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DESIGN AND IMPLEMENTATION OF A CO_2 FLOOD UTILIZING ADVANCED RESERVOIR CHARACTERIZATION AND HORIZONTAL INJECTION WELLS IN A SHALLOW SHELF CARBONATE APPROACHING WATERFLOOD DEPLETION

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OBJECTIVE

The first objective is to utilize reservoir characterization and advanced technologies to optimize the design of a CO_2 project for the South Cowden Unit (SCU) located in Ector County, Texas. The SCU is a mature, relatively small, shallow shelf carbonate unit nearing waterflood depletion. The second objective is to demonstrate the performance and economic viability of the project in the field. The work reported here is on the reservoir characterization and project design objective. This objective is scheduled to be completed in early 1996 at which time work on the field demonstration phase is scheduled to begin.

SUMMARY OF TECHNICAL PROGRESS

EVALUATION OF UNIT PRODUCTION HISTORY AND WATERFLOOD REPONSE

Waterflood performance of the unit was re-evaluated. Increased unit production in 1966 - 1968 reflected changing production well allowables and not waterflood response as previously interpreted. First waterflood response occurred in 1970 - 1974 after waterflood fill-up.

CORE DESCRIPTION AND PETROGRAPHIC STUDIES

The "chaotic lithology" which makes up the bulk of the reservoir interval in the South Cowden Unit (SCU) is a burrow-mottled, tan/gray dolomite. Tan, irregularly shaped, oil-stained dolomite areas with core analysis porosities in the mid-teens to low twenties are mixed with gray, irregularly shaped, dolomite areas with single digit porosities. Core from Unocal's Moss Unit Well No. 16-14 located to the northwest of the SCU was examined. The examination indicated the dolomites comprising the reservoir interval in that core contained significant amounts of anhydrite which markedly reduced porosity. This finding led to a more detailed look at the amounts of intercrystalline anhydrite cement in the cores from SCU wells 8-19, 7-10, 8-11 and 6-23. The conclusion was that the porosity in the reservoir interval is affected by the amount of bioturbation, i.e. tan vs. gray dolomite, and the amount of anhydrite cement.

PREPARATORY RESERVOIR SIMULATION STUDIES

Grid size sensitivity studies to select the appropriate model grid to use were completed. These studies were necessary to ensure that numerical modeling artifacts, such as numerical dispersion or grid orientation effects, do not distort the simulation results.

Simulation studies were completed on a selected area of the field using both the fully compositional model with 16 components and the black oil model with Todd and Longstaff logic. These studies were necessary to determine the adjustments required in the full-field black oil model results to mimic those from the fully compositional model.

INTEGRATION OF GEOLOGICAL PETROPHYSICAL, AND SEISMIC DATA INTO A 3-D GEOLOGICAL RESERVOIR DESCRIPTION

Landmark Graphics Corporation's Stratigraphic Geocellular Model (SGM) will be the primary tool used to integrate the diverse geologic, petrophysical, and seismic data into a coherent 3-D reservoir model. A SGM framework was set up using layers that are 2-ft in thickness to compare interpolated porosity distributions with 3-D kriged porosity from the geostatistical study. First pass of the kriged porosity distribution shows more geologically reasonable appearance than the direct interpolated mode. However, where data spacing exceeds the correlation distance of the geostatistical model, the porosity values are left undefined. The final model will probably have these holes filled in with direct-interpolated values.

The permeability modelling method will use a production statistic, such as maximum fluid production rate, to capture the areal variability in reservoir quality and well performance. This variable will be used as a normalizing parameter for the porosity-permeability correlation to ensure that higher permeabilities are computed for the high oil recovery areas of the unit. The correlation equation will be applied to the porosity logs to compute ft x ft permeability curves for each well with digital log information. The permeability curves will be used to construct a 3-D kriged permeability model in a similar manner as the porosity is being handled.

LABORATORY FLOW TESTS TO DETERMINE CO_2 TRAPPED GAS SATURATION AND MISCIBLE RESIDUAL OIL SATURATION

A water-alternating-gas experiment was conducted using SCU core plugs, recombined oil, synthetic brine and CO_2 as the injection gas. Preliminary processing of the data indicates the CO_2 trapped gas content to be 30% of the total pore volume. A short series of follow-up experiments are planned to determine the influence of dry versus water saturated CO_2 injection gas.

LABORATORY FLOW TESTS TO IDENTIFY FOAMING SURFACTANTS FOR CO_2 MOBILITY CONTROL

Equipment was constructed to evaluate the performance of CO_2-foaming surfactants in core plugs from the SCU. A core plug was fitted with three pressure taps, coated with epoxy, placed in a vessel and pressured to 2100 psig with water. Transducers were used to monitor the pressure in the four sections of the plug and a capillary tube was used to monitor the viscosity of the fluids leaving the plug. After measuring the permeability of the four sections of the plug (18 to 170 md) to brine, various mixtures of a 500 ppm Chaser® CD-1045 surfactant solution and CO_2 were injected into the plug which was maintained at the reservoir temperature of 98°F. A data acquisition system was used to monitor the performance of the foam in the plug.

Resistance factors were calculated based on the injection of the surfactant solution in the absence of CO_2 (0% foam quality). Resistance factor and viscosity data were collected for foam qualities between 70 and 100%. Additional experiments at 10 and 60% foam qualities are needed to verify the polynomial fits for resistance factor vs. foam quality and viscosity vs foam quality. Additional data are also needed to verify the suggestion that the resistance factor increases with the permeability of the plug. Results will be presented upon completion of the experiments during the next reporting period.

SCREENING STUDIES TO IDENTIFY SUITABLE GELLED POLYMERS FOR PROFILE MODIFICATION

This phase of bulk gel work involved gel stability tests under 2000 psi CO_2 pressure to simulate field use. Two systems, the low toxicity OFXC® 1163 with Zirtech® LA110 system and Alcoflood® 254S with MARCIT® chromium (III) acetate system, were tested. The testing gels were prepared first using 1% OFXC® 1163 with 250-1500 ppm Zr in pH unadjusted SCU produced water and 2% Alcoflood® 254S with 250-1500 ppm Cr in pH adjusted (4.2) SCU produced water. It is interesting to note that Alcoflood® 254S, even at a 4% concentration level, did not produce gels with Cr in pH unadjusted produced water. The preformed gels were then exposed to 2000 psi pressure of CO_2 and aged at 98°F for three weeks. The results are given in Table 1. The gels of both systems are stable with no sign of deterioration or water phase separation. However, since the MARCIT® chrome acetate gels are produced in pH adjusted water, these gels may not withstand the CO_2 pressure for a very long time due to the possibility of over cross-linking which will cause syneresis.

Table 1. Gel Stability Tests at 98°F Under 2000 psi Pressure of CO_2

Gel System	Cross-linker Concn. Ppm	%Gel Strength Before Exposure to CO_2	%Gel Strength After Exposure to CO_2
1% OFXC® 1163 and Zr	250	70	70
in pH unadjusted water	500	93	93
	750	98	98
	1000	98	98
	1500	97	97
2% Alcoflood®254S and	250	95	95
Cr in pH adjusted (4.2)	500	97	97
water	750	98	98
	1000	98	98
	1500	97	97

GEOSTATISTICAL STUDIES

Three-dimensional (3-D) porosity models have been generated for the F, D and E zones using the latest edited well log porosity information from 132 wells in the unit. Ordinary 3-D kriging was used to generate three models with different vertical grid resolution, i.e. 2 ft, 5 ft, and 10 ft. Horizontal grid resolution was 100 ft x 100 ft for all three models. The spatial information used in the 3-D kriging algorithm consisted of the vertical and horizontal variogram models generated from variogram analysis of the well porosity for each zone and the variogram models of the top and bottom surfaces of each zone that describe the stratigraphic trend surfaces. The range of the horizontal variograms varied between 6,000 ft and 10,000 ft with the range of vertical variograms varying between 15 ft and 45 ft. These porosity models will be combined with core permeability and permeability derived well log porosity information to generate 3-D co-krigied maps of permeability for the three zones that will be used in fluid flow simulation studies and for optimizing the placement of the horizontal wells.

GENERATION OF AN AUTHORITY FOR EXPENDITURE (AFE)

Subtasks II.3 through II.7 in the Project Statement of Work are subtasks required to generate the input data required for the evaluation of an AFE and the generation of an AFE if such is justified. The subtasks include reservoir simulation studies for project design and performance forecasting, design and cost estimation work on various well placement scenarios and various injection and production facility alternatives, and economic and risk analysis studies to evaluate the project. Work was initiated this reporting period on these subtasks using the best reservoir characterization information available at this time. If future reservoir characterization work significantly alters the performance forecast this segment of the work will be updated using the new information.

Full-field simulation runs were made to evaluate CO_2 flood performance under various alternative pattern configurations and project development scenarios. Forecasted well rates and pressure data were provided to the facilities design team for use in sizing and design of well and surface facilities. Compositional simulation runs were made to provide forecasts of produced gas composition and NGL content. CO_2

purchase and recycle volumes were forecast under various CO_2 injection strategies.

The aforementioned forecasts and subsequent facilities designs are being used to establish investment and operating cost estimates. It is anticipated that the work required, including economic and risk analysis studies, for AFE generation will be completed during the next reporting period.