D. and Knezek, Raymond B.: "Gas Injection for Upstructure Drainage," Journal of Petroleum Technology. (March, 1971) 361-372.).

LSU's work will be based primarily on the previous work performed by Strickland, Combs, Knezek and Harvey (Harvey, A. Herbert: "A Comparison of Nitrogen and Methane Injection for Attic Oil Recovery," Unsolicited - SPE Publication.)

Sub-Task 4.3 - Perform Critical Process Parameter Experiments - Based on these primary simulation observations and parameters, laboratory investigations will proceed to develop three phase relative permeability relationships, definition of minimum miscibility pressures for various injectants, definition of critical velocities of gas movement in gravity stable miscible displacement processes, and determination of the impact of the use of various injectant gases in miscible and immiscible processes.

Sub-Task 4.4 - Integrate Lab Work with Model Modifications from Sub-Task 3.2. - Observations and conclusions from laboratory work will be incorporated into reservoir simulators.

Task 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. This model 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 results will be subject to peer review. ICF will be primarily responsible for this task.

Sub-Task 5.1 - Develop Models for Attic Oil Recovery - Models for attic oil recovery should include representative characteristics of those steeply dipping reservoirs found in the Gulf of Mexico with the primary purpose of identifying bypassed oil.

Sub-Task 5.2 - Calibrate Models for Tasks 3 and 4

Task 6 - Characterize Representative Reservoirs

The purpose of this task is to develop detailed geological, geophysical and reservoir engineering assessments of selected Gulf of Mexico salt dome related oil reservoirs. Representative reservoirs will be selected (Subtask 6.1), required data will be acquired (Subtask 6.2), and detailed geological and reservoir characterization of these reservoirs using available geological, geophysical, and reservoir data, some of which will be provided by operators, will be performed (Subtask 6.3) in order to evaluate undeveloped and attic reserve potential. The results of this task will be utilized in the material balance and reservoir simulation work under Task 7. BDM will be primarily responsible for this task.

Sub-Task 6.1 - Select Reservoirs - Criteria will be developed for the selection of representative Gulf of Mexico salt dome oil reservoirs which will be evaluated in detail in Tasks 6 and 7. The selection criteria will consider such parameters as the depth of the productive formations, field size, geologic complexity, salt dome characteristics, water depth, and operator interest. Gulf of Mexico salt dome fields will be identified through analysis of readily available public data. The selection criteria will be applied to the salt dome fields to identify the highest priority fields for consideration as study candidates. The operators of these fields will be contacted to identify those operators who are willing to supply the data required to conduct this study. Other industry sources, such as seismic service companies, will also be contacted to help identify operators who have recently conducted redevelopment programs to exploit bypassed oil. Reservoirs for detailed study will then be selected. A sufficient number will be studied to apply on a regional basis for Task 8.

Sub-Task 6.2 - Acquire/Manipulate Reservoir and Seismic Data - The available geological, geophysical, and reservoir engineering data on the selected reservoirs will be identified and collected from the operators and related industry sources. The data will be manipulated and analyzed to determine if additional data will be required. All public domain information should have been collected during the screening process. Specific and detailed information on selected reservoirs will now be obtained from MMS proprietary data and willing operators. LSU, ICF and BDM will collect MMS proprietary data. LSU will make initial contacts with operators, while actual gathering of data from willing operators will be an equally combined effort. The additional required data could include geologic data, seismic lines, 3-D data, velocity surveys, vertical seismic profiles, seismic reprocessing, well logs, or pressure data. Manipulation of acquired data will be primarily BDM's responsibility, with emphasis on reprocessing old seismic information.

Sub-Task 6.3 - Develop Detailed Geology, Geophysical, and Reservoir Assessments - Detailed geological, geophysical, and reservoir engineering assessments will be performed on the selected reservoirs. The geological analysis will include log evaluations, paleostructural analysis, depositional environment analysis, and development of cross sections, isopach maps, structure maps, and salt maps. The geophysical analysis will include time and depth mapping, velocity studies, amplitude with offset

analysis for HCI determination, migration analysis, and possibly vertical seismic profile analysis. The reservoir engineering analysis will include the evaluation of production history, evaluation of drilling and completion history, analysis of pressure data, and volumetric reserves analysis.

Task 7 - Define Production Potential for Representative Reservoirs The production potential for undeveloped and attic oil zones in representative reservoirs characterized in Task 6 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. The results of this task will be integrated with the TORIS modeling work in Task 8. BDM will be primarily responsible for this task.

Sub-Task 7.1 - Prepare and Contrast Material Balance and Reservoir Simulation Assessments - Detailed material balance studies will be performed on each reservoir and the results compared with the volumetric reserve calculations which were developed in Task 6. The available static pressure data, pressure build-up data, and pressure fall-off data will be thoroughly analyzed for use in the material balance calculations. The results of the detailed material balance work will be compared with the volumetric calculations to identify potential bypassed oil volumes and to quantify the impact of aquifers.

Reservoir simulation studies will be performed on the selected reservoirs utilizing the models which were modified in Task 3. The optimum grid dimensions, orientation, and layering will be defined and the geologic and reservoir engineering parameters for each grid block will be determined. The reservoir models for each of the selected reservoirs will be initialized and history matched and the results compared to the results of the volumetric and material balance work. Modifications to the input parameters will be made, as required, to achieve the best possible history match for each reservoir. Predictive simulation runs will be made for each reservoir under various possible recovery scenarios to define the productive potential for undeveloped and attic oil zones.

Sub-Task 7.2 - Interpret Sub-Task 7.1 - Results will be used for representation of regional assessment in Task 8. The specific reservoirs that were selected and characterized in Task 6 and subsequently evaluated and modeled in Subtask 7.1 will be utilized in Task 8 to calibrate the TORIS predictive models.

Task 8 - Integrate and Complete Regional Assessment of 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. ICF will be primarily responsible for this task.

Sub-Task 8.1 - Modify TORIS Models to Incorporate Results of Tasks 4, 6 and 7 - The laboratory work performed in Task 4, the reservoir characterization work performed in Task 6 and the analysis of production potential performed in Task 7 will be incorporated into the TORIS models.

Sub-Task 8.2 - Collect and Model Cost/Economics - Estimated costs and economics for implementation of projects associated with the recovery of bypassed and attic oil recovery will be evaluated.

Sub-Task 8.3 - Conduct TORIS Level Assessments of Recovery Potential - Based on the TORIS models assessments will be made on the recovery of the identified bypassed and attic oil potential.

Task 9 - Install TORIS Models at BPO

The TORIS models developed by this research program will be installed at the Bartlesville Project Office. ICF will utilize economic parameters developed in Task 8 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, the laboratory and simulation tasks, the detailed reservoir analysis tasks, and the TORIS models will be prepared and presented as a summary report of the project. ICF will be responsible for this task.

Sub-Task 9.1 - Install TORIS Models/Data

Sub-Task 9.2 - Overall Project Report

Task 10 - Technology Transfer

This technology will be transferred to the industry through publications, presentations and continuing internet homepage access. LSU will be primarily responsible for this task.

Sub-Task 10.1 - Setup Internet homepage access

Sub-Task 10.2 - Publications/Presentations

Task 11 - Project Reporting

Project reporting will be the responsibility of LSU.

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