Increasing Heavy Oil Reserves in the Wilmington Oil Field through Advanced Reservoir Characterization and Thermal Production Technologies

DE-FC22-95BC14939

Goal

The overall objective of this project is to increase heavy oil reserves in slope and basin clastic (SBC) reservoirs through the application of advanced reservoir characterization and thermal production technologies. The project involves improving thermal recovery techniques in the Tar Zone of Fault Blocks II-A and V of Wilmington field near Long Beach, CA. A primary objective is to transfer technology applicable to other heavy oil formations of Wilmington field and other SBC reservoirs, including those under waterflood.

Performers

City of Long Beach/Tidelands Oil Production Company
Long Beach, CA

University of Southern California
Los Angeles, CA

Stanford University
Stanford, CA

Results

The first budget period phase addressed several producibility problems in the Tar II-A and Tar V thermal recovery operations that are common in SBC reservoirs. A few of the advanced technologies developed include a 3-D deterministic geologic model, a 3-D deterministic thermal reservoir simulation model to aid in reservoir management and subsequent post-steamflood development work, and a detailed study on the geochemical interactions between the steam and the formation rocks and fluids. State-of-the-art operational work included drilling and performing a pilot steam injection and production project via four new horizontal wells (2 producers and 2 injectors); implementing a hot water-alternating-steam (WAS) drive pilot in the existing steamflood area to improve thermal efficiency; installing a 2,400-foot insulated, subsurface harbor channel crossing to supply steam to an island location; testing a novel alkaline steam completion technique to control well sanding problems; and starting work on an advanced reservoir management system through computer-aided access to production and geologic data to integrate reservoir characterization, engineering, monitoring, and evaluation.

Heavy oil production facilities in Wilmington oil field, Long Beach, CA.

The second budget period phase continued to implement state-of-the-art operational work to optimize thermal recovery processes, improve well drilling and completion practices, evaluate the geomechanical characteristics of the producing formations, and update the 3-D geologic and reservoir simulation models. The objectives were to further improve the characterization of the heterogeneous turbidite sands, identify the high-permeability thief zones to reduce water breakthrough and cycling, and analyze the nonuniform distribution of the remaining oil-in-place. This work resulted in the redevelopment of the Tar II-A and Tar V post-steamflood projects by drilling a few new wells and converting idle wells to more effectively drain the remaining oil reserves by improving sweep efficiency and reducing water cuts while minimizing further thermal-related formation compaction. With no steam currently available to inject, efforts are being made to test cold heavy oil production techniques. The project will utilize all the tools and knowledge gained throughout the DOE project to maximize recovery of the oil-in-place.

Benefits

Tidelands is experiencing the most successful drilling in 25 years at the Wilmington onshore oilfield area owned by the City of Long Beach. Since 2003, Tidelands has drilled 34 producers and 6 water injectors and had planned to drill another 15 producers and 7 water injectors. The producers had peak production rates totaling 7,974 barrels of oil per day (BOPD) and 45,071 barrels of daily gross fluid (BGFPD; 82 percent water cut) compared to the projected first year average rates of 3,207 BOPD and 46,125 BGFPD (93 percent water cut). The 34 producers as of March 31, 2006, had been active from 1 month to 3 years, and production well test rates totaled 2,431 BOPD and 51,187 BGFPD (95.3 percent water cut). The 2,431 BOPD represented 31 percent of Tidelands' 7,738 BOPD operated production in March 2006. The best wells have been drilled to the Fault Block 3 Upper Terminal zone in an area the City of Long Beach had almost given up on as depleted. Initial well rates have ranged from 159 to 1,048 BOPD and March 2006 production tests from the five wells were 504 BOPD. The company attributes these successes to technologies learned from Tidelands' two Class III DOE projects (DE-FC22-95BC14939 and DE-FC22-95BC14934).

A highlight from the steamflood project is the sand-consolidation well completion technology that prevents sand entry into the producing wellbore. This new technology offers lower capital costs, provides more operating flexibility, and appears to have higher productivity indexes than other sand-control completions.

Background

Thermal operations at Wilmington were economic when oil prices were lower due to the availability of inexpensive steam that is no longer available. Future expansion of heavy oil recovery projects to other parts of Wilmington field will depend on improving the efficiency and economics of thermal or other enhanced oil recovery methods or by using cold heavy oil recovery techniques. This project may produce 13 million barrels of additional oil, and if these efforts are

expanded field-wide, it could add 525 million barrels of production. As mentioned earlier, the project has also helped improve drilling and completion methods that are applied to the development of all producing zones.

Summary

The 3-D reservoir simulation model was used to drill horizontal producing well UP957 in March 2004 to the best remaining oil-saturated sands in the D1 sands. The well reached peak oil production in April 2004 at 259 BOPD, over 100 percent better than projected.

The Tar II-A post-steamflood project accommodated the Port of Long Beach (POLB) container terminal expansion by plugging and abandoning four of the best producing wells totaling 345 BOPD from January to March 2005. The POLB paid for three replacement producing wells, which were drilled and activated from October 2004 to February 2005. The three replacement wells were initially proposed as the first three DOE BP2 wells to be drilled. Well UP-959 was drilled as an updip directional delineation well that showed significant oil depletion, ranging from 20 percent to 75 percent recovery of the original-oil-in-place. Two new horizontal wells were completed in the updip oil-depleted steam chest areas to accelerate the upward migration of hot oil. Well UP-958 was completed in the T2 sands and reached a peak rate of 226 BOPD/1,749 BPD gross (87 percent water cut) in November 2005. Well W-900 was completed in the D1, D1b amd D1d sands and averaged 155 BOPD at 93 percent water cut in November 2005.

Well UP-960 was drilled as a vertical infill pattern well to delineate the remaining oil saturations in the steamflood area downdip of UP-959. The well showed pre-waterflood oil saturations in the T sand and steam depleted D sands. Well UP-961 was drilled for the DOE project in place of well W-900 as a horizontal D1 sand well, only instead of drilling into the updip depleted steam chest, the well was completed in the downdip cold tar sands in a highly oil saturated area where vertical wells produced at 98+ percent water cuts.

The 3-D reservoir simulation model showed that continued operations through the year 2013 would not recover oil from the highly oil saturated D1 sands in the cold, structurally downdip areas south of the steamflood patterns. Recent drilling of replacement Tar II-A downdip water injectors and other new, deeper-zone wells in this area confirmed the very high oil saturations at the top of the D1 sands. When Union Pacific Resources developed its Tar II-A waterflood in 1960, the firm avoided this area because initial vertical waterflood wells had 98-99 percent water cuts; instead, they concentrated their efforts on the upstructure sands. New horizontal well UP-961 was drilled in November 2005 structurally downdip along the top of the cold D1 sands—again a very counterintuitive decision based on past well performance. This well peaked at 185 BOPD and 635 BGFPD in November 2005. A vertical steamflood pattern infill well, UP-960, was drilled in November 2005 and found the T sands oil saturated at pre-waterflood levels, even though waterflood and steamflood injectors surround the well, whereas the D1 sands appear oil depleted. The T sands do not appear resaturated because the temperature survey showed the sands as relatively cold, as if they never were steamed. These patterns were steamflooded for 6-7 years and then hot waterflooded; therefore, it is difficult to understand why the sands are not hot from conductive heat transfer alone. The resistivity log from an offset 1953 well that was completed deeper in the Lower Terminal zone shows similar T sand resistivities to UP-960. The D1 and D3 sands were very hot and exhibited the same characteristics as in well UP-959, only the resistivities were even lower. Based on the So versus Rt chart developed for UP-959 and assuming reservoir temperature of 300 °F and 20,000 ppm salinity, the D1 sands (0.7 - 2.0 ohms) had less than 15 percent So at the top and 40 percent So at the middle to bottom of the sands. The well was cased to TD, selectively perforated at the tops of the various T sands and the top of the D1 sands, assuming that the remaining D1 oil will migrate and resaturate the top of the sands, and an inner wire-wrapped screen was gravel-packed inside the casing for sand control. The well reached a peak rate of 70 BOPD and 1,328 BGFPD in March 2006.

Seven idle wells were activated and converted for use as Tar IIA producers (wells AT-43, AT-42, AT-63, UP-927) or water injectors (2AT-21, 2AT-22, 2AT-23) during 2005. All of the wells except UP-927 are completed in a single sub-zone, T or D1 sands, to provide better reservoir management control in an effort to increase oil production rates and reduce water cuts. The four producers peaked at 221 BOPD and 6,092 BGFPD (96 percent water cut). Two of the three injection wells were successfully placed on water injection, while the third well had casing damage.

Tar II-A oil production from October 2005 to March 2006 averaged 1,228 BOPD at a 3.31 percent oil cut (29.1 WOR), substantially better than in November 2003, when it averaged 902 BOPD at a 3.3 percent oil cut (28.9 WOR).

The Tar V post-steamflood pilot project experienced an increase in oil production from two new horizontal wells, wells A-603 and A-115, at the top of the S4 sands outside the steamflood pattern in cold oil. The two wells peaked at 633 BOPD and 1,746 BGFPD and were producing 351 BOPD and 3,187 BGFPD in March 2006. The offset operator, THUMS Long Beach Company, intends to drill similar Tar S sand horizontal wells in fault block V in 2006.

Stanford researchers completed their contract work injecting hot alkaline fluid into formation cores and quart sand vessels to determine if they could duplicate the sand-consolidation empirical process from the field in the laboratory. Initial results did not generate the expected calcium silicate cements. The experimental design assumptions were reexamined, and further testing indicated the calcium silicate cements probably originated from dissolution of wellbore cements used in completing the well. Their results show that it may be possible to add calcium silicate to injected hot alkaline water to consolidate formation sands in a perforated well completion. A second phase of laboratory research to formulate hot alkaline, geochemical solutions to consolidate formation sands was to start in 2006 and may extend past the contract date. Costs incurred after the contract date would be covered by Tidelands and the City of Long Beach.

Current Status (April 2007)

This project has been completed, and the final report is being prepared.

Funding

This project was selected in response to DOE's Reservoir Class III solicitation, DE-PS22-94BC14972/73, for Slope and Basin Clastic Reservoirs.

Publications

The project team has published over 100 original papers, poster sessions, and DOE reports. See listings under Reference Shelf at www.netl.doe.gov.

Project Start: March 30, 1995
Project End: March 31, 2007

Anticipated DOE Contribution: $7,891,000
Performer Contribution: $12,182,000 (60 percent of total)

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