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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) mid-term plans are to implement a full-scale miscible CO₂ project in the CVU. The current market precludes acceleration of such capital intensive projects in many cases. 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 began in November, and after a short shut-in period for the soak, the well was returned to production in late December, 1995.

SUMMARY of TECHNICAL PROGRESS

Field Demonstration

Even though simulation exercises suggested reservoir heterogeneity would not play a large role, a well with average reservoir characteristics of the CVU was desired. Additionally, the parametric study showed that a higher water-cut production stream would have a better CO₂ utilization ratio. CVU No. 97 was selected in part based on these guidelines. The well has several distinct, relatively thin, higher permeability flow units which are common within CVU. The remainder of the net pay is of average reservoir quality.

CVU No. 97 was drilled in 1938 to a depth of 4,725 ft. An open-hole completion was made with 7.0 in. casing set at 4,099 ft. Cement was circulated back up into the surface casing. This completion left 161 ft. of impermeable strata above the pay zone exposed in the 6.125 in. wellbore. Casing integrity or unknown thief zones have been cited in the literature to be primary causes of failure in other work. A casing-inspection log and cement-bond log revealed a

competent wellbore. There is no record of fluid production from, or losses to, the exposed non-pay interval at CVU.

A volume of 50,000 McfCO₂ was required. The volume was determined to be sufficient for the storage volume available in the near wellbore vicinity, yet small enough to reduce concerns of any loss of CO₂ beyond the interwell distance if the three higher flow-capacity zones took all the injectant. Based on average reservoir parameters, this volume would expose the reservoir to less than a 100 ft. radius of CO₂.

Downhole Operations. The production equipment was removed from the wellbore after tagging 10 ft. of fill material at total depth. Since the well had been acidized in recent months, no further remedial action was performed. An on-off tool and injection packer trimmed for CO₂ service was run on 2.875 in. coated tubing and set in the casing. Inhibited water was placed on the backside. Testing frequency was stepped up in the prior month to confirm a stabilized production trend.

Surface Operations. The theory of ceasing offset water injection was not strongly supported by simulation. However, recognizing that simplistic models may not have the capability to quantify this case, the offset injection was shut-in 17 days before CO₂ injection commenced at CVU No. 97.

CO₂ Storage/Injection Equipment. The CO₂ was trucked 50 miles from a site near Allred, Texas. Each truck could haul 345 McfCO₂. Storage vessels were set in order to eliminate night deliveries. Approximately 145 round-trips were required for the project. The storage vessels were manifolded into a trailer mounted quintuplex positive displacement pump, with self-contained booster, which was connected to the wellhead. Injection rate and volume, temperature, and pressures were continuously recorded.

Test Separator. Frequent and detailed testing was planned for the duration of the project. Therefore, a dedicated horizontal, three-phase, skid-mounted test vessel was fabricated for the demonstration and set at the well site. Data gathering was automated. Flowing tubing pressure, casing pressure, and temperature are monitored continuously. Liquid volumes are measured daily. Gas production rates and volumes are also being measured. Automated gas sampling provides a daily sample for gas chromatography. Liquid samples are initially gathered daily for visual inspection, API gravity determination and occasional compositional analysis. Testing frequencies will decrease with time. The well was connected to the separator with polyethylene pipe. The test separator dumps liquids through another polyethylene pipe to the existing production satellite.

Produced Gas Handling. One of the major hurdles this demonstration faced was disposal of the produced gas stream. Original plans fell apart when the existing gas purchaser committed to significant new gas contract volumes. The added volumes did not leave enough plant capacity for the CO₂ (acid gas) within the facility.

Air quality regulations would not permit venting the hydrocarbon enriched CO₂ stream to the atmosphere. A CO₂ processing facility was in operation on the offsetting lease (miscible CO₂

flood). An idle 6.0 in. gas line, which passed by both the demonstration site and a satellite at the offset CO₂ flood, was used to deliver the contaminated gas to the CO₂ processing facility. Polyethylene pipe was used at both ends to tie the delivery line into the satellite and test separator.

Initial Results. Injection was initiated November 13 and completed on December 7, 1995. Based on the offset miscible CO₂ flood injection rates and pressures, an average rate of 1,500 McfCO₂/Day was expected in the demonstration. Actual injection averaged 2,210 McfCO₂/Day over 23 days net injection. Two days (separate incidents) were lost to mechanical problems involving the injection pump. Injection line temperature fluctuated between -14°F and 20°F, averaging 3.4°F. Wellhead injection pressure averaged 644 psig and did not exceed 817 psig.

Concern over the open-hole section, lower injection pressures and higher injection rates than expected prompted an injection profile once half the target volume was injected. The CO₂ was distributed within both the Grayburg and San Andres formations. Although the injectant was confined to the pay zone, the distribution was somewhat weighted toward the Lower San Andres. The injectant was at the reservoir temperature of 101°F by the time it reached the bottom injection interval. The estimated average bottomhole injection pressure of 2,175 psig never approached the parting pressure of the formation (3,200 psig). It is doubtful that any part of the near-wellbore vicinity was able to maintain a pressure below the MMP of 1,250 psig as originally desired.

Offset production was monitored on a regular basis for CO₂ breakthrough. Levels remained in the normal 4-5% background range.

Once the target volume was in place, offset water injectors were returned to active service. CVU No. 97 was shut-in for a 20-day soak period--6 days longer than plan due to labor issues. Wellhead pressure averaged 630 psig during the last week of injection and had increased steadily to 889 psig during the soak period. Although common in the CVU injectors, it is unknown if any cross-flow from higher permeability to lower quality zones occurred in the wellbore during the soak period.

CVU No. 97 was returned to active status under flowing conditions on December 27, 1995. Flowing tubing pressure averaged 631 psig with choke settings between 13/64 in. and 18/64 in. Initially, production has averaged 901 Mcf/Day. No appreciable water production has been seen. Compositional analyses of the gas stream is running at 94% CO₂. Liquid hydrocarbon production was initially too small to measure and began increasing on the third day. Samples are being collected and retained. The fluid is

colorless, suggesting that lighter hydrocarbons are being effected (or paraffins & asphaltenes are being left behind). The well had achieved a 70 BOPD rate by the tenth net day of flow-back (average pre-demonstration was 68 BOPD). Approximately 20% of the injected CO₂ volume has been produced.

Winter weather is hampering flowback, exasperating hydrate formation. An in-line heater was temporarily placed near the wellhead until liquid volumes increase sufficiently to eliminate the need. The gas flow line freezes in the evenings where liquids collect. The line has been leveled in an attempt to control the situation. The field demonstration history through January 8, 1996 has been provided above.

SITE-SPECIFIC SIMULATION:

Reservoir description was found not to be as important a parameter in a H-n-P as in a standard CO₂ flood. H-n-P predicted performance was found to be similar over a range of injection pressures and gas production limits. Forecasted recoveries were found to be related to the total CO₂ volume injected, similar to typical miscible floods. Gas trapping by hysteresis was found to be the dominant factor influencing recoveries. This work was previously reported. A graphical display of the history match (primary + secondary) and forecast are shared in the Figures at right for reference purposes.

A need for model refinement has been demonstrated by the differences between predictions and early results (injection rates & pressures). Monitoring of the CVU field demonstration continues. Early results do not provide enough data to make an informed opinion; the project continues under nervous optimism. Over the next several months, production will be monitored and history matched with the compositional simulator. The mechanisms investigated during the parametric simulation exercise will be incorporated as warranted.

Following a successful demonstration and associated history matching, the development of guidelines for the cost-effective selection of candidate sites, along with estimation of recovery potential, will be pursued.

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). Both Conference's Program Committee formally selected our abstract for inclusion to the meeting proceedings. Manuscripts will be forwarded during the first quarter of 1996. 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 is attempting 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 complements 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 is being conducted in parallel, at no cost to the DOE. Initial findings suggest that the CO₂ "cloud" is visible. Findings are expected for public disclosure during the second quarter 1996.