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QUARTERLY TECHNICAL PROGRESS REPORT

CO_2 HUFF-n-PUFF PROCESS IN A LIGHT OIL SHALLOW SHELF CARBONATE RESERVOIR

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OBJECTIVES

The principal objective of the Central Vacuum Unit (CVU) CO_2 Huff-n-Puff (H-n-P) project is to determine the feasibility and practicality of the technology in a waterflooded shallow shelf carbonate environment. The results of parametric simulation of the CO_2 H-n-P process, coupled with the CVU reservoir characterization components will determine if this process is technically and economically feasible for field implementation. The technology transfer objective of the project is to disseminate the knowledge gained through an innovative plan in support of the Department of Energy's (DOE) objective of increasing domestic oil production and deferring the abandonment of shallow shelf carbonate (SSC) reservoirs. Tasks associated with this objective are carried out in what is considered a timely effort for near-term goals.

BACKGROUND

Texaco Exploration and Production Inc's. (TEPI) long-term plans are to implement a full-scale miscible CO_2 project in the CVU. However, the current market precludes acceleration of such a capital intensive project. This is a common finding throughout the Permian Basin SSC reservoirs. In theory, it is believed that the "immiscible" CO_2 H-n-P process might bridge this longer-term "miscible" project with near-term results. A successful implementation would result in near-term production, or revenue, to help offset cash outlays during the initial startup of a miscible flood. The DOE partnership provides some relief to the associated R & D risks, allowing TEPI to evaluate a proven Gulf-coast sandstone technology in a waterflooded carbonate environment. Numerous sites exist for widespread replication of this technology following a successful field demonstration.

SUMMARY of TECHNICAL PROGRESS

GEOSTATISTICAL REALIZATIONS:

Geostatistics has been used to distribute wellbore porosity data to interwell locations (cells) within the geological model. This exercise was expected to provide a more realistic distribution of the data than the typical algorithm used in mapping software. Normalized wireline porosity data from 455 wells in the project area were available for use. Results to date have proved too conservative relative to current and forecast recoveries. Continued investigation into the impact of various inputs is progressing. Meanwhile, a deterministic model that was constructed parallel to this geostatistical work has been incorporated to keep the project on schedule.

The neural network, which was introduced in earlier reports, was applied to the porosity distributions to define the permeability. Capillary pressure data, also previously reported, was combined and used to calculate original oil-in-place.

SITE-SPECIFIC SIMULATION:

A parametric study of the CO_2 Huff-n-Puff technology was conducted using Western Atlas' VIP-COMP simulator. The equation-of-state developed in the previous part of this project was used. The basic objectives of the parametric study were to identify reservoir characteristics that might be favorable or unfavorable, and to identify the best operational procedures. The results, which have been reported previously, are being incorporated into a site-specific model.

A site-specific model was selected in the north half of Section 6, T18S R35E. The model covers an area that was developed on 10-Acre spacing in early 1995. The site cover 160 acres (m/l), which includes four of the original 40-Acre five-spot injection patterns. Producers are located on the periphery of the model. The site spans various reservoir architectures. The northwest pattern is more contiguous, and has exhibited textbook waterflood characteristics. The southeast quarter is heterogeneous and has had a much poorer waterflood history. The model site covers the margin between the Northwest Shelf and the Delaware Basin. Four of the six production wells within the interior of this model are considered candidates for the CO_2 Huff-n-Puff technology.

The model has been finely gridded. Additional local grid refinement is imposed at individual producing wellbores in an effort to more accurately mimic the process. This refinement is necessary since the injected volume would typically only reflect changes in a single cell otherwise. The model currently has 22 columns and 26 rows, coupled with 12 layers which results in 6,864 cells, exclusive of the local grid refinements. History matching is underway for the waterflooded period of 1978 through 1995. Although the primary production is available, it cannot be accurately history matched with the current equation-of-state since it was developed from Pressure, Volume, and Temperature (PVT) studies on the waterflooded oil properties. No PVT data is available prior to waterflooding. The history match should be concluded by early August, 1995. A forecast will be developed for the field demonstration(s) which will follow in Budget Period No. 2. A continuation application was submitted to DOE in June, 1995.

Methods were identified during the earlier parametric simulation studies which could be used during Huff-n-Puff history matching to compensate for the absence of flow mechanisms important for Huff-n-Puff processes. Commercial reservoir simulators such as the one that was used do not have a number of the mechanisms which have been identified/suggested as being present in Huff-n-Puff processes. The mechanisms which are absent include diffusion during the soak period and increased oil relative permeability (from relative permeability curve hysteresis) during the production phase. These are important because diffusion permits CO_2 to move away from the well and oil to move back toward the well during the soak, and because increased oil relative permeability leads to a larger oil rate during the production phase. Methods were found to overcome these simulator limitations. Increasing the gas-oil capillary pressure to very large levels was found to mimic diffusion, and a method was found to change the relative permeability curves in mid-simulation so that an increase in the oil relative permeability curve during the production phase could be approximated. In addition, the VIP-COMP simulator can include directional relative permeability so that a decrease in the gas relative permeability can be modeled. A decrease in the gas relative permeability is another mechanism claimed to occur in a Huff-n-Puff. Although these procedures to overcome simulator limitations were identified, they were not used during the parametric studies but were instead left to be used as needed for history matching the

field demonstration(s). A moderately large gas-oil capillary pressure and trapped gas hysteresis were the only special relative permeability features which were used in the parametric studies. This same approach will be applied to the site specific forecast.

WATERFLOOD REVIEW:

A proper review of past operations is not complete without a proper relationship to the initial hydrocarbons in the formation. The procedures for calculating Original Oil-In-Place (OOIP) within Stratamodel software have been developed and tested. OOIP was calculated for each cell in the model. Calculating OOIP in this manor requires porosity, permeability, and Sw values for each cell in the model. Porosity is derived from the distribution of porosity data from each well location. Permeability is determined for each cell using the Neural Network described in previous reports. Initial water saturation is calculated for each cell using the Leverett "J" function (described in earlier reports). Polygons for unit boundaries and water flood patterns were added to the model. These polygons allowed summation of OOIP for specific areas and individual waterflood pattern review. Summation by stratagraphic sequence is also possible, allowing each of the five sequences to be summed individually. Many parameters, such as net pay, hydrocarbon pore volume, etc. are being mapped. Refinements to the acreage associated with periphery waterflood patterns is underway. Without the correction, a volume of OOIP that has contributed to the pattern recovery was being omitted, resulting in an overly optimistic recovery efficiency. This was leading to erroneous interpretations. Some leaseline OOIP calculations were also found to have an error in the manner of summation. These issues have now been resolved.

Current observations are that overall, either, 1) the property is experiencing ultimate recovery efficiencies above normal, at approximately 44.8% OOIP, 2) the OOIP is too low, or 3) two independent approaches to estimating ultimate recoveries, although equivalent findings, resulted in erroneous forecasts. Investigations continue. The site specific modeling will help address this issue during the history matching phase. Volumes and efficiencies fit with structural and geologic trends. Details from this study will be provided in the annual technical report.

A review of waterflood efficiencies continues. It is anticipated that this detail review will allow proper selection of the eight sites for the field demonstration of the proposed technology. The results of the parametric simulation studies will be coupled with the waterflood review information. The intent is to be able to select a sufficient variation is reservoir conditions/character to support the parametric study findings with field demonstrations. Guidelines will ultimately be developed to assist operators in selecting candidate sites based on this information and actual field trials.

RESERVOIR CHARACTERIZATION:

Most reservoir characterization tasks have already been completed. However, some final exercises are being refined.

Final copies of the Stratagraphic cross sections through all CVU and VGSAU wells have been completed using Geographix Software. A process was also developed which converted the perforation database information stored in an Excel Spreadsheet format, to a form usable by Geographix, for display on these cross sections. In all, 25 North-South and 27 East-West cross sections are completed with perforation information. This information is being used to assist with interpretation of production anomalies within the waterflood review. The information has also expedited history matching and model setup for the site specific simulation exercises.

REFERENCES/PUBLICATIONS

No technical papers were submitted or published during the second quarter 1995. The Petroleum Recovery Research Center continues to provide updates on the project in its quarterly newsletter. In addition, the newly formed Petroleum Technology Transfer Counsel, a joint venture between the Independent Producers Association of America (IPAA) and DOE is providing complete quarterly and annual Technical Reports on an Industry Bulletin Board called GO-TECH. This will allow a more timely dissemination of information to interested parties.

An update of the project was presented to industry representatives in attendance at the DOE Contract Review meeting June 27, 1995 at Lake Eufalla, Oklahoma. Abstracts will be submitted to program committees associated with the upcoming Society of Petroleum Engineers' (SPE) Permian Basin Oil and Gas Recovery Conference (March 1996) and SPE/DOE Improved Oil Recovery Conference (April 1996). These presentations should be timely, as results from the first field demonstration(s) should be available for inclusion. In that regard, a Continuation Application (and all associated reports) to proceed to Budget Period No. 2 has been submitted.

A consortium led by the Colorado School of Mines is considering the Central Vacuum Unit as a site to conduct 4-D, 3-C seismic studies. The project would attempt to monitor dynamic reservoir conditions associated with the introduction of CO_2 into the reservoir along with stress field changes. The information gained through this proposed seismic demonstration would complement the subject project at no cost. The information may provide necessary data for refinements to the reservoir model (layering, flow capacity, fracture orientation, etc.) and fluid characterization (saturations, fluid flow; etc.). Their consideration of the CVU as a demonstration site is made possible by the fact that the accumulation of data from this CO_2 Huff-n-Puff project is available in the public domain; obligated by the use of DOE funding.