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QUARTERLY TECHNICAL PROGRESS REPORT

**CO₂ HUFF-n-PUFF PROCESS
IN A LIGHT OIL
SHALLOW SHELF CARBONATE RESERVOIR**

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**Texaco Exploration & Production Inc.
Midland, TX**

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OBJECTIVES

The principal objective of the Central Vacuum Unit (CVU) CO₂ 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 CO₂ 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 CO₂ project in the CVU. However, the current market precludes acceleration of such a capital intensive projects. This is a common finding throughout the Permian Basin SSC reservoirs. In theory, it is believed that the "immiscible" CO₂ H-n-P process might bridge these longer-term "miscible" projects 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.

TEPI has concluded all of the Tasks associated with the First Budget Period. The DOE approved the TEPI continuation application. Budget Period No. 2 is now in progress. Initial injection of CO₂ is planned for early November, 1995.

SUMMARY of TECHNICAL PROGRESS

GEOSTATISTICAL REALIZATIONS:

The geostatistical portion of the project has been completed. Geostatistics, along with other more common approaches, have been used to distribute wellbore porosity data to interwell locations (cells) within the geological model. Krigged porosity values were generated using Texaco's Gridstats program. Normalized wireline porosity data from 455 wells in the project area were input to the program, along with picks for the top of the Grayburg Dolomite, Grayburg Sandstone, and San Andres. This exercise was expected to provide a more realistic distribution of the data than the typical algorithm used in standard mapping software. Initial geostatistical results proved too conservative relative to current and forecast recoveries. However, continued investigation into the impact of various inputs resulted in relatively similar results. As it turned out, the difference between the geostatistics and other approaches stemmed from a mis-formatted

datafile. The following table compares the three methods of porosity distribution and the resulting original oil-in-place (OOIP).

MODEL TYPE	OOIP CENTRAL VACUUM UNIT
STRATAMODEL DETERMINISTIC (POWER FACTOR = 2)	209.6 MMBO
STRATAMODEL STATISTICAL (POWER FACTOR = 5)	201.4 MMBO
GRIDSTATS (Texaco Geostatistics Software)	211.1 MMBO

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 in calculating the OOIP reported above.

Resulting OOIP calculated from the geostatistical (Texaco's Geostats program) derived porosity compares favorably to that using the distributions (deterministic and statistical) within the Stratamodel program. The lower value for the Stratamodel Statistical (Power Factor=5) model was to be expected. The porosity values of actual wireline measurements are not maintained at wellbore cells with this particular approach. The resulting calculations tend to represent the reservoir flow units as a more continuous architecture, with lower porosity in any given zone of comparison (i.e. the data is heavily averaged). The Stratamodel Deterministic and GridStats (geostatistics) approaches were quite similar in OOIP calculations. But, it is only the geostatistical approach that does not rely heavily on any user defined input (power factor for scaling). Had the investigators chosen different scaling factors in Stratamodel, the results could have been quite variable, or the Stratamodel Statistical approach could have even had a similar result to the other two. Both the Geostatistical and StrataModel Deterministic approaches match fairly well with the estimated ultimate recovery forecast trends.

SITE-SPECIFIC SIMULATION:

A parametric study of the CO₂ 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, were 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 covers 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 more 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 CO₂ Huff-n-Puff technology.

The model was finely gridded. Additional local grid refinement was imposed at individual producing wellbores in an effort to more accurately mimic the process. This refinement was necessary since the injected volume would typically only reflect changes in a single cell otherwise. The model had 22 columns and 26 rows, coupled with 12 layers which results in 6,864 cells, exclusive of the local grid refinements. History matching the waterflooded period of 1978 (initial H₂O inj.) through 1995 was performed. 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 was concluded in early August, 1995. A forecast was developed for the field demonstration(s).

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 CO₂ 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. These same approaches were applied to the site specific area in generating a forecast.

Over the next several months, following the introduction of the CO₂ in the demonstration site, production will be monitored and history matched with the compositional simulator. The mechanisms above will be incorporated as warranted.

WATERFLOOD REVIEW:

A proper review of past operations is not complete without a comparison 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 manner requires porosity, permeability, and S_w 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 stratigraphic sequence is also possible, allowing each of the five sequences to be summed individually. Many parameters, such as net pay, hydrocarbon pore volume, etc. were investigated and mapped

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 in findings, resulted in erroneous forecasts. Investigations continued during the third quarter of 1995. The site specific modeling helped address this issue during the history matching phase. The history matching went very smoothly. This was due to the detail provided in the geologic model, coupled with the initialization parameters developed within this study. The simulation suggests that the calculation of, and distribution of hydrocarbons is good. Overall, volumes and efficiencies fit with structural and geologic trends. Therefore, it is inferred that the ultimate recovery efficiency is above normal when compared to other San Andres waterfloods. Details from this study will be provided in the annual technical report.

DEMO. DESIGN/PROCEDURES PLANNING:

Several tasks have been performed early in Budget Period No.2. A demonstration site was selected within the site specific simulation area. Central Vacuum Unit No. 97 was selected due to its relatively high water cut (simulations suggest greater efficiency with higher water cuts). The Electrical Submersible Pump (ESP) was exchanged for a Rotaflex Rod Pump system (costs not included with the DOE project). This should provide better pumping efficiencies during the high gas production periods following introduction of the CO₂ to the reservoir system.

A contract was consummated with Phillips Petroleum Company to temporarily dispose of the CO₂ contaminated gas production. A temporary polypropylene line will be installed to transport the low pressure gas to an offlease gathering point.

CO₂ supply arrangements have been investigated and selected. A pipeline alternative was investigated, but was found to be somewhat costlier for the near-term demonstration component. Services for trucking and injecting the CO₂ were solicited. The services were awarded to CO₂, Inc. out of Midland, Texas. Injection is planned to begin around November 1, 1995.

The CVU No. 97 will be broken out of the existing satellite and diverted through an isolated satellite for testing purposes.

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.

Abstracts were 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). The PBOGRC has formally selected our abstract for inclusion to the meeting proceedings. These presentations should be timely, as results from the first field demonstration(s) should be available for inclusion.

A consortium led by the Colorado School of Mines selected the Central Vacuum Unit as a site to conduct 4-Dimensional, 3-Component seismic studies. The project would attempt to monitor dynamic reservoir conditions associated with the introduction of CO₂ 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 (saturation, 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 CO₂ Huff-n-Puff project is available in the public domain; obligated by the use of DOE funding. The 4D, 3C Seismic project will be conducted in parallel, at no cost to the DOE.