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DISCLAIMER

OBJECTIVES

The Class 2 Project at West Welch was designed to demonstrate the use of advanced technologies to enhance the economics of improved oil recovery (IOR) projects in lower quality Shallow Shelf Carbonate (SSC) reservoirs, resulting in recovery of additional oil that would otherwise be left in the reservoir at project abandonment. Accurate reservoir description is critical to the effective evaluation and efficient design of IOR projects in the heterogeneous SSC reservoirs. Therefore, the majority of Budget Period 1 was devoted to reservoir characterization. Technologies being demonstrated include:

1. Advanced petrophysics
2. Three-dimensional (3-D) seismic
3. Cross-well bore tomography
4. Advanced reservoir simulation
5. Carbon dioxide (CO_2) stimulation treatments
6. Hydraulic fracturing design and monitoring
7. Mobility control agents

SUMMARY OF TECHNICAL PROGRESS

West Welch Unit is one of four large waterflood units in the Welch Field in the northwestern portion of Dawson County, Texas. The Welch Field was discovered in the early 1940's and produces oil under a solution gas drive mechanism from the San Andres formation at approximately 4800 ft. The field has been under waterflood for 30 years and a significant portion has been infill-drilled on 20-ac density. A 1982-86 pilot CO_2 injection project in the offsetting South Welch Unit yielded positive results.

Recent installation of a CO_2 pipeline near the field allowed the phased development of a miscible CO_2 injection project at the South Welch Unit.

The reservoir quality at the West Welch Unit is poorer than other San Andres reservoirs due to its relative position to sea level during deposition. Because of the proximity of a CO_2 source and the CO_2 operating experience that would be available from the South Welch Unit, West Welch Unit is an ideal location for demonstrating methods for enhancing economics of IOR projects in lower quality SSC reservoirs. This Class 2 project concentrates on the efficient design of a miscible CO_2 project based on detailed reservoir characterization from advanced petrophysics, 3-D seismic interpretations and cross wellbore tomography interpretations.

During the quarter, simulation performance forecasts were made using the base geologic model. The surface seismic and wellbore data were combined to develop an improved geologic model for the simulator. Efforts to integrate the wellbore seismic results into the reservoir characterization continue. Problems with the wellbore seismic processing were traced to the processing software which is being corrected.

3-D SEISMIC INTEGRATION

The second stage of the geologic modeling required the integration of the 3-D seismic data and the well data to capture the interwell porosity variations portrayed by the seismic interpretations.

A methodology was developed to convert seismic attributes to log properties of porosity and thickness x porosity (pore volume) within the San Andres reservoir beneath the DOE demonstration area. This technique is discussed in detail in the proceedings of a platform carbonate workshop[1] The vertical resolution of the 3-D seismic within the San Andres reservoir was approximately 30 ft, which allowed the two major depositional parasequences within the main pay - M1 to M3 and M3 to M5 to be identified (Fig. 1). Hence, it was possible to develop a seismic-derived map of porosity and thickness x porosity for both intervals that represents the two dimensional (x-y) distribution of the values averaged over the vertical interval. The basic reservoir model represents the M1 - M3 interval with three layers and the M3 - M5 interval with four layers. Therefore, the 3-D seismic vertical resolution is inadequate to describe the model layering.

A methodology was developed to subdivide the seismic intervals to match the model layering. At each wellbore control point, the model layers' percentage of the total thickness and thickness x porosity was determined for both the M1 - M3 and M3 - M5 intervals. Percentage maps were constructed from this information which were then integrated with the seismic maps to produce thickness and thickness x porosity maps for each of the seven model layers between the M1 and M5 markers. This approach appears to be superior to using a single proportioning factor. The thickness and thickness x porosity maps were integrated together to obtain a porosity distribution map for each layer. A porosity vs permeability transform was developed from wellbore data for each layer, which allowed the construction of a permeability distribution map. For the layers above and below the seismic intervals, well data alone provided the model input. The impact of these layers on oil recovery is much less than those within the seismic intervals.

The result incorporates the wellbore data and the geophysical data for all nine layers and provides average porosity, average permeability, thickness and structure for model grids. Several passes were made to maximize the efficiency of the computer gridding to represent the variability of the reservoir parameters. The dimensions of the 3-D seismic bins (110' x 82.5') are such that at least one control point is available for each model grid cell. These layers will be sampled to the simulation grid for history matching to test the approach.

TOMOGRAPHY

The wellbore seismic processing continues to be refined. Changes were made to the processing software that should put the reflections and calculated velocities at the correct depths to improve the correlation of seismic and wellbore data.

NUMERICAL SIMULATION

A radial model was set up to simulate the water alternating gas (WAG) injection test run in the 4816w injection well. The objective was to obtain a history match of the field test by adjusting the relative permeability hysterises curves. The model pore volume was set large enough so the two-week test would not raise the average pressure significantly. Alternating three-day injection periods of CO_2 followed by water then CO_2 again were run and the relative permeability adjusted until the bottomhole injection pressures measured during actual injection were matched. The resulting relative permeability hysterises curves were input into the full area model to simulate the WAG cycles to be evaluated. Using the exact curves from the radial model proved impossible and the new hysterises curves had to be adjusted closer to the original curves for the full model to run to completion.

The simulator used the new hysterises curves to predict the performance of several scenarios to determine an optimum operating plan for the project which would maximize the economics. A continuous CO_2 injection case was run to aid in designing the CO_2 distribution system. Figure 2 shows the forecasted production for three scenarios. The continuous case assumes continuous CO_2 injection for 3 yrs before switching to a 1-mo water then 1-mo CO_2 WAG injection. The base case assumes 6-mos of continuous CO_2 before changing to the 1:1 WAG injection. The fracture case is identical to the base case except the eight injection wells in the south had high permeability zones extended east and west for four gridblocks from the wellbore gridblock to simulate a 400 ft fracture that appears achievable from the fracture optimization field testing. The result shows the fracturing case improves CO_2 utilization, increases recovery, and accelerates production.

Two equations of state were used in the simulation studies in an effort to match the slim-tube miscible performance. Work continues on improving the representativeness of the equations of state.

PROJECT AREA PREPARATION

Facilities design criteria are based on the simulator's forecasted production and injection rates. The facilities being designed include a tap into the Este CO_2 pipeline, CO_2 distribution system, and wellhead design for the future injection of recycled gas. Also, the production and gas gathering facilities are being upgraded to allow more detailed measurement of the produced fluids. The gas gathering system will deliver the total produced gas stream to the Welch gas plant for: 1) removal of the natural gas liquids (NGL) consisting of propane, and heavier components, 2) compression, and 3) return of the CO_2 volume contaminated with residue gas for reinjection. The contaminated gas will have a higher miscibility pressure of about 1450 psi than the original 1200 psi for pure CO_2.

The revenue from NGL recovery should at least offset the compression and dehydration costs since the gas processing facility is already in place. Prior to the CO_2 flood, the NGL recovery was about 2.0 gallons of NGL per barrel of oil produced. During the CO_2 flood, the NGL recovery is estimated to average 5.5 gallons per barrel of oil produced. This value will vary depending on the initial oil composition but can be an important source of revenue if processing facilities are already available.

ECONOMIC ANALYSIS

The simulation performance forecasts for the various operating scenarios were converted to cash flow projections for evaluation purposes. This required estimation of development and operating costs and a forecast of future prices ($19.09/Bbl oil and $13.39/Bbl NGL escalated at 4%/annum from 11/1/97). The project economics were maximized under the base scenario for the fracturing case using the wwu10 equation of state. Under this scenario, an additional two million barrels of oil were recovered over a 14 yr period with a gross CO_2 utilization of 17.4 MCF/yr. The indicated gross (no DOE funding) project economics were a 13.8% annual rate-of-return and a 7.4 yr. payout.

TECHNOLOGY TRANSFER

In November, Archie Taylor and Greg Hinterlong made a presentation before the Fall Symposium of the West Texas Geological Society titled "Use of Multiple Log Curves to Predict Permeability in a Dolomite Reservoir." A poster session was also conducted at the Symposium covering the conversion of seismic attributes to log properties.

The main technology transfer effort during the quarter was the preparation of the final report for Budget Period 1.

REFERENCES

1. Watts, G.P., Hinterlong, G.D. etal, "Seismic Estimate of Porosity in the Permian San Andres Carbonate Reservoir, Welch Field, Dawson County, Texas," March 1996 Proceedings: Oklahoma Geological Society Workshop on Platform Carbonates of the Southern Midcontinent.

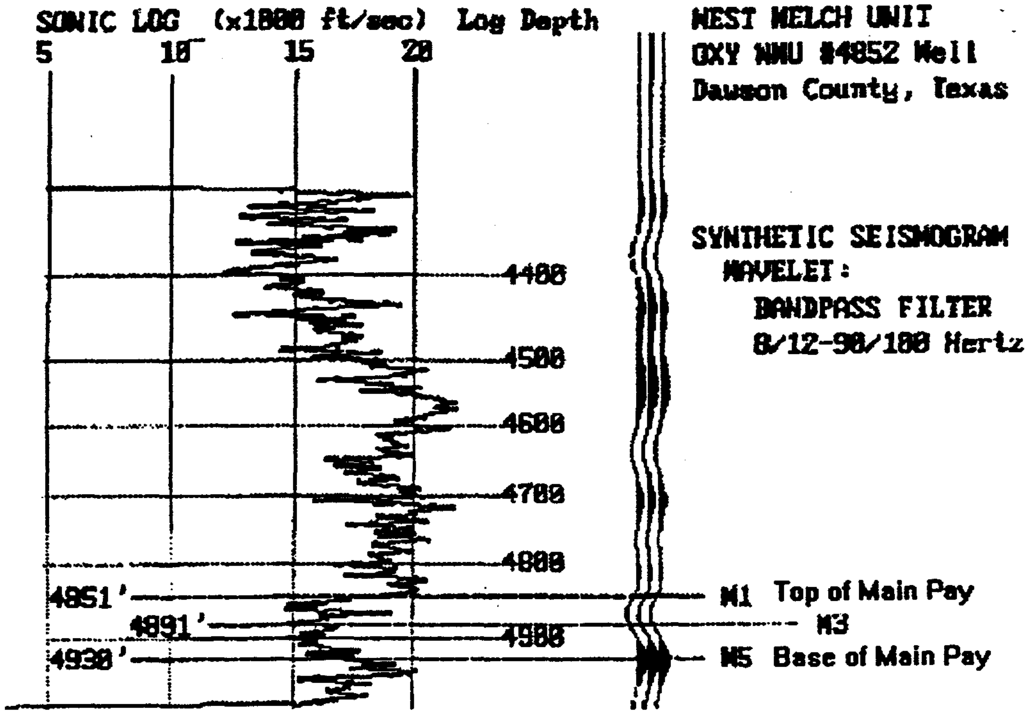

Figure 1 Comparison of Acoustic log and seismic trace for a typical well.

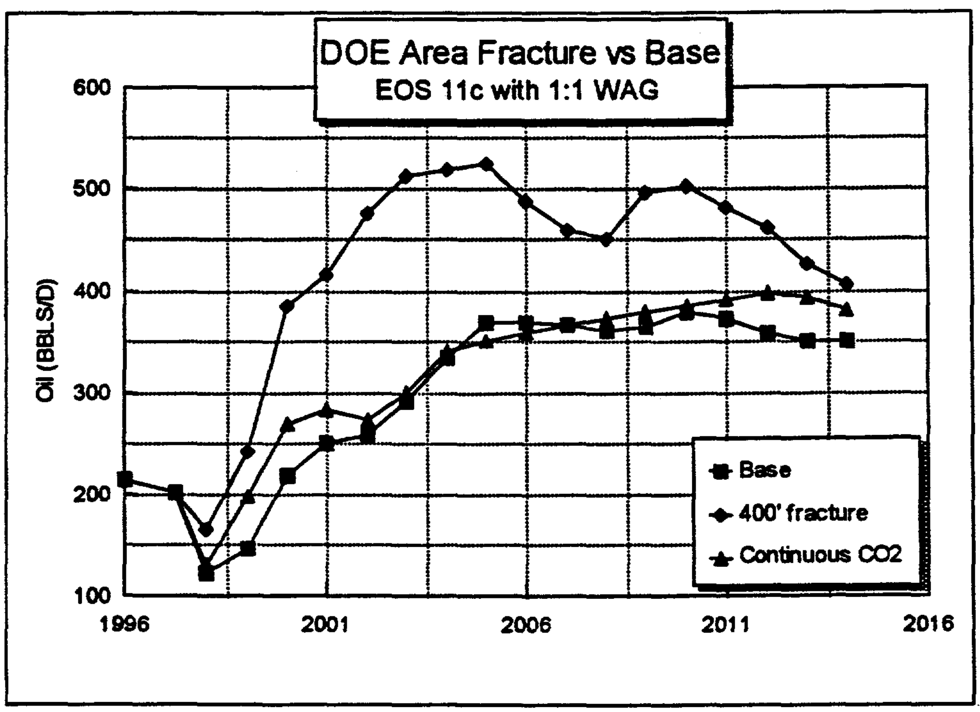

Figure 2 Comparison of production for different operating cases.