INCREASED OIL PRODUCTION AND RESERVES UTILIZING SECONDARY/TERTIARY RECOVERY TECHNIQUES ON SMALL RESERVOIRS IN THE PARADOX BASIN, UTAH

Contract No. DE-FC22-95BC14988

Utah Geological Survey (UGS), Salt Lake City, Utah 84114-6100

Submitted: February 1997

Award Date: February 9, 1995

Anticipated Completion Date: February 8, 2000

Government Award for Current Fiscal Year: \$448,800

Principal Investigator: M. Lee Allison, UGS

Program Manager: Thomas C. Chidsey, Jr., UGS

Contracting Officer's Representative: Rhonda P. Lindsey, National Petroleum Technology Office, Bartlesville, Oklahoma

Reporting Period: October 1 - December 31, 1996

Objectives

The primary objective of this project is to enhance domestic petroleum production by demonstration and technology transfer of an advanced oil recovery technology in the Paradox basin, southeastern Utah. If this project can demonstrate technical and economic feasibility, the technique can be applied to approximately 100 additional small fields in the Paradox basin alone, and result in increased recovery of 150 to 200 million barrels of oil. This project is designed to characterize five shallow-shelf carbonate reservoirs in the Pennsylvanian (Desmoinesian) Paradox Formation and choose the best candidate for a pilot demonstration project for either a waterflood or carbon dioxide-(CO₂-) flood project. The field demonstration, monitoring of field performance, and associated validation activities will take place in the Paradox basin within the Navajo Nation. The results of this project will be transferred to industry and other researchers through a petroleum extension service, creation of digital databases for distribution, technical workshops and seminars, field trips, technical presentations at national and regional professional meetings, and publication in newsletters and various technical or trade journals.

Summary of Technical Progress

Three activities continued this quarter as part of the geological and reservoir characterization of productive carbonate buildups in the Paradox basin: (1) interpretation of new seismic data in the Mule field area, (2) reservoir engineering analysis of the Anasazi field, and (3) technology transfer.

Interpretation of Seismic Data, Mule Field

The Mule field, near the southwestern edge of the Greater Aneth field (Fig. 1), was

Fig. 1. Location of Mule and Anasazi fields (dark shaded areas with names in bold type) on the Navajo Nation, San Juan Co., Utah, southwestern Paradox basin.

identified as a seismic anomaly expressed by isochron thickening of the Desert Creek zone of the Paradox Formation, amplitude dimming of the Desert Creek reflector, and a "doublet" development of the Desert Creek event.¹ The field consists of two wells, the Mule No. 31-K-1 (N) discovery well (SE 1/4 SW 1/4 sec. 31, T. 41 S., R. 24 E., Salt Lake Base Line) and the Mule No. 31-M well (SW 1/4 SW 1/4 sec. 31, T. 41 S., R. 24 E., Salt Lake Base Line), completed in 1991 and 1992, respectively. The Mule field is a lenticular mound consisting of a mud-free, phylloid-algal buildup combined with mound-flank detrital deposits.^{2, 3} The Mule No. 31-K-1 (N) well was deviated about 1140 ft south-southeast, avoiding topographic problems and a highway, to encounter what was thought to be the main part of the buildup.² Several beds in the well core exhibit characteristics of mound-flank deposits such as down slope gravity transport

and sharp erosional basal contacts. The Desert Creek zone tested approximately 10 bbls of oil per hour (based on several swab tests) with water cut increasing on each test, and produced only 283 bbls of oil before the well was shut-in. The Mule No. 31-M offset well encountered a thick mound-core interval and had an initial potential flow of 735 bbls of oil and 97 thousand cubic ft (MCF) of gas per day from the Desert Creek zone.

A new seismic program was permitted and conducted in the Mule field. The additional seismic data were used to determine the extent of the algal-mound buildup in the field and the orientations and lengths of any horizontal development drilling. Five miles of two-dimensional swath seismic data were generated along northeast-southwest lines across the Mule area (Fig. 2). These seismic data were interpreted and incorporated into the overall interpretation of the southwest Aneth region. The following isochron maps were constructed: Ismay zone to Desert Creek zone (Fig. 3), Desert Creek zone to Akah zone, and Ismay zone to Gothic shale. These maps indicate the Mule field is a lenticular, northeast- to east-trending, linear mound with

Fig. 2. Southwest-northeast migrated seismic line (Mule 300) defining the Mule field algal-mound buildup. Traces per inch = 20; inches per second = 10; 0.900 second is approximately 5850 ft (see Fig. 3 for seismic line and shot-point locations).

Fig. 3. Ismay zone to Desert Creek zone (Pennsylvanian Paradox Formation) isochron map, Mule field area. Contour interval = 1 millisecond.

additional reservoir potential on strike to the northeast of the Mule No. 31-M well. Harken Southwest Corporation, the field operator, plans to re-enter the Mule No. 31-K-1 (N) well and drill horizontally in a northwest direction to penetrate a significant portion of the mound buildup.

Reservoir Engineering Analysis, Anasazi Field

The two main work tasks for the fourth quarter of 1996 included: (1) history matching of the primary production phase of the Anasazi field, Navajo Nation, San Juan Co., Utah (Fig. 1), using

the full field three-dimensional simulation model, and (2) initiation of a series of reservoir performance prediction studies based on CO₂ injection.

The history matching of the primary production phase of the Anasazi field was based on one of the geostatistical realization of the reservoir geologic model. History matching involves the input of historical well/field oil production data with the predicted gas production and reservoir pressure being matched to well/field observed data. Because of the geometric and lithologic complexity of the Anasazi reservoir, a substantial history matching effort has been required. A large number of reservoir parameters and reservoir parameter combinations was investigated to match historical gas production and well to well and reservoir to reservoir (northeast to southwest buildup lobes [Fig. 4]) interaction present during the primary reservoir production phase. Reservoir and fluid properties investigated include many different combinations of these variables:

1. reservoir size/volume,
2. reservoir permeability (both horizontal and vertical) and porosity and their distribution areally as well as between the two principal reservoir facies,
3. gas relative permeability,
4. solution gas content of the original reservoir fluid,
5. rock compressibility,
6. volume of different reservoir facies,
7. transmissibility between the principal mound-core (limestone) and supra-mound (dolomite) intervals ², and
8. the use of reservoir unit barriers or transmissibility reduction areas.

No local (is near the wellbore) changes were employed to match production. Reservoir description changes on a regional basis were used to match the reservoir-wide fluid movement occurring within the system which in turn controlled local well behavior. Figures 5 and 6 present oil and gas production data from one of the most recent history match runs. Simulation data is represented by solid curves and the actual field production by discrete points. Figure 7 presents the gas saturation distribution in the reservoir for this run at December 31, 1996. Notice the segregation and accumulation of gas in the upper supra-mound interval while the lower mound-core interval remains oil saturated. Figure 8 presents the pressure distribution for the same time point in the simulation. Note the depressurization of the southwest and northeast lobes with the off-flank areas at higher pressure. The key reservoir description changes required to achieve this match are presented below.

1. A substantial reduction of the pore volume of the producing element of the northeast lobe of the buildup. This was accomplished by partitioning the north

and south areas of the mound.

Fig. 4. Combined Desert Creek zone structure contour and gross interval isopach map, Anasazi field.⁴

Fig. 5. Anasazi field oil production rate and cumulative oil production vs. time from history match runs of the two-dimensional reservoir simulation. Simulation data is represented by solid curves and the actual field production by discrete points.

Fig. 6. Anasazi field gas production rate and predicted cumulative gas production vs. time from history match runs of the two-dimensional reservoir simulation. Simulation data is represented by solid curves and the actual field production by discrete points.

Fig. 7. Cross section, through the Anasazi No. 1 well of the Anasazi reservoir grid-system model illustrating gas saturation distribution as of December 31, 1996. The model uses 15 stratigraphic layers (z axis) and 50 cells (x axis).

Fig. 8. Cross section, through the Anasazi No. 1 well of the Anasazi reservoir grid-system model illustrating reservoir pressure distribution as of December 31, 1996.

2. Partial isolation of the drainage volumes associated with the Anasazi No. 1 and Anasazi No. 5L-3 wells (see Fig. 4 for well locations). This was accomplished by the introduction of a transmissibility reduction approximately midway between the two wells.
3. A reservoir volume expansion south and west of the Anasazi No. 5L-3 well.
4. A reduction in vertical permeability of the supra-mound interval overlying the reservoir mound-core interval in the southwest lobe of the buildup.
5. A reduction of the initial solution gas-oil ratio from that reported in the initial reservoir fluid sample analysis. This was required to better match the field observed producing gas-oil ratio prior to the reservoir pressure decreasing below the bubble point pressure (liquid expansion phase of the primary production period).

Concurrently with the completion of the history match, some initial prediction runs were completed to assess the additional oil recovery that would be obtained by injecting CO₂ and repressuring the reservoir to values between 2000 and 3000 pounds per square inch (psi). The first set of CO₂ injection runs were designed to identify appropriate injection well locations to optimize oil recovery. One prediction case, with a single CO₂ injector located in the off-mound area of the southwest lobe, recovered an additional 1.3 million stock tank bbls (MMSTB) of oil after eight years of CO₂ injection. The 1.3 MMSTB represents 57% of the volume of oil produced to date under primary production. Additional prediction case runs are planned to: (1) investigate the optimum number of injection wells, their locations, and their configuration (vertical versus horizontal), (2) evaluate reservoir operating pressure (controls miscibility), and (3) investigate produced gas re-injection to reduce CO₂ utilization, cost, and use of water instead of CO₂.

Technology Transfer

The UGS Deputy Director was invited to attend the Utah Tribal Leaders meeting of the Utah Indian Cooperative Council of the Division of Indian Affairs of the Utah Department of Community and Economic Development, held on the Goshute Indian Reservation, Ibapah, Utah, October 11, 1996. The Deputy Director presented a Paradox basin project overview, and provided a written summary of the project and complimentary copies of the UGS co-sponsored guidebook publication *Geology and Resources of the Paradox Basin*.

The UGS acquired Harken's collection of core from 34 wells in the project area. This collection consists of 3632 ft of conventional core (including slabs and butts) and is now publicly available at the UGS Sample Library. The Sample Library provides service to all interested individuals and companies who require direct observation of actual samples for their research or investigations. The Paradox basin project core may be examined at the UGS Sample Library or borrowed for a period of as much as six months. Destructive sampling is occasionally permitted with UGS approval. The UGS requires copies of all reports, photographs, and analyses from investigations using borrowed UGS samples; this information can be held confidential for one year upon request but then is available for public examination.

References

1. J. F. Johnson, and W. G. Groen, Seismic Structure and Seismic Stratigraphy of the Giant Aneth Field and Its Satellite Fields of Southeast Utah [abs.]: *Amer. Assoc. of Petrol. Geol. Bull.* 77 (8): 1452-1453 (August 1993).
2. T. C. Chidsey, Jr., D. E. Eby, and D. M. Lorenz, Geological and Reservoir Characterization of Small Shallow-shelf Carbonate Fields, Southern Paradox Basin, Utah, *Geology and Resources of the Paradox Basin* (A. C. Huffman, Jr., W. R. Lund, and L. H. Godwin, Eds.), Utah Geol. Assoc. Pub. 25: 39-56 (1996).
3. T. C. Chidsey, Jr., D. E. Eby, W. G. Groen, Kris Hartmann, and M. C. Watson, Mule Field, *Oil and Gas Fields of Utah* (B. G. Hill, and S. R. Bereskin, Eds.), Utah Geol. Assoc. Pub. 22 (Second Edition): non-paginated (1996).
4. T. C. Chidsey, Jr., D. E. Eby, W. G. Groen, Kris Hartmann, and M. C. Watson, Anasazi Field, *Oil and Gas Fields of Utah* (B. G. Hill, and S. R. Bereskin, Eds.), Utah Geol. Assoc. Pub. 22 (Second Edition): non-paginated (1996).