INCREASING HEAVY OIL RESERVES IN THE WILMINGTON OIL FIELD THROUGH ADVANCED RESERVOIR CHARACTERIZATION AND THERMAL PRODUCTION TECHNOLOGIES

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\$733,207 (1996 YTD Actual)

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Objectives

The project involves improving thermal recovery techniques in a slope and basin clastic (SBC) reservoir in the Wilmington field, Los Angeles Co., Calif. using advanced reservoir characterization and thermal production technologies.

The existing steamflood in the Tar zone of Fault Block (FB) II-A has been relatively inefficient because of several producibility problems which are common in SBC reservoirs. Inadequate characterization of the heterogeneous turbidite sands, high permeability thief zones, low gravity oil, and nonuniform distribution of remaining oil have all contributed to poor sweep efficiency, high steam-oil ratios, and early steam breakthrough. Operational problems related to steam breakthrough, high reservoir pressure, and unconsolidated formation sands have caused premature well and downhole equipment failures. In aggregate, these reservoir and operational constraints have resulted in increased operating costs and decreased recoverable reserves. The advanced technologies to be applied include:

- (1) Develop three-dimensional (3-D) deterministic and stochastic geologic models.
- (2) Develop 3-D deterministic and stochastic thermal reservoir simulation models to aid in reservoir management and subsequent development work.
- (3) Develop computerized 3-D visualizations of the geologic and reservoir simulation models to aid in analysis.
- (4) Perform detailed study on the geochemical interactions between the steam and the formation rock and fluids.
- (5) Pilot steam injection and production via four new horizontal wells (2 producers and 2 injectors).
- (6) Hot water alternating steam (WAS) drive pilot in the existing steam drive area to improve thermal efficiency.
- (7) Installing a 2100 foot insulated, subsurface harbor channel crossing to supply steam to an island location.
- (8) Test a novel alkaline steam completion technique to control well sanding problems and fluid entry profiles.
- (9) Advanced reservoir management through computer-aided access to production and geologic data to integrate reservoir characterization, engineering, monitoring, and evaluation.

Summary of Technical Progress

This is the sixth quarterly technical progress report for the project. Through September 1996, the project continues to make good progress but is slightly behind schedule. Estimated costs are on budget for the work performed to date. Technical achievements accomplished during the quarter include placing the first two horizontal wells

on production following cyclic steam stimulation, completing several draft technical reports and preparing presentations on the deterministic geologic model, steam channel crossing and horizontal well drilling for technical transfer. The draft reports have the following titles: "Application of Basic Reservoir Engineering Techniques to the Tar Zone Fault Block IIA, Wilmington, CA"; "Study of Pre-1960 Well Logs in Fault Block IIA, Wilmington Field"; "Study of Water Injection Surveys, Tar Zone Fault Block II, Wilmington Field"; "Rock-Log Model Tar Zone (T and D Sands) Wilmington Field"; "Stratigraphic Equivalents of the Wilmington Field 'Tar Zone' in the Subsurface Los Angeles Basin, California"; and "Barrier Characteristics of the Geologic Faults". Each of the draft reports is under technical review by the other team partners to assure technical consistency and accuracy and should be completed by year-end. Once the reports have been finalized, executive summaries of the reports will be presented in the next applicable quarterly report and in the next annual report and the full reports will be made available for public review at the West Coast office of the Petroleum Technical Transfer Council (PTTC) at the University of Southern California. Cyclic steam injection into the first two horizontal wells was completed in June 1996 and initial oil production from the project began the same month. Work has commenced on the stochastic geologic and reservoir simulation models. High temperature core work and reservoir tracer work will commence in the First Quarter 1997.

Regarding technical transfer, a paper will be presented at the 1996 SPE Annual Technical Conference from October 6-9. The project team made presentations on the major activities completed and status of the project to representatives from the DOE Bartelsville Project Office on September 19 in Tidelands' office in Long Beach. A new home page is active on the Internet (<http://www.usc.edu/peteng/doe.html>) for the project. A CD-ROM of the project has been completed for content and is in the final review and editing process which should be completed by year-end.

● **Compilation and Analysis of Existing Data**

A computer database of production and injection data and previous reservoir studies were compiled for the FB II-A Tar zone. Digitized and normalized log data were completed for 171 wells (over 600 wells penetrate the Tar zone in the fault block). The digitized logs include the electric or induction and the spontaneous potential (SP) and/or gamma ray (GR). The log data from the 171 wells are distributed throughout the fault block and will provide the base case log file for developing the 3-D stochastic geologic and reservoir simulation models. Another 100 logs will be digitized and normalized to use as "confirmation" logs for the stochastic modeling. Conventional cores throughout the zone were obtained from the previous operator in nine of the 171 wells which were used to correlate the formation rock and log data.

● **Advanced Reservoir Characterization**

The basic reservoir engineering technical work was completed and several draft reports covering the various aspects of the study were completed this quarter. The reports are entitled "Application of Basic Reservoir Engineering Techniques to the Tar Zone Fault Block IIA, Wilmington, CA"; "Study of Pre-1960 Well Logs in Fault Block IIA, Wilmington Field"; and "Study of Water Injection Surveys, Tar Zone Fault Block II, Wilmington Field". Historical problems with oil, gas, and water production allocations to each well and to each zone completed in the wells are evident in the material balance calculations. Work was performed on evaluating the aquifer for water influx and determining original oil in place from gas saturations to support the material balance work. Work completed includes an analysis of the primary and waterflood recoveries, permeability estimates from performance data, comparing water injection profile surveys to the allocated injection volumes for each sub-zone, determining the quality of the new and old well logs, determining the vertical communication between sands, evaluating the aquifer and solution gas, and performing correlation studies on projected steam drive recoveries from vertical and horizontal wells.

The tracer program has been delayed because the main hot water distribution line was temporarily disconnected to accomodate the surface landowner. Lab work has been completed to identify non-radioactive reservoir tracers effective in high temperature (500°F) environments. The tracer program includes two tracers, ammonium thiocyanate and lithium chloride which will be bulk injected into the "T" and "D" zone in the WAS pilot injectors in January 1997 after the hot water injection system is reconnected. The tracers will follow the liquid phase of the injected fluids rather than the steam phase. Computer software has been developed to map formation permeability in 3-D from production and injection data. The software is being tested using a compositional model at a major research company in California.

The high temperature core work has been delayed until lab procedures for measuring rock compaction due to steamflooding can be incorporated into the original proposal to perform steam pot tests and measure the geochemical effects of high temperature steam on the reservoir rocks and fluids. All of the special core work above will be used in the thermal reservoir simulation model. Lab work on the cores should commence in the First Quarter 1997.

A 3-D deterministic geologic model was completed which is being used to develop the 3-D stochastic geologic model and was used for drilling the observation and horizontal wells^{1,2}. The deterministic model correlates eighteen sand tops in the Tar zone. All existing cores were visually inspected and the core and log data were evaluated to develop a core-based log model, a porosity-permeability model and a rock-log model³. These models will provide the rock and reservoir data for the stochastic geologic model in locations where only well log data exists. A draft report entitled "Rock-Log Model Tar Zone (T and D Sands) Wilmington Field" was completed in October 1996.

Other deterministic geologic draft reports completed this quarter include "Stratigraphic Equivalents of the Wilmington Field 'Tar Zone' in the Subsurface Los Angeles Basin, California"; and "Barrier Characteristics of the Geologic Faults". The first report will provide information to the Los Angeles Basin oil producers regarding which reservoirs they operate are analogous to the Tar zone in the Wilmington field. The second report analyzed the possibility of fluid movement across faults using production and injection data and capillary transition and oil-water contact data. This analysis is being used in the basic reservoir engineering and reservoir simulation modeling.

On the stochastic geologic model, a neural network analyzer has been developed to analyze the similarities of various zones and sub-zones in terms of sequence stratigraphy using gamma ray and spherically focused logs⁴. Sample stochastic grid block models are being test run on FB II-A logs using the 3-D Earth-Vision™ visualization software to ensure compatibility. The work on actual examination of the FB II-A well log data for variogram modeling requirements of geostatistical modeling is in progress. Of particular interest is whether log normalization and environmental correction work can significantly affect log character with regard to variogram modeling. The application of facies distribution and heterogeneity description is being examined using indicator modeling. The technical work on using production data to condition stochastic images has been finished and a report should be completed in the Fourth Quarter 1996.

● Reservoir Simulation

The STARS™ thermal reservoir simulation program by the Computer Modelling Group (CMG) of Calgary and the R10,000 Onyx RE2 work station by Silicon Graphics Incorporated (SGI) have been selected for the stochastic modeling. Benchmark tests performed by the project team, CMG, and SGI confirmed the capabilities of the software and hardware platforms. Purchase and installation of the simulation software and computer hardware was completed in September 1996.

● Reservoir Management

Four horizontal wells (two steam injectors and two producers) were drilled in late 1995. The two injection wells, 2AT-61 and 2AT-63, were selectively completed with 11 quarter inch limited entry perforations per well over the last 600 ft of the horizontal section to inject a calculated 1500 barrels of cold water equivalent steam per day (BCWESPD). Cyclic steam injection began in December 1995 at low rates of 300 BCWESPD per well and increased to 1500 BCWESPD per well after breaking down the perforations with high pressure water. The purpose of the cyclic steam injection is to consolidate the formation sands around the perforated completions⁵ and to stimulate initial oil production.

Well 2AT-61 completed cyclic steam injection on May 3 after injecting 101,329 BCWES and began producing on June 13 at an initial rate of 1000 BPD gross and 25 BPD

net oil. Production gradually increased to 1340 BPD gross and 32 BPD net oil by August 2 and stabilized until the well was idled August 13 for a pump change. Of note is that while changing the pump, no sand fill was found, indicating a successful sand consolidation job. The well was placed back on production August 23 at the previous rates, idled from September 12 - 23, and restarted at the previous rates through the end of the quarter. Well 2AT-63 completed cyclic steam injection on June 20 after injecting 140,339 BCWES and began producing on July 27 at 800 BPD of 100% water. The well produced all water until August 16 when the rates changed to 845 BPD gross and 5 BPD net oil which continued to September 10 when the well was idled. The well was restarted on September 23 and produced 800 BPD gross and 15 BPD net oil until the end of the quarter. Initial gross production rates have met expectations but oil production rates are disappointing compared to the projected peak oil rate of 300 BPD net oil per well. The reasons for the poor oil production will be evaluated during the next quarter.

Production well UP-955 was completed with 48 0.29-in. perforations and placed on cyclic steam injection in June. Production well UP-956 was completed with 36 0.29-in. perforations and placed on cyclic steam injection in August 1996. Both wells will complete steam injection and be placed on production next quarter.

The 2100 ft steam transmission line under the Cerritos Channel was placed in service in mid-December 1995 and has performed very well with no problems to date.

Four existing steam injection wells were converted to hot water injection from March, 1995 to February 1996. Hot water injection rates ranged from 500-3000 BWPD during this period. No incremental production response was observed. Hot water injection was discontinued in February due to surface owner requirements to move the hot water injection lines. Hot water injection is planned to be restarted by November 1996. The reservoir tracers will be injected into one "T" and one "D" injector in the First Quarter 1997.

Detailed thin section, scanning electron microscope, and x-ray diffraction work on wellbore fill samples from the existing steam drive wells show several types of scale including calcites, dolomites, barites, anhydrites, and magnesium-silicates. A study of the cores, produced fluids, and injection water has been completed that determined the mineralogy and source of the scales and how to prevent their occurrence^{5,6}.

● Operational Management

Most of this work is dependent upon the results of the high temperature core work to be performed.

● Technical Transfer

A magazine article was published in the September 1996 issue of The American Oil

and Gas Reporter on how 3-D mapping and horizontal wells breathes new life into mature oil fields, which is specifically about this DOE Class III project².

A paper on characterization of well log traces for 3-D mapping using a neural network approach will be presented at the 1996 SPE Annual Technical Conference in Denver in October⁴.

The project team made presentations on the major activities completed and status of the project to representatives from the DOE Bartelsville Project Office on September 19 in Tidelands' office in Long Beach.

The project team is conducting an innovative program to transfer the dozens of anticipated technological advances from the project. Several project team members are significantly involved in the planning of the 1997 Society of Petroleum Engineers Western Regional Meeting (WRM) scheduled in June, 1997 in Long Beach, California and a two-volume book on the geology and operation of slope and basin clastic oil and gas reservoirs. The WRM is being restructured to provide more practical and timely presentations to a broader industry audience. A new home page was created for the project on the Internet (<http://www.usc.edu/peteng/doe.html>). A CD-ROM of the project has been completed for content and is in the editing process which should be completed by year-end. The technical transfer commitment for this and other DOE projects has induced the project team members to establish a Regional Lead Organization office of the Petroleum Technology Transfer Council (PTTC) at the University of Southern California. Quarterly PTTC workshops are planned beginning in November 1996 and January 1997 and the DOE Class III projects will be highlighted.

References

1. Abstract and exhibits (original and additional annotations provided for exhibits) for a presentation given by Don Clarke, Chris Phillips and Linji An as a poster session entitled "Tertiary Development of Heavy Oil Sands Through Thermal Stimulation in the Wilmington Oil Field, California: a Geological Perspective" at the 1996 Annual Meeting of the American Association of Petroleum Geologists (AAPG) in San Diego.
2. Chris Phillips, Don Clarke, Linji An, Article in September 1996 issue of The American Oil and Gas Reporter entitled "3-D Modeling, Horizontal Drilling...Give New Life To Aging Fields", pages 106-115.
3. Abstract for a presentation given by D. K. Davies as a poster session entitled "Flow Unit Modeling in Complex Reservoirs" at the 1996 Annual Meeting of the American Association of Petroleum Geologists (AAPG) in San Diego, California in May 1996.
4. Ershaghi, I. and Hassibi, M.: A Neural Network Approach for Correlation Studies in

a Complex Turbidite Sequence, SPE Paper No. 36720 presented at the 1996 SPE Annual Technical Conference in Denver, CO

5. Abstract for a presentation given by Julius Mondragon and Scott Hara as a poster session at the 1996 Annual Meeting of the American Association of Petroleum Geologists (AAPG) in San Diego, California in May 1996 entitled "Novel Sand Consolidation Completion Technique Using Alkaline Steam Injection in the Tar Zone, Wilmington Field, California".
6. Abstract for a presentation given by D. K. Davies as a poster session at the 1996 National AAPG Convention in San Diego in May 1996 entitled "Mineralogy and Origin of Well-bore Scales in an Active Steamflood: Tar Zone, Fault Block IIA, Wilmington Field, California".
7. Davies, D. K., et al: Nature, Origin, Treatment and Control of Well-bore Scales in an Active Steamflood, Wilmington Field, California, SPE Paper No. 35418 presented at the SPE/DOE Improved Oil Recovery Symposium in Tulsa, OK, 21-24 April 1996.