DOE/BC/14986-5

QUARTERLY TECHNICAL PROGRESS REPORT

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

(No. DE-FC22-94BC14986)

Texaco Exploration & Production Inc.
Midland, TX

Date of Report:	04-21-95
Award Date:	02-10-94
Anticipated Completion Date:	12-31-97
DOE Obligation/Award (current year):	$469,466.00
Program Manager:	Scott C. Wehner
Principal Investigator(s):	Roger Cole John Prieditis Joe Vogt Scott Wehner
Contracting Officer's Representative (COR):	Jerry Casteel / BPO
Reporting Period:	1st Qtr. 1995

RECEIVED
USDOE/PETC
95 MAY -2 AM 10: 32
ACQUISITION & ASSISTANCE DIV.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

LEGAL NOTICE/DISCLAIMER

This report was prepared by Texaco Exploration and Production Inc. (TEPI) pursuant to a Cooperative Agreement partially funded by the U. S. Department of Energy (DOE), and neither TEPI nor any of its subcontractors nor the DOE, nor any person acting on behalf of either:

(A) Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately-owned rights; or

(B) Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the DOE. The views and opinions of authors expressed herein do not necessarily state or reflect those of the DOE.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

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. 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 is being used to distribute wellbore data to interwell locations (cells). This exercise is expected to provide a more realistic distribution of the data than the typical algorithm used in mapping software. Normalized porosity and permeability data from 455 wells in the project area were available for use. This figure has been reduced to 322 wells due to statistical variations being introduced by sonic logs which do not account for secondary porosity. Markers within the pay were taken from the project database. Variograms suggest an Easterly-Westerly bias to the porosity distributions. Not surprisingly, this trend follows the strike of the basin margin.

At 852,720 cells, the geostatistical exercises are handling a rather large volume of data for the study. The 3-D gridding consists of 170 layers within the Grayburg and San Andres formations, with an aerial distribution of 76 rows, by 66 columns. Three stratigraphic porosity grids were made for the study area: a 13 layer grid for the Grayburg Dolomite, a 7 layer grid for the Grayburg Sandstone, and a 150 layer grid for the combined Upper San Andres, Lovington Sandstone, and Lower San Andres. Since no flow simulation is planned for this large study area, no conditional simulation was done--all grids were made using kriging. The layers are

approximately 4.00' thick. Each cell is 250' X 250' on a side. This work is being performed on a personal computer with a geostatistical software package developed by Texaco, called GRIDSTAT. The grid can be visually analyzed with Stratamodel.

Attention has focused on a smaller study area which encompasses the site specific simulation area and impending initial field demonstration. The geostatistical exercise was repeated in this area for added modeling detail. A total of twenty stratigraphic porosity grids were made for this smaller study area. Five zones were created by kriging, and the same five zones by three successive conditional simulations. The five gridded zones are a 13 layer grid for the Grayburg Dolomite, a 7 layer grid for the Grayburg Sandstone, a 30 layer grid for the Upper San Andres, a 15 layer grid for the Lovington Sandstone, and a 90 layer grid for the Lower San Andres. Each cell is 132' X 132' on a side. The layers are approximately 4.00' thick. This model covers that same vertical component of gross pay as the larger study, after excluding some non-pay footage from the bottom of the model. The site specific model for compositional simulation will be extracted from this work.

Originally, it was anticipated that the variograms developed from the porosity data would be used in construction of the permeability grids. This approach has been abandoned in favor of directly applying the neural network permeability relationships corresponding to the geostatistically distributed porosity. The original approach left concern regarding the redistribution of permeability data which was partially defined based on its 3-D spatial distribution in the reservoir.

PARAMETRIC SIMULATION:

A parametric study of the CO_2 Huff-n-Puff technology has been 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. A radial model with 25 grid cells in the radial direction was used. A water injector was placed in the outside radial grid so that waterflooding could be simulated and pressure in the model could be maintained. Models with as little as one layer and as many as 14 layers were used. Results from different numbers of layers were qualitatively similar. Relative permeability curves obtained from laboratory measurements were employed. The porosity, permeability, and net pay were representative of the vicinity selected for the site specific simulation study. The parameters studied included reservoir heterogeneity, the water-oil ratio before the Huff-n-Puff, and Huff-n-Puff operational procedures.

In addition to the parametric simulations, methods were identified 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. 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.

A typical result of a Huff-n-Puff is presented in Fig. 1 . A CO_2 volume of 25 MMscfCO_2 was injected into a well with 390 ft of net pay and an average porosity of about 9%. The watercut was 85 % prior to the Huff-n-Puff. The oil rates are shown for the puff and for a continued waterflood without a Huff-n-Puff. The peak oil rate for this case was doubled; being a typical result. The increased oil rate persisted for about as long as the CO_2 was produced back. This period depends on the amount of CO_2 injected. For 25 MMscfCO_2 injected, incremental production typically lasted about 50 to 80 days. It should also be noted that the period of the improved water-oil ratio also lasted for this same amount of time (i.e., the period of 50 to 80 days). The initial period of production was one of essentially pure CO_2 which lasted for about 10 days. The length of this period could have been adjusted by changing the magnitude of the gas-oil capillary pressure and the gas relative permeability. The incremental oil attributed to the CO_2 was calculated by determining the cumulative oil production during the demonstration until the oil rate crossed the rate for the extended waterflood (for this case about 80 days) and then subtracting the cumulative oil production for the extended waterflood at this point. The incremental oil for this particular example was 1,400 STB. The incremental oil volumes typically ranged from about 500 to 2,600 STB's with 25 MMscfCO_2 injected for the other cases studied. The apparent CO_2 utilization factors were consequently about 10 Mscf/STB or greater. They were much greater than the factors of about 1 Mscf/STB which have previously been reported for Huff-n-Puff trials. The present utilization factors and the amount of incremental oil could have been increased somewhat by increasing the oil relative permeability during the injection phase. This was not done for most of the parametric cases because the objective was to compare the relative effects of selected parameters.

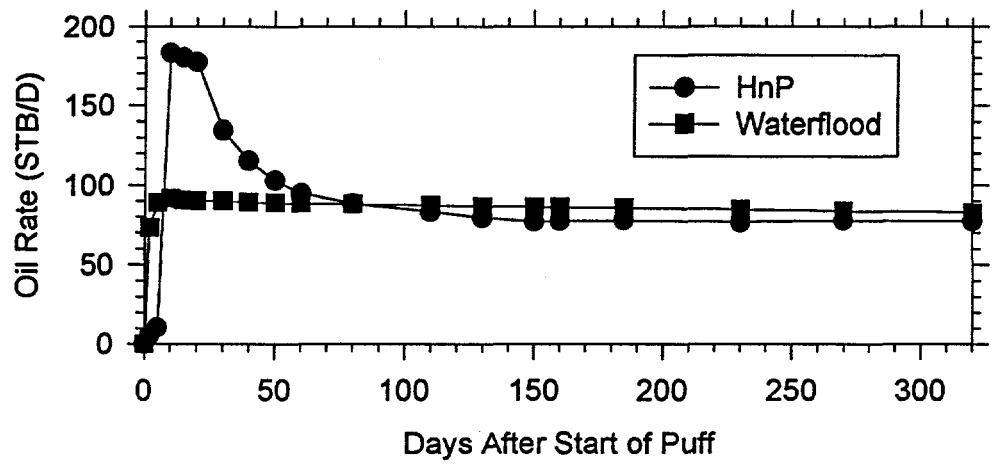

Fig. 1 Oil Rate versus Days after Start of Production.

One effect of actual Huff-n-Puffs is to increase the total liquid production for an extended period of time. If this happens, the oil rate can increase for a substantial period of time without an improvement in the stabilized water-oil ratio. For the cases simulated here, this did not occur. The stabilized total liquid production rate and the water-oil ratio returned to pre-Huff-n-Puff levels.

One set of parameters which was investigated involved reservoir heterogeneity. The Huff-n-Puff process was not found to be extremely sensitive to reservoir heterogeneity. Reservoir heterogeneity does not appear to degrade the Huff-n-Puff process substantially unless there are very high permeability zones without vertical permeability. The presence of vertical permeability largely prevents high permeability streaks from degrading the process. A large amount of vertical permeability is not needed and values as little as 0.1 to 0.2 md are effective. The vertical permeability makes a layered system with heterogeneity more effective than a completely homogeneous system. If vertical permeability is present, the CO_2 enters the high permeability streaks but can move vertically into other layers. If there is no vertical permeability, zones of very high permeability will degrade the process since the CO_2 is confined primarily to the high permeability layers. The only wells which should be excluded as candidates for Huff-n-Puffs are wells with very high permeability channels.

Another parameter which was investigated was the water cut prior to the Huff-n-Puff. The Huff-n-Puff process in an ongoing waterflood appears to work better for wells in which the water cut is high rather than very low. This would suggest doing the process for wells with a high water cut rather than recently drilled infill wells in which the oil rate is high and the water-oil ratio is still very small.

An important set of parameters focused on Huff-n-Puff operating conditions. The effect of reservoir pressure was examined and the Huff-n-Puff was found to be more effective under immiscible rather than miscible conditions. The CO_2 utilization factor was more advantageous for the immiscible case. In addition, another effective strategy was to inject the CO_2 under immiscible conditions, let the pressure build during the soak, and then produce the well. However, it may not be possible to inject the CO_2 under immiscible conditions in the field. The average reservoir pressure in the field is above the minimum miscibility pressure (MMP). The pressure changes in the near well region were examined when the well was shut in. High permeability layers reached the MMP after one day. The low permeability layers approached the MMP after about 3 days. The original idea for operating the Huff-n-Puff was to inject the CO_2 under immiscible conditions, let the pressure build, and put the well back on production. This may not be possible since simulation results suggest that the near well region will reach the MMP after a few days even without the added pressure increase of the CO_2 injection. The average pressure in the pattern (or model) could be decreased by stopping water injection. However, about 15 days without injection are required to reduce the average reservoir pressure by about 100 psi. A long period without injection would be required to reduce the average pressure below the MMP. A reservoir of different character than described here may make this approach more advantageous. Because it appeared unlikely that the Huff-n-Puff could be operated below the MMP, a number of CO_2 injection pressures above the MMP were examined. It was found that surface injection pressures up to 2,700 psi did not reduce the effectiveness of the Huff-n-Puff if the injection pressure was already above the MMP.

The CO_2 injected volume was another parameter which was investigated. Some additional investigation is needed, but it appears that a volume of about 25 MMscfCO_2 is required for a well in which the net pay is almost 400 feet. This volume is much less than the 150+ MMscfCO_2 which would be required for the CO_2 to penetrate to an idealized 100 feet radius. A distance of 150 feet for CO_2 penetration has sometimes been proposed as a guideline for Huff-n-Puff operation in pressure depleted reservoirs. Soak times of 5 to 30 days were examined. Similar to the results of other investigators, no essential differences were found with the simulator for different soak times.

Future work will focus on simulating a Huff-n-Puff in the first demonstration site which has been selected. This model will be of greater detail and will be history matched.

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 have been

added to the model. These polygons will allow summation of OOIP for specific areas and individual waterflood pattern review. Summation by stratagraphic sequence will also be possible, allowing each of the five sequences to be summed individually. Many parameters, such as net pay, hydrocarbon pore volume, etc. will now be mapped.

Preliminary OOIP volumes have been calculated. Three separate reservoir models have been generated using, 1) deterministic, 2) statistical, and 3) geostatistics. The first two model descriptions were created using algorithms within Stratamodel. The third is a separate topic discussed in this and previous reports. A comparison of the three models is underway. These values will be compared with historical estimates based on more simplistic volumetric approaches and material balance.

A review of waterflood efficiencies is in progress. 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.

Initial findings suggest that the waterflood has performed very well. Recoveries are estimated to ultimately recover nearly 40.0 % OOIP. Volumes and efficiencies fit with structural and geologic trends. Details from these studies will be provided in the annual technical report.

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 are nearing completion using Geographix Software. A process was developed which converts perforation database information stored in an Excel Spreadsheet format to a form usable by Geographix, for display on the cross sections. This process involved a three step procedure. First, an Access Software module (Access Basic Program) was created to locate and check the existing log data against maximum perforation depth. In some cases, additional data points were added where log depth was less than perforation depth. Next, a module was created to read the spreadsheet data into the Access database for Active Perforations, Squeezed Perforations, Plug Back Depth, and Casing Shoe Depth. Finally, an Access report was created to generate a LAS (Logging ASCII Standard) format log file for each well. In Geographix, the perforation information is treated as "other" log curve data being printed on the cross sections. In all, 25 North-South and 27 East-West cross sections are completed with perforation information. This information will be used to assist with interpretations of production abnormalities. This information is further needed for history matching and model setup for the site specific simulation exercises.

REFERENCES/PUBLICATIONS

No technical papers were submitted or published during the first 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.

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.