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

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Contractor Names: City of Long Beach Department of Oil Properties (City) and Tidelands Oil Production Company (Tidelands), Long Beach, CA.

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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 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 an 2400 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 third quarterly technical progress report for the project. Through December, 1995, the project is on schedule and on budget. Several significant technical achievements have already been successfully accomplished including the drilling of four horizontal wells (two producers and two steam injectors) utilizing a new

and lower cost drilling program, the drilling of five observation wells to monitor the horizontal steamflood pilot, the installation of a subsurface harbor channel crossing for delivering steam to an island location, and a geochemical study of the scale minerals being created in the wellbore. Steam injection into the two horizontal injection wells began in mid-December 1995 utilizing the new 2400 ft steam line under the Cerritos Channel. Work on the basic reservoir engineering is expected to be completed in March 1996. A working deterministic geologic model was completed which allowed work to commence on the stochastic geologic and reservoir simulation models.

Regarding technical transfer, several presentations are being prepared for the 1996 Annual American Association of Petroleum Geologists Convention in May. Several project team members are significantly involved in the planning of this convention as well as the 1997 Society of Petroleum Engineers Western Regional Meeting. A home page was created on the Internet (<http://spidey.usc.edu/~yusuf/pet.html>) for the project.

- **Compilation and Analysis of Existing Data**

A computer database of production and injection data from the 1930's to the present were input, quality checked, and ready for use on November 1. This date was also used as a cutoff for searching of previous reservoir engineering studies and data. Digitized and normalized log data were completed for 146 wells which was sufficient to start work on the basic reservoir engineering and geologic stochastic models. Log digitization and normalization for another 25 wells should be completed by March. 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 stochastic geologic and reservoir simulation models. Another 100 logs (over 600 wells penetrate the Tar zone in the fault block) will be digitized and normalized to use as "confirmation" logs for the stochastic modeling.

- **Advanced Reservoir Characterization**

Basic reservoir engineering proceeding with analysis of primary and waterflood recoveries and material balance. Work completed includes 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, and determining vertical communication between sands. Work is continuing on evaluating the aquifer and performing correlation studies on projected steam drive recoveries from vertical and horizontal wells. Scheduled completion is March 1996.

Lab work completed to identify non-radioactive reservoir tracers effective in high temperature (500°F) environments. The tracer program includes two tracers,

ammonium thiocyanate and ammonium nitrate, which will be bulk injected into the "T" and "D" zones, respectively, in March. The tracers will follow the liquid phase of the injected steam. The program will be finalized in January.

Three observation wells and two core hole/observation wells were drilled. Four of the wells are for monitoring reservoir temperatures in the horizontal well steam drive pilot area. The D1 sub-zone is the steam drive interval for the horizontal wells. The fifth well is located in the original pilot steam drive area to determine post-steam oil saturations and mineral alterations to the formation rocks. Core recovery through the T and D sub-zones was excellent as over 99% of the planned core interval of 517 ft was recovered. The plan is to perform conventional porosity, permeability, and oil saturation measurements on core plugs. A proposal has been completed on high temperature core work to determine residual oil saturations to different steam temperatures, to determine formation rock and fluid alterations caused by different steam temperatures, and to determine the physical phenomena behind the successful perforated well completions in unconsolidated sands when initially stimulated with steam. Core work should commence in February.

A working deterministic 3-D geologic model was completed which was sufficient to start work on the stochastic 3-D geologic model and to use for drilling the observation and horizontal wells. Refinements to the deterministic model such as re-evaluating the fault picks and increasing the defined sand tops in the Tar zone from ten to eighteen should be completed in the First Qtr 1996. All existing core data was visually inspected in order to develop a core-based log model. The model will incorporate the two new cored wells and will be completed in the First Qtr 1996. The core-based log model will be used for developing the porosity-permeability model and rock-log model.

Other deterministic geologic studies underway include the barrier characteristics of the geologic faults and correlating the stratigraphic characteristics of the Tar zone with similar deposits in neighboring fields. Both of these studies should be completed in the first half 1996.

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 GR logs. Sample stochastic grid block models are being test run on the 3-D Earth-VisionTM visualization software to ensure compatibility.

● Reservoir Simulation

The effort to select and negotiate terms for a thermal reservoir simulator program should be completed in February. Purchase and installation of the simulation software and computer hardware should take a month.

● Reservoir Management

Four horizontal wells were drilled during the quarter. A new drilling procedure was successfully implemented that significantly reduced the rig time and cost compared to other horizontal wells drilled in the Wilmington field. The procedure involved setting 10.75 in. surface casing at 600 ft, drilling the remainder of the horizontal well to total depth of about 4600 ft, and cementing one string of 7.625 in. casing from the surface to total depth, including the average horizontal section of 1300 ft. The new procedure eliminated the cost and the rig time to install an intermediate casing string at the top of the oil zone. The two injection wells were selectively completed with a total of 11-12 quarter inch limited entry perforations over the last 600 ft of the horizontal section to inject a calculated 1500 barrels of cold water equivalent steam per day (BCWESPD).

The horizontal wells employed measurement while drilling (MWD) and logging while drilling (LWD) tools which provided sufficient real-time data to keep the wells within five feet vertically of the target well path. The LWD tools provided correlatable resistivity and gamma ray measurements when compared to the recently drilled observation well logs and exhibited consistent deep and shallow resistivity characteristics when approaching within five feet of the underlying shale. The sub-zone sands appear to be continuous going west to east across the fault block.

Steam injection was initiated into the two horizontal injectors in mid-December at low rates of 300 BCWESPD each. The plan is to perform 100,000 bbl steam injection cycles on each well to consolidate the formation sands around the perforated completions and to stimulate initial oil production. Cyclic steam injection into the two horizontal producers will follow. The injectors will be placed on permanent injection either after the post-cycle production either becomes uneconomic or after four months.

The 2400 ft steam transmission line under the Cerritos Channel was installed the previous quarter and was hooked up to the existing steam distribution system and to the new horizontal wells on Terminal Island and placed in service in mid-December. A low initial steam rate of 300 BCWESPD was delivered to allow the line to expand slowly. Through the end of December, the steam rate was increased to 600 BCWESPD and the line has performed very well with no problems. In review, the steam line included a 42 in. bore under the channel, a 30 in. outer line which was pulled through the bore and cemented in place, and dual concentric lines consisting of a 14 in. insulated steam line inserted inside a 24 in. backup line which were pulled through the 30 in. line together.

Four existing steam injection wells were converted to hot water injection in March, 1995. Injection rates ranged from 2000-3000 BCWESPD during this quarter. No production response to date.

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 determines the mineralogy and source of the scales and how to prevent their occurrence. The study will be presented at the SPE/DOE Improved Oil Recovery Symposium in Tulsa in April 1996. Design of high temperature lab work on the cores was completed in December. Actual high temperature lab work on the cores is scheduled to begin in February 1996.

The horizontal steam drive wells will be operated based on a pseudo "steam assisted gravity drainage (SAGD)" technique. The SAGD technique was designed by Butler^{1,2} and has been tested extensively in the heavy oil fields in Canada. Several articles have been written on the SAGD technique in the Canadian Journal of Petroleum Technology. A good article summarizing the heavy oil recovery techniques used in Canada was written by Polikar and Redford³. The pseudo SAGD method to be employed involves completing the last 600 ft of the horizontal wells in the most updip section of the reservoir. The horizontal segments of the wells average 1300 ft and were drilled going west to east at a 96-99° angle (going uphill) to compensate for the reservoir dip. The concept is to concentrate the steam updip in a smaller area to take advantage of gravity segregation of the steam in order to promote earlier development of a steam chest. As the steam chest grows to envelop the producer completion intervals, more perforations will be opened downdip and the updip perforations will be plugged off, if necessary. The pseudo SAGD technique is preferred over a conventional SAGD technique because the Tar zone has more mobile oil (13° API gravity) than the bitumen in Canada and has very mobile free water located primarily downdip and along the bottom of the sands caused by prior waterflooding.

- **Operational Management**

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

- **Technical Transfer**

The project team is conducting an innovative program to transfer the dozens of anticipated technological advances from the project. The goal is to present each technical advance within twelve months of its completion at a professional society meeting or convention. These technological advances will be highlighted in a CD-ROM of the project scheduled for 3rd Qtr, 1996 and on a home page created on the Internet (<http://spidey.usc.edu/~yusuf/pet.html>) for the project. 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 and restructure the Western Regional Meeting of the Society of Petroleum Engineers to provide more practical and timely presentations to a broader industry audience.

References

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