DOE/BC/14991--8

DESIGN AND IMPLEMENTATION OF A CO2 FLOOD UTILIZING ADVANCED RESERVOIR CHARACTERIZATION AND HORIZONTAL INJECTION WELLS IN A SHALLOW SHELF CARBONATE APPROACHING WATERFLOOD DEPLETION

Cooperative Agreement Number:	**DE-FC22-94BC14991**
Contractor Name and Address:	**Phillips Petroleum Company** **4001 Penbrook Street** **Odessa, Texas 79762**
Date of Report:	**April 19, 1996**
Award Date:	**June 3, 1994**
Anticipated Completion Date:	**January 2, 2001**
Government Award for 1996 Fiscal Year:	**$2,659,515**
Project Director:	**John S. Chimahusky**
DOE Project Officer:	**Jerry F. Casteel**
Reporting Period:	**January 1, 1996 - March 31, 1996**

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OBJECTIVE

The first objective is to utilize reservoir characterization and advanced technologies to optimize the design of a CO2 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. This report includes work on the reservoir characterization and project design objective and the demonstration project objective.

SUMMARY OF TECHNICAL PROGRESS

PHASE I

Evaluation of Surfactants Adsorption

Previous adsorption studies with South Cowden Unit cores performed in the laboratory indicated a strong dependency of surfactant adsorption on core porosity. In an effort to rank the best two surfactants (Phodapex CD-128 and Chaser CD-1045) for the South Cowden Unit CO2-foam applicatiaons, Baker Dolomite cores which are quite uniform were selected for these studies. Ten adsorption tests were performed in Baker Dolomite cores in the absence of crude oil. Each core was flooded with 1000, 2000 or 3000 ppm surfactant. A total of 30 mg surfactant was injected in each core test followed by sufficient amount of synthetic South Cowden Unit brine. The core effluents were monitored with a Waters Model 410 Differential Refractometer. The surfactant concentration in the effluents was also determined by measuring the Total Organic Carbon (TOC). Average surfactant adsorption for CD-1045 measured at 10 pv by Refractive Index (RI) and TOC are 419 and 425 lbs/acre-ft, respectively. Average surfactant adsorption for Phodapex CD-128 are 81 lbs/acre-ft (RI) and 93 lbs/acre-ft (TOC).

Technology Transfer

A poster session entitled "Reservoir Characterization of an Upper Permian Platform Carbonate in Preparation for a Horizontal-Well CO2 Flood, South Cowden Unit, West Texas" was presented by C.D. Caldwell at the Oklahoma Geological Society / U.S. Dept. Of Energy Symposium, "Platform Carbonates in the Southern Midcontinent", Oklahoma City, OK, March 26-27, 1996. A number of core samples were included in the exhibit. Copies of the abstract and the symposium schedule are attached. (Attachment I)

The Society of Petroleum Engineers Permian Basin Oil & Gas Recovery Conference held March 27-29, 1996 in Midland, TX included a poster session entitled "Construction of a 3-D Geologic Reservoir Description from Core and Well Log Data, South Cowden Field CO2 Project". A technical paper, SPE 35226, "Use of Production and Well Test Data with Predictive History

Matching to Improve Reservoir Characterization for CO2 Flooding at the South Cowden Unit" by K. J. Harpole, M.G. Gerard, S.C. Snow, and C.D. Caldwell was also presented. This paper presented the approach used in the South Cowden project to improve the delineation of the porosity and permeability distribution in the reservoir by integrating production performance data with 3-D geological modeling and predictive history matching techniques. A copy of the session schedule is attached, along with a copy of the technical paper. (Attachment II) Reprint removed for separate cycling.

PHASE II

Reservoir Simulation

The South Cowden full-field simulation model was expanded and updated to accomodate revised reservoir desciption information resulting from: (a) inclusion of data from five additional wells drilled in the project area, and (b) improvements in delineating the porosity and permeability distribution in the project area by integrating production performance data with 3-D geological modeling. The field performance history match was updated using the revised model. This resulted in significant improvements in individual well performance matches.

The revised simulation model was used to update CO2 flood performance forecasts and to optimize final horizontal well locations, orientation, and completion strategy. Based on the revised forecasts, the western horizontal well (SCU 7C11H) was reoriented to conform to local reservoir quality trends. The simulation model forecasts indicate that this should result in more rapid production response to CO2 injection. The revised project performance forecasts were also used to aid in final design of surface facilities and to finalize well conversion and workover strategies prior to implementation of CO2 injection.

Well Drilling

The drilling and completion plans for the two horizontal injectors were completed after the final well locations were determined. The first horizontal well, SCU 6C25H, was spudded on March 17, 1996. Land purchase for the project area was completed in January, 1996. Surface injection facility construction was begun in February, 1996.

Petrographic Study of Core from SCU 6-24

Burrow mottled dolopackstones composing the SCU reservoir interval are composed of gray, relatively low-porosity and low-permeability dolowackestones/dolopackstones and tan, oil-stained, more porous and permeable dolopackstones/dolograinstones. Tan dolomite areas are burrows. Interburrow areas are gray lower porosity dolomite. The relative amounts of gray and tan dolomites composing the SCU reservoir interval markedly affect the reservoir porosity and permeability. A clear mylar sheet with a one-inch-square grid pattern was used to determine the relative amounts of

gray and tan dolomites composing the reservoir interval in the SCU 6-24 core. These amounts, determined for each one-foot interval of the Grayburg reservoir, will be compared with gray/tan percentages similarly determined for the SCU 8-19, 7-10, 6-23, and 8-11 cores.

Reservoir porosity is also a function of anhydrite content. Thin section study of burrow mottled dolopackstones from the SCU 8-19, 7-10, 6-23, and 8-11 and the Moss Unit 16-14 shows that as anhydrite content increases reservoir porosity decreases. Thin section study of reservoir dolomites from the SCU 6-24 confirms these findings. Average anhydrite content of tan dolomites, determined from thin sections; and average porosities, determined from core analysis, are given below:

WELL	AVER. POROSITY	AVER. ANHYDRITE
SCU 8-19	24%	1%
SCU 6-23	21%	1%
SCU 7-10	21%	5%
SCU 8-11	14.5%	11.5%
Moss 16-14	6%	15.5%

Anhydrite content in the lower part of the reservoir interval in the SCU 6-24 (Zone E below 4675', log depth) averages less than 1% anhydrite. Porosity estimated from thin section for this interval is approximately 12%. Zones E and F above 4675' average 19% anhydrite and 4.5% porosity as determined from thin section (porosities estimated from thin section are typically lower than those determined by core analysis).

Tan dolomite areas have varying permeabilities related to pore size. Tan dolomites with similar porosities may have markedly different permeabilities. The average porosity of tan dolomites from SCU 6-23 and 7-10 is 21%, but the average permeabilities are 90 md and 10 md, respectively. Tan dolomites from SCU 7-10 have markedly smaller pores and finer dolomite crystal size than tan dolomites from SCU 6-23. Tan dolomite samples from SCU 6-24 vary markedly in crystal size and consequent pore size, resembling samples from both SCU 7-10 and 6-23.

Workshop Announcement and Program

PLATFORM CARBONATES IN THE SOUTHERN MIDCONTINENT

March 26–27, 1996

Research and Studies Dealing With:

Platform-Carbonate Deposition, Diagenesis, Reservoir Characterization, Exploration, and Petroleum Production; Arbuckle, Viola, Hunton, Mississippian, Pennsylvanian, and Permian Carbonates

To be held at:
Clarion Hotel/Comfort Inn Conference Center
Oklahoma City, Oklahoma

Co-Sponsored by:
Oklahoma Geological Survey and
Bartlesville Project Office, U.S. Dept. of Energy

Monday, March 25

REGISTRATION AND INFORMATION
Main Lobby of Clarion Hotel
5:00–8:00 p.m.

EARLY-BIRD PARTY
Gold Crown Room, Clarion Hotel
6:00–8:00 p.m.

Tuesday, March 26

REGISTRATION 7:30 a.m.–5:00 p.m.

TECHNICAL PROGRAM
Gold Crown Room, Clarion Hotel
8:30 a.m.–4:30 p.m.

POSTER SESSION
Gold Crown Room, Clarion Hotel
4:30–6:30 p.m.

BANQUET
Congress Room, Clarion Hotel, 7:00 p.m.
(Cocktails at 6:00 p.m.)

Wednesday, March 27

REGISTRATION 7:30 a.m.–3:00 p.m.

TECHNICAL PROGRAM
Gold Crown Room, Clarion Hotel
8:00 a.m.–3:30 p.m.

University of Arkansas, and Patrick K. SUTHERLAND, University of Oklahoma

1:30 **Characteristics of Cyclical, Mixed Carbonate/Siliciclastic Reservoirs: Early Permian Chase Group, Northern Oklahoma**, by James R. CHAPLIN, Oklahoma Geological Survey

2:00 **Improved Dolomite-Reservoir Characterization Through Integrated Log and Core Analysis: Example from Welch Field, Dawson County, Texas**, by Gregory D. HINTERLONG, OXY USA, Inc., Midland

2:30 **Seismic Prediction of Reservoir Properties in a San Andres Carbonate Reservoir, Welch Field, Dawson County, Texas**, by George P. WATTS and Gregory D. HINTERLONG, OXY USA, Inc., Midland

3:00 **Discussion of afternoon papers**

3:30 **End of workshop**

Poster Session

Tuesday, March 26, (4:30–6:30 p.m.)

Gold Crown Room; Clarion Hotel

Carbonate Development and Potential Productivity in the Southern Fort Worth Basin, Texas, by Deborah K. SACREY, Sacrey Geological Services, Houston, and A. H. WADSWORTH, Independent Geologist, Houston

Production and Reservoir Characteristics of Selected Hunton Fields in the Anadarko Basin, by Paul W. SMITH, Walter J. HENDRICKSON, and Craig M. WILLIAMS, Dwight's Energydata, Oklahoma City

Petroleum Production from Platform Carbonates of Oklahoma, by G. Carlyle HINSHAW, Geo Information Systems, Norman, Kenneth S. JOHNSON, Oklahoma Geological Survey, and Robert A. NORTHCUTT, Independent Geologist, Oklahoma City

Integrated Reservoir Management and Reservoir Characterization of the North Robertson Unit, Gaines County, Texas, by P. K. PANDE and James E. KAMIS, Fina, Midland, Richard VESSEL, D. K. Davies & Associates, Houston, Mike CLARK, Fina, Houston, Mohan KELKAR, University of Tulsa, and L. DOUBLET and Tom BLASINGAME, Texas A&M University

Microbial Reservoir Characterization of the Hobart Field, Kiowa County, Oklahoma, by Daniel HITZMAN, James D. TUCKER, and Brooks A. ROUNTREE, GMT, Inc., Ochelata, OK

Sonic Velocity in Carbonates—A Product of Original Composition and Post-Depositional Porosity Evolution, by Flavio S. ANSELMETTI and Gregor P. EBERLI, University of Miami

Four Hundred Feet of Core from the Cambrian Signal Mountain Formation, Slick Hills, Oklahoma, by Richard E. WHITEHEAD and R. Nowell DONOVAN, Texas Christian University

Reservoir Characterization of an Upper Permian Platform Carbonate in Preparation for a Horizontal-Well CO_2 Flood, South Cowden Unit, West Texas, by Craig D. CALDWELL, Phillips Petroleum Co., Bartlesville, OK, and Matt GERARD and Susan SNOW, Phillips Petroleum Co., Odessa, TX

Depositional Environments/Carbonate Diagenesis of the Council Grove Group, Hugoton Embayment, Southwest Kansas, by Nicholas J. PIERACACOS, Baylor University

Facies, Stratigraphic Relationships, and Fracturing in the Wapanucka and Spiro, by Darrell MAULDIN, Independent Geologist, Clyde, TX

The Boundary Between the Fort Sill and Signal Mountain Formations in the Lower Arbuckle Group, Slick Hills: Candidate for a Grand Cycle Boundary, by Randy HOSEY, Cross Timbers Oil Co., Fort Worth, and R. Nowell DONOVAN, Texas Christian University

Lithofacies Distribution and Reservoir Heterogeneity within Pennsylvanian Bioherms, Western Orogrande Basin, New Mexico, by Gerilyn SOREGHAN, University of Oklahoma, and Katherine GILES, New Mexico State University

Union Valley Limestone Bank (Morrowan, Pennsylvanian), Eastern Oklahoma, by James R. DERBY and James O'BRIEN, Independent Geologists, Tulsa

Depositional and Diagenetic History of Mississippian Chat Reservoirs, Northern Oklahoma, by Suzanne M. ROGERS, James M. FORGOTSON, Jr., and Thomas A. DEWERS, University of Oklahoma

Lithostratigraphy and Biostratigraphy of a Core from the Viola and Simpson Groups in Keener #1-B Well, Creek County, Oklahoma, by James R. DERBY and James O'BRIEN, Independent Geologists, Tulsa, and John E. REPETSKI, U.S. Geological Survey, Reston, VA

Stratigraphy of the Roubidoux Formation of Missouri and Correlative Units in the Southern Midcontinent, by John E. REPETSKI, U.S. Geological Survey, Reston, VA, James D. LOCH, Central Missouri State University, and Raymond L. ETHINGTON and Russell I. DRESBACH, University of Missouri – Columbia

Regional Correlations of the Springer and Chester Groups Within the Oklahoma Portion of the Anadarko Basin and Shelf Demonstrating the Facies Changes Within the Springer Which Have Resulted in Springer Being Misidentified as Chester, by Paul W. SMITH, Lindell C. BRIDGES, Walter J. HENDRICKSON, Craig M. WILLIAMS, and Ronald J. WOODS, Dwight's Energydata, OK City

Integrated Analyses of Reservoir Petrofacies in Platform Carbonates of Kansas: Techniques and Case Studies, by John H. DOVETON, W. Lynn WATNEY, and Willard J. GUY, Kansas Geological Survey

Preliminary Cyclic Stratigraphy of the Upper Arbuckle Group in the Richard's Spur Quarry, Slick Hills, Oklahoma, by Danielle AYAN, Andrea K. BUCHEIT, Mathew J. KULOW, and R. Nowell DONOVAN, Texas Christian Univ.

Outcrop-Based Sequence Stratigraphic Analysis of the Admire and Council Grove Groups of Kansas and Oklahoma, by Darwin R. BOARDMAN II, Oklahoma State Univ.

ATTACHMENT I

RESERVOIR CHARACTERIZATION OF AN UPPER PERMIAN PLATFORM CARBONATE IN PREPARATION FOR A HORIZONTAL-WELL CO2 FLOOD, SOUTH COWDEN UNIT, WEST TEXAS

Craig D. Caldwell, Matt G. Gerard, Susan G. Snow, and Ken J. Harpole, Phillips Petroleum Co.

Since initial development in the late 1940s, South Cowden Unit (SCU), located on the eastern margin of the Central Basin Platform, has produced 35 million barrels of oil from the Upper Permian Grayburg Formation. Grayburg strata at SCU drapes over a Lower San Andres thick resulting in an unfaulted anticlinal structure. Under waterflood since 1965, SCU is approaching the economic limit of waterflood operation, and a CO2 flood employing horizontal injection wells has been proposed. In preparation for the proposed flood a detailed geologic description of the reservoir interval was prepared for integration into a reservoir simulation model.

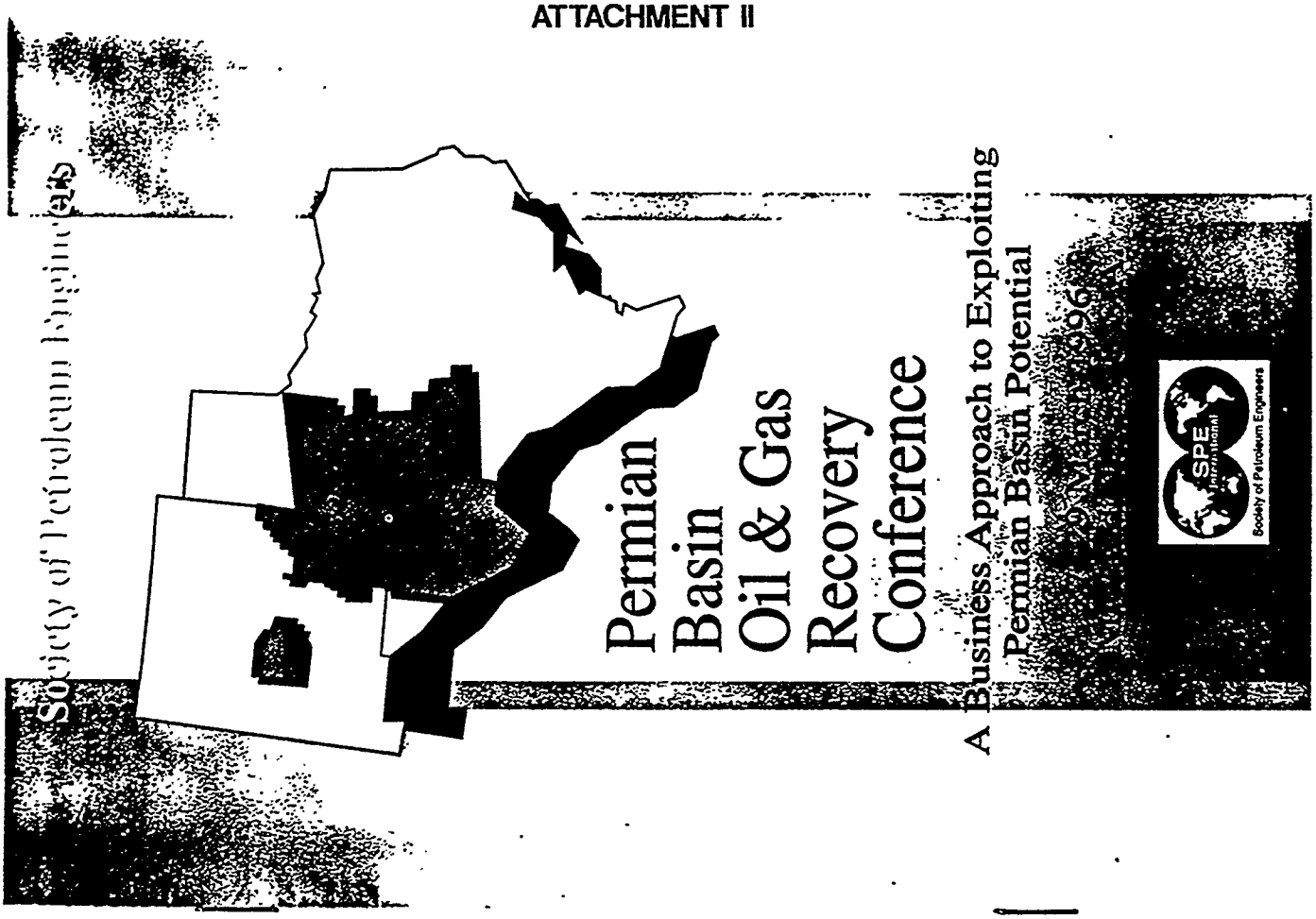
The reservoir interval at SCU is approximately 150 ft. thick and is composed mainly of burrow-mottled dolopackstone. These dolomites are characterized by a distinctive gray/tan mottling reflecting variations in oil staining. Tan oil-stained areas, interpreted to be carbonate-sand-filled burrows, are typically 2 to 8 cm in width, up to a few tens of centimeters in length, and vertically oriented. Tan areas are dolograinstones, dolopackstones, and washed dolopackstones. Porosity in these areas is intergranular, moldic, and intercrystalline and ranges typically from 10 to 32%. Permeability varies generally from 2 to 400 md. Gray interburrow areas lacking oil staining are dolopackstones and dolowackestones with 2 to 9% moldic and intercrystalline porosity and 0.002 to 2 md permeability. The relative amounts of tan and gray dolomite determined by the degree of bioturbation can profoundly affect reservoir porosity and permeability.

Reservoir porosity and permeability are also a function of anhydrite content. An inverse relationship exists between porosity and permeability and the amount of poikilotopic anhydrite cement in the tan dolomite areas. Limited data suggests the decrease in porosity in the northwestern (paleolandward) part of SCU is related, at least in part, in an increase in anhydrite content.

Reservoir permeability is also affected by pore size as related to crystal size and depositional texture of the tan dolomite areas. Finely to medium-crystalline tan dolomites typically have markedly larger pores and significantly greater permeabilities than very finely to finely crystalline tan dolomites with similar porosities. Very finely to finely crystalline tan dolomite areas reflect muddier burrow-filling sediments. This porosity/permeability relationship necessitates more than one porosity/permeability transform to characterize rocks of the SCU reservoir interval.

The vertically oriented character of porous and permeable tan dolomite areas characterizing rocks of the reservoir interval provides a favorable condition for the application of a CO2 flood which employs horizontal injection wells. The vertical movement of fluids and gases through the reservoir interval may be partially restricted, however, by two, laterally continuous, relatively low-permeability sandy dolopackstone layers. These relatively thin sandy dolomites are used to establish a reservoir zonation.

ATTACHMENT II



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35201 **Pulsed-Neutron Capture Logging in Reservoir Management: Three Permian Basin Examples** • F.M. Haynes, Exxon Co. USA

35202 **Areal Distribution of Remaining Oil Saturation in a Mature West Texas Waterflood—A Case History** • A.K. Sharma and A. Kumar, Mobil E&P U.S. Inc.

35203 **A New Approach to Large-Scale Infill Evaluations Applied to the Ozona Canyon Gas Fields** • G.W. Voneiff, S.A. Holditch and Assocs. Inc.; and C.L. Cipolla, Union Pacific Resources Co.

35204 **Reserves and Performance of Canyon Sand Gas Wells, 1970-1994** • G.S. Swindell, Gary S. Swindell and Assocs.

35205 **Evaluation of Injection Well Performance Using Type Curves** • S. Prachumchon and T.A. Blasingame, Texas A&M U.

Alternate
30202 **Predicting Production Using a Neural Network (Artificial Intelligence Beats Human Intelligence)** • R.J. Boomer, Texaco E&P Inc.

Thursday, 28 March 1996 • 2:00–5:00 p.m.
Horizontal Well Applications • Midland Center, Room 2
Session Chairmen: Stephen N. Guillot, Texaco E&P Inc.
Samuel L. Pickett, Mobil E&P Services Inc.

SPE
35207 **Status of Horizontal Drilling in the Permian Basin** • C.R. Vanorsdale, T. Scott Hickman and Assocs. Inc.; and R. Vogel, Vogel Engineering Inc.

35208 **Simulation Studies of Waterflood Performance With Horizontal Wells** • H. Ferreira, Petresim Integrated Technologies Inc.; and D.D. Mamora and R.A. Startzman, Texas A&M U.

35209 **Waterflood Infill Well Pattern Strategies for Horizontal and Multilateral Wells** • C.A. Ehlig-Economides, Anadrill

35210 **Field Application of Multilateral Horizontal Wells in a 5-Spot Waterflood, S.E. Utah** • S.D. Hall, Texaco E&P Inc.

35211 **Evaluation of Horizontal Wells With Transverse Hydraulic Fractures in a Layered Multi-Phase Reservoir** • R.A. Wattenbarger and E.A. Elrafie, Texas A&M U.

35212 **An Engineer's Guide to Legal and Regulatory Issues for Horizontal Wells in Texas** • J.S. Judah, McElroy and Sullivan LLP

Alternate
35213 **Interactions of the Horizontal Wellbore Hydraulics and Formation Damage** • F. Civan, U. of Oklahoma

Thursday, 28 March 1996 • 2:00–5:00 p.m.
Production Operations • Midland Center, Room 5
Session Chairmen: Victoria B. Jackson, Unocal
Richard S. Prentice, Ref-Chem

SPE
30680 **Tubing Flowrate Controller: Maximize Gas Well Production From Start to Finish** • W.G. Elmer, Conoco Inc.

35214 **Euler Loads and Measured Sucker Rod/Sucker Bar Buckling** • S.W. Long and D.W. Bennett, Flexbar Inc.

30636 **Automation in Cyclical Rate Primary Reservoir Significantly Reduces Beam Pump Failures** • C.P. Findlay II and R.B. Herring, Conoco Inc.; and J.L.S. Pike, Delta-X Corp.

35216 **Improved Water Flood Operation in the Permian Basin Through Microbial Culture Treatment** • D.R. Schneider, Micro-Bac Intl.; T. Ratliff, Bio-Tech Inc.; and B.C. Hoskins, Micro-Bac Intl.

35217 **Review of Downhold Dynamometer Testing** • R.L.Soza, Exxon Co. USA

35218 **ALWORKS–An Artificial Lift Surveillance Tool** • G.L. Burleson, Exxon Co. USA; and J.D. Redden, Exxon Production Research Co.

Alternate
35219 **Water and Gas Coning in the Oil Reservoirs With Steady State and Transient Flow (Part I: Vertical Wells)** • F. Azamejad, W.S. Tortike, and S.M. Farouq Ali, U. of Alberta

Thursday, 28 March 1996 • 9:00 a.m.–5:00 p.m.
Poster Session II/Core Workshop • Midland Center, Room 3
Session Chairman: Michael J. Rauert, Ref-Chem

SPE
27657 **Application of Integrated Reservoir Management and Reservoir Characterization to Optimize Infill Drilling** • P.K. Pande and M.B. Clark, Fina Oil & Chemical Co.; T.A. Blasingame, Texas A&M U.; M. Kelkar, U. Of Tulsa; R.K. Vessell, David K. Davies and Assocs. Inc.; and P.E. Hunt, Mobil Corp.

35221 **Construction of 3D Geologic Reservoir Description From Core and Well Log Data, South Cowden Field CO_2 Project** • C. Caldwell, M.G. Gerard, and M. Nagaty, Phillips Petroleum Co.

35225 **Application of Analytical Techniques to Evaluate the Heterogeneities of the Upper Spraberry Formation (Permian) and Its Influence on the Quality of the Reservoir** • C.J. Saleta, A.K. Banik, M.E. Cather, and D.S. Schechter, New Mexico Petroleum Recovery Research Center

Friday, 29 March 1996 • 9:00 a.m.–12:00 noon
Department of Energy Projects • Midland Hilton Civic Room
Session Chairman: Leon M. Roe, Chevron USA Inc.

SPE
35223 **CO_2 Huff-n-Puff: Initial Results From a Waterflooded SSC Reservoir** • C.S. Wehner, Texaco E&P Inc.; and J. Prieditis,Texaco E&P Technology Div.

35224 **Characterization of the Naturall -Fractured Spraberry Trend Shaly Sands Based on Core and Log Data** • A.K. Banik and D.S. Schechter, New Mexico Petroleum Recovery Research Center

35469 **Reservoir Characterization and CO_2 Pilot Design in the Naturally-Fractured Spraberry Trend Area** • D.S. Schechter, New Mexico Petroleum Recovery Research Center

35226 **Use of Production and Well Test Data With Predictive History Matching to Improve Reservoir Characterization for CO_2 Flooding at the South Cowden Unit** • K.J. Harpole, M.G. Gerard and S.C. Snow, Phillips Petroleum Co.

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