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GENERAL RESEARCH

NIPER-120 **1985 Annual Report. National Institute Petroleum and Energy Research. March 1986. 254 pp. NTIS Order No. DE86000265.** The National Institute for Petroleum and Energy Research or NIPER has completed its second year of operation under a cooperative agreement between its parent organization, IIT Research Institute and the U.S. Department of Energy. The organization is divided into two research departments: Energy Production Research with principal DOE research and development program on enhanced oil recovery technology and the Fuels Research Department which is concerned with the effect of extending feedstocks from predominantly light petroleum crudes to include heavy oils, tar sand liquids, shale oil, and coal liquids for both processing and utilization. Some major accomplishments for 1985 are outlined in this annual report. Many of these research efforts are commercially viable and others will provide a broader base for future scientific research. The DOE supports two NIPER programs: a fully-funded Base program, that is designed for basic, long-term, high-risk research and an Optional program that is cooperatively funded by DOE and other organizations (both government and industry). In addition, NIPER has a "Work for Others" program for proprietary work that is funded outside of the cooperative agreement and therefore not a part of this report.

Enhanced Oil Recovery—Chemical Flooding

NIPER-103 **Crystalline Surfactant Dispersions By Radio Frequency Absorption. Topical Report. National Institute for Petroleum and Energy Research. March 1986. 26 pp. NTIS Order No. DE86000267.** The object of work described in this report was to develop a method of measuring the electrical properties of colloidal surfactant particles, which control the structure and stability of the surfactant dispersion. A further object was to find how these electrical properties are affected by the method used to mix the components of the dispersion. The results may be useful in solving several practical problems, including the identification of optimally performing liquid crystalline surfactant formulations for oil recovery use. Another possible end use is to identify and categorize effects of the method of mixing surfactants on the final product. This information would provide guidelines for field handling of chemical recovery agents.

NIPER-104 **Adsorption Calorimetry of Water-Wet and Oil-Wet Minerals. Topical Report. National Institute for Petroleum and Energy Research. March 1986. 26 pp. NTIS Order No. DE86000268.** This project is a continuation of a research program designed to understand and model adsorption of enhanced oil recovery chemical flooding material onto reservoir minerals. The understanding of modeling of adsorption will ultimately lead to an effective way to select EOR chemicals which are most cost effective. This report describes progress made from October 1, 1984 to September 30, 1985. It is divided into three parts: (1) modeling of adsorption, (2) adsorption of surfactants from solutions of brine and aqueous cosurfactant, and (3) proving the usefulness of titration calorimetry. In the first part, the surface described was water-wet; in the other parts, surfaces of different wettability were used in the investigation.

NIPER-107 **Determining the Effectiveness of Additives for the Control of Sweep and Mobility in Steamflooding. Topical Report. National Institute for Petroleum and Energy Research. 20 pp. NTIS Order No. DE86000276.** Steamflooding is currently the major EOR method used by industry. However, the recovery efficiency is often lowered by gravity override, viscous fingering, and reservoir heterogeneity effects. The injection of additives with steam to generate foam in situ has been proposed as a means to lessen these problems. This topical report details the experiments done so far with screening tests designed to predict the effectiveness of additives in improving the oil recovery efficiency by steam injection.

DOE/BC/10095-22 **Mobility Control and Scaleup for Chemical Flooding — Final Report for the Period October 1983-September 1984. The University of Texas at Austin. February 1986. 344 pp. NTIS Order No. DE85000149.** This project was designed to determine quantitatively the effects of dispersion, relative permeabilities, apparent viscosity and inaccessible pore volume on micellar/polymer flooding, and to develop numerical simulators which incorporate these and other features of the processes, so that mobility control design and scaleup of the micellar/polymer flooding process can be better accomplished. The final report is divided into four parts. The first part is a description of a current three-dimensional simulator as well as some of the simulation studies in both one and three dimensions. The second part of this report contains the theoretical description of this phase behavior model and comparison with our experimental data. The partitioning of either one or two alcohols in surfactant/oil/brine/alcohol mixtures is accounted for in a simple way entirely practical for even large scale three-dimensional simulation. The third part contains the most recent three-phase relative permeability data and the tracer data taken during these same experiments along with the theoretical interpretation of these tracer data with a capacitance-dispersion model. In the last part, rheology data on polymer solutions is given.

DOE/BC/10116-31 **Flow in Porous Media, Phase Behavior and Ultralow Interfacial Tensions: Mechanisms of Enhanced Oil Recovery. Final Report. University of Minnesota. February 1986. 365 pp. NTIS Order No. DE85000150.** This report is a summation of major accomplishments during the period from October 1, 1983 to September 30, 1984, produced by a team of investigators researching the basic mechanisms of enhancing petroleum recovery at the University of Minnesota. A compilation of 40 scientific and engineering papers published in leading journals are abstracted. Four Ph.D theses and one M.S. thesis were produced from this research

program. Further details of information transfer and personnel exchange with industrial, governmental and university laboratories appear in quarterly reports. The Minnesota program has continued beyond the report period with the aid of supplemental grants-in-aid from 10 U.S. companies in the petroleum industry and one European company, plus some interim funding from the University and Department.

DOE/BC/10830-1 Evaluation of the Storms Pool Improved Waterflood Project — Topical Report. Keplinger Technology Consultants, Inc. March 1986. 46 pp. NTIS Order No. DE86000271. The Storms Pool Improved Waterflood project was a cost-shared enhanced oil recovery project operated by Energy Resources Company, Inc. (ERCO) and its sub-contractor, Elf-Acquitaine Oil and Gas Company, under DOE contract. Preparation and testing for the polymer flood began in September 1977 and polymer injection was terminated in June 1982. The objective of the cost-shared project was to evaluate the technical efficiency and economic feasibility of polymer enhanced waterflooding as a tertiary recovery process in a heterogeneous sandstone reservoir that had been successfully waterflooded. The purpose of this report is to provide an appraisal of the project, to suggest ways in which project performance could have been improved and to emphasize areas needing additional research. This analysis will be helpful in advancing the technology of using polymers for improving oil recovery.

DOE/ET/13077-115 Commercial Scale Demonstration Enhanced Oil Recovery By Micellar-Polymer Flood–Eighth Annual Report for the Period October 1984-September 1985. Marathon Oil Company. February 1986. 80 pp. NTIS Order No. DE86000263. This commercial scale test, known as the M-1 Project, is located in Crawford County, Illinois. It encompasses 407 acres of Robinson sand reservoir and covers portions of several waterflood projects that were approaching economic limit. The project includes 248 acres developed on a 2.5 acre five-spot pattern and 159 acres developed on a 5.0-acre five-spot pattern. After 18% of pore volume injection, the 2.5-acre pattern oil cut increased from 5% to a peak of 12.2% at 37.5% of a pore volume. The oil cut remained relatively flat until 55% pore volume had been injected. The oil cut has gradually decreased to 1.5% in September of 1985. This compares to 2.7% in September of 1984. The initial response in oil cut at the 5.0-acre pattern area occurred after 23% of a pore volume had been injected. A second and much sharper increase in oil cut was observed after 34% pore volume injection. By 46% pore volume injection, the oil cut had peaked at 13.3%. This occurred in October of 1982 and since that time the oil cut of the 5.0-acre pattern area has steadily decreased. As of September 1985, the oil cut at the 5.0-acre pattern area is 5.2%. As a result of project operations, 1,223,464 barrels of oil have been recovered from the project area.

DOE/SF/11999-1 Chemical Additives for Improving Steamflood Performance–Annual Report for the period January-December 1984. University of Southern California. March 1986. 68 pp. NTIS Order No. DE86000273. The extent of caustic reaction with silica at elevated temperatures was investigated under static and batch conditions in fired Berea cores. Significant progress has been made but the ultimate pH which can be perpetuated through the reservoir in a solution buffered with dissolved silica has not as yet been established as a function of the many fluid and reservoir properties which determine that pH. Displacement experiments have shown that pH in excess of 11 will recover waterflood residual oil for specific Long Beach crudes. Recoveries at pH less than 11 may be obtained with buffered solutions containing carbonates in addition to silicates. The measurement of relative oil and water permeabilities at elevated temperatures and reduced interfacial tensions has been completed and the results are summarized.

Enhanced Oil Recovery—Thermal Recovery

DOE/BC-86/2/SP Supporting Technology for Enhanced Oil Recovery - EOR Thermal Processes. Republic of Venezuela Ministry of Energy and Mines and U.S. Department of Energy. March 1986. 362 pp. NTIS Order No. DE86000278. This report contains the results of efforts under the several tasks of the Second Amendment and Extension of Annex IV, Enhanced Oil Recovery Thermal Processes of the Venezuela/USA Energy Agreement. The report is presented in sections by tasks and each section contains one or more reports prepared by various individuals or groups and describing the results of each particular task. A statement of each task is presented at the beginning of each section. The tasks are numbered 11, and 14 through 24. The first and second reports of Annex IV, DOE/BETC/SP-83/15 and DOE/BC-84/6/SP, contain the results from the first 14 tasks, with the exception of an INTEVEP Survey for Task II which is included in this report.

DOE/BC/10354-16 Evaluation of Methods of Reducing Permeability in Porous Media By In Situ Polymer Treatments–Final Report. The University of Kansas. February 1986. 380 pp. NTIS Order No. DE86000264. This report describes a study of two processes which are used commercially to reduce the permeability of reservoir rocks by crosslinking polyacrylamide. These processes are the chrome redox process and the aluminum citrate process. Research was conducted on properties of bulk gels as they formed as well as in situ gelation in sandpacks and Berea core material. Results of research activites are summarized in this final report.

DOE/SF/11564-14 Interpretation of In-Situ Combustion Thermal Oil Recovery Falloff Test–Supri TR-50. Stanford University Petroleum Research Institute. March 1986. 189 pp. NTIS Order No. DE86000272. This study deals with the interpretation of in situ combustion thermal oil recovery injection well falloff tests using the pseudo-steady state concept. This concept is based on the fact that during the combustion process the inner (swept) region around the gas injection well is usually filled with high mobility gas while the unswept region contains low mobility fluid. Due to the large contrast between conductivity of the gas in the swept volume and that in the unswept sand ahead, transient effects caused by the swept volume would be characteristic of a section of very high transmissivity. Hence, the swept zone will behave like a separate "closed" reservoir and attain a temporary pseudo-state during falloff testing. A Cartesian graph of pressure versus shut-in time during this period will yield a straight line the slope of which is related to the swept volume.

Enhanced Oil Recovery–Microbial

NIPER-105 Survival of MEOR Systems in Porous Media. Topical Report. National Institute for Petroleum and Energy Research. March 1986. 32 pp. NTIS Order No. DE86000269. Many potential environmental hazards from MEOR technology are extensions of EOR environmental problems. One unique concern of MEOR is that interactions between injected microorganisms and molasses, and those microorganisms already present in the reservoir might pose novel problems. It was necessary to obtain information regarding the indigenous microbial flora and the survival characteristics of a MEOR system after it encounters simulated reservoir microbial conditions. From laboratory studies, it was determined that adventitious microbial species present in the molasses overgrew several of the indigenous microorganisms in Berea sandstone cores and also overgrew the injected MEOR microorganisms. From the results of these studies, it can be concluded that (1) the introduction of nutrients into a petroleum reservoir could stimulate the growth of indigenous microorganisms; (2) microorganisms present in injected non-sterile nutrients can overgrow both injected microbes and indigenous microorganisms; and (3) spore-forming bacteria cannot survive time periods in porous media of 4-20 weeks if there are other bacterial types present.

DOE/BC/10811-1 Isolation and Screening of Anaerobic Clostridia for Characteristics Useful in Enhanced Oil Recovery–Final Report for the Period October 1983-February 1985. Oklahoma State University. October 1985. 82 pp. NTIS Order No. DE85000144. Strains of *Clostridium* isolated and screened for properties thought to be useful in enhanced oil recovery were tested for reactions to high sodium chloride concentrations,

with the ultimate goal to develop more salt-resistant strains. Gas and solvent production by certain high gas-producing strains were tested in the presence of various pulverized cores. The minerals in these can enhance or delay spore germination or growth and metabolism of the bacteria in situ. The presence of a source of nitrogen and of energy are essential for continued gas production. A sampling of viable bacteria present in connate water, holding tanks, and other sites near oil fields show a majority to be Gram positive, aerobic strains. For downwell work with Clostridium, beet molasses is a generally good and economical source of energy. Tests of connate water for toxicity for strain to be used, in the medium to be used, are essential. We have achieved downwell fermentations, as shown by CO_2 and solvent production, and in one case, a significantly increased oil production.

Enhanced Oil Recovery–Environmental

NIPER-102 Computer Simulation Models Relevant To Ground Water Contamination From EOR Or Other Fluids–State-Of-The-Art. Topical Report. National Institute for Petroleum and Energy Research. March 1986. 87 pp. NTIS Order No. DE86000266. Ground water contamination is a serious national problem. The use of computers to simulate the behavior of fluids in the subsurface has proliferated extensively over the last decade. Numerical models are being used to solve water supply problems, various kinds of energy production problems, and ground water contamination problems. Modeling techniques have progressed to the point that their accuracy is only limited by the modeller's ability to describe the reservoir in question and the heterogeneities therein. Pursuant to the Task and Milestone Update of Project BE3A, this report summarizes the state of the art of computer simulation models relevant to contamination of ground water by enhanced oil recovery (EOR) chemicals and/or waste fluids.

PROCESSING AND UTILIZATION

NIPER-78 Stability Aspects of the Recovery of Navy Distillate Fuel From Reclaimed Product Project. Topical Report. National Institute for Petroleum and Energy Research. December 1985. NTIS Order No. DE86000261. Stability data collected during the project on the recovery of Navy distillate fuel from reclaimed product are presented and analyzed. This includes the characterization of 20 waste diesel fuel samples and the samples generated during the process evaluation phase of the project. Analyses of the 20 diesel samples show that the stability of the waste diesel fuel cannot be successfully correlated with carbon residue, ash, metals, or heteroatom content. This results from the variable nature of the contaminants in the waste fuel. The process evaluation phase included careful testing of sorbent treatment, chemical treatment, distillation, solvent extraction and hydrotreating. The analysis of the process evaluation phase samples shows that sorbent treatment with clay and distillation processes successfully upgrade the stability of the waste fuel. Specifically, sorbent treatment with a clay dramatically improved the stability of the waste fuel. Distillation also improved the stability. Chemical pretreatment was found not to affect stability. Hydrotreating could not be effectively evaluated independently because of a distillation pretreatment of the feed, which stabilized the fuel prior to hydrotreating. All the stability results generated indicate the compounds causing stability problems are heavy unsaturated, aromatic and/or heteratom compounds.

DOE/BC/10525-15 Mechanisms of Syncrude/Synfuel Degradation–Third Annual Report for the Period October 1, 1982-September 30, 1983. Department of the Navy, Naval Research Laboratory. March 1986. 109 pp. NTIS Order No. DE86000270. The study of the oxidation of 2,5-dimethylpyrrole (DMP) has been extended to a model solvent system (n-dodecane). The formation of sediment by DMP is believed to occur by way of a charge-transfer mechanism, unlike radical chain mechanisms which are characteristic of hydrocarbon autoxidation. Activation parameters, which have been determined for the reaction in dodecane, suggest that the rate determining step in the oxidation is bimolecular (DMP and O_2) and leads to a transition state which is more polar than the starting materials. Some soluble/volatile products and/or intermediates from the oxidation of DMP have been detected by GC/MS. Sediments which formed in diesel fuel following addition of several other nitrogen compounds are incorporated into the sediments. Several 1,2,5-trisubstituted pyrroles were synthesized and found to be only slightly active in sediment promotion in diesel fuel (the 2- and 5- substituents were phenyl groups). Hydroperoxide and sediment analyses, which have completed for the high temperature (100-250 Centigrade) stability tests using DMP as dopant, confirm that although the kinetics of fuel stability in the DMP/diesel fuel system change at high temperatures, the resulting insoluble products of the oxidations are nearly identical with those formed at lower temperatures.

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GENERAL RESEARCH

Quarterly Reports

DOE/BC—85/3 **Contracts for Field Projects and Supporting Research on Enhanced Oil Recovery. Progress Review No. 43. Quarter ending June 30, 1985. May 1986. 107 pp. NTIS Order No. DE86000259.** Status reports are given for various enhanced oil and gas recovery projects sponsored by the Department of Energy. The field tests and supporting research on enhanced oil recovery include chemical flooding, gas displacement, thermal/heavy oil, resource assessment, extraction technology, and microbial technology.

Enhanced Oil Recovery—Chemical Flooding

NIPER-129 **Reaction of Sodium Hydroxide with Silicate Minerals. Topical Report. April 1986. National Institute for Petroleum and Energy Research. 44 pp. NTIS Order No. DE86000275.** The reactions of individual silicate minerals with caustic solution were measured over a 1-week period. These silicate minerals included: two feldspars (microline and albite), two micas (biotite and muscovite), and three clays (chlorite, kaolinite and montmorillonite). Bottle tests were at 24 and 70 C using three different sodium hydroxide concentrations: 0.01, 0.1, and 1 equi/dm^3. Changes in the concentrations of the following aqueous species were monitored with time: sodium, silicate, aluminate, and hydroxide. Experimental results show that all of the silicate minerals cited above dissolve in caustic solution, but the extent of dissolution varies from one mineral to another. The extent of dissolution increases with increasing pH and temperature. Caustic consumption by kaolinite was observed: 1.0 N NaOH solution was found to precipitate at 0.03 equiv/(kg kaolinite)/hr when mixed with kaolinite at 70 C. Caustic solution was injected through a Berea core, and silicate and aluminate were observed in the effluent, indicating silicate-mineral dissolution in a flowing mode. A model was developed to predict the kinetics of caustic consumption by a mixture of three minerals: quartz, kaolinite, and phillipsite. The model illustrates mineral dissolution and precipitation in a simplified system without including all of the known reservoir minerals. With knowledge of the reaction kinetics between sodium hydroxide and individual silicate minerals, one can extrapolate caustic consumption data beyond the laboratory time scale to the time scale of oilfield operations. Implications of the kinetic model to alkaline flooding are discussed.

NIPER-94 **A Postflood Evaluation of the North Burbank Surfactant–Polymer Pilot. Topical Report. National Institute for Petroleum and Energy Research. June 1986. 38 pp. NTIS Order No. DE86000287.** In a follow-up evaluation to the Phillips-DOE surfactant-polymer pilot in the North Burbank field of Osage County, Okla., a test program was designed to determine the relative importance of the various detrimental factors – heterogeneity, crossflow, ion exchange, partitioning–leading to nonconformance, and degradation of surfactant and polymer slugs. A diagnostic well was drilled 80' southeast of an injection well, within the drainage area of one of the best producing wells for tertiary oil. Rock, brine, and oil samples were taken from three noncommunicating reservoir zones and analyzed for sulfonate, polyacrylamide, alcohol, calcium, and residual oil, along with a complete brine analysis. Comparisons were made with core analyses on adjacent wells at the start of the project, and with fluids produced from them. Chloride and residual oil were low, indicating that the region had been swept and oil displaced. Sulfonate and alcohol were surprisingly high. At a sweep of less than 5% of the area, surfactant and cosurfactant were segregated, and the slug was markedly displaced toward the Type II$^+$ direction from optimality. No polyacrylamide was detected in the brine or on the rock suggesting a change in flow patterns that diverted polymer around the region so that sulfonate and alcohol were not fully displaced. These observations indicate that the performance of the pilot was influenced by both heterogeneity and degradation of the chemical slug. The relative role of the polymer is still uncertain.

Enhanced Oil Recovery—Carbon Dioxide

NIPER-76 **Heavy Oil Recovery By CO_2 Immiscible Displacement Method. Topical Report. April 1986. National Institute for Petroleum and Energy Research. 70 pp. NTIS Order No. DE86000281.** This report describes the results of studies made to investigate the mechanisms of immiscible CO_2 displacement for heavy oil recovery. Viscosity reduction, oil swelling, and hydrocarbon extraction are the major mechanisms being studied. Measurements of viscosity reduction, density change, swelling factor, and CO_2-solubility have been conducted for seven heavy crudes API gravity in the range of 10-20°. A correlation has been developed between the viscosity reduction and the quantity of CO_2 dissolved. The viscosity correlations developed in this work can be used to predict the viscosity of heavy oils and mixtures of CO_2 for process design and simulation of immiscible displacement process. The extraction of oil by high pressure CO_2 has also been studied. Laboratory tests were conducted to determine the quantity of oil extracted by CO_2 from a heavy crude (21.6 °API gravity) at 2000 and 3000 psig, and at temperatures of 100 and 150 °F.

DOE/BC/10830-3 **Evaluation of the Little Knife CO_2 Minitest. Topical Report. Keplinger Technology Consultants. April 1986. 88 pp. NTIS Order No. DE86000279.** A joint DOE-Gulf Oil Corporation, nonproducing carbon dioxide minitest was conducted in the Little Knife Field in western North Dakota. At the time of the project, the reservoir was undergoing primary depletion and had no secondary recovery operations underway. The five-acre inverted four-spot tested the applicability of a CO_2-alternating-with-water injection process to commercially displace oil in the nonflooded Mission Canyon Formation located in the Williston Basin. The nonproducing test was evaluated using time-lapse logging and fluid sampling to monitor fluid movement as injected CO_2 and water displaced 41 °API oil in three observation wells which surrounded a central injector. Numerical simulation studies using the time-lapse logging data provided the basis for estimating pilot performance and evaluating a proposed expansion of the process to a 160-acre pattern. The concept of a nonproducing minitest offers the advantage of information being generated faster and at a lower cost when compared to a conventional oil-in-the-tank pilot test. There are certain inherent disadvantages in a nonproducing test which include the uncertainty in simulation analyses. Both analyses can be subject to significant inaccuracies. Lateral variations

in heterogeneity could also more significantly impact minitest results compared to a conventional test. In this evaluation of the project, results emphasized the analysis of logging data. Results obtained in the pilot show an optimistic incremental recovery over waterflooding of 8.0% of the OOIP with an optimistic 1.0 STB of oil production estimated per 5.0 to 8.0 MSCF of injected CO_2 depending on exclusion or inclusion of Zone W. Assuming a more realistic 1.0 STB of oil recovered per 10.0 MSCF of injected CO_2, these results still encourage the commercial application of the process to the Little Knife Field upon location of a suitable CO_2 source.

DOE/MC/21136-6 **Improvement of CO_2 Flood Performance. Annual Report for the Period April 1, 1984-September 30, 1985. New Mexico Institute of Mining and Technology. June 1986. 174 pp. NTIS Order No. DE86000283.** This report gives detailed descriptions of progress in three major areas of CO_2 flooding. Topic I concerns mixing and phase behavior of CO_2 and crude oils at reservoir conditions and methods of predicting pressures required for miscibility. A principal instrument of the experiments is the continuous multiple contact (CMC) apparatus, developed at the PRRC, that speeds acquisition of such data. Both measurements and theoretical calculations are presented. Topic II examines the process of displacement in reservoir rock, concentrating on those aspects that influence flood efficiency and the extent of the mixing zone. This bears directly on the formation of the "developed miscibility" or Hutchinson-Braun transition zone in CO_2 flooding. Mathematical and computer description is performed on the output concentration curve from core floods, with the goal of scaling these results up to the reservoir-size process. In the opposite direction, work at the smaller scale has produced informative video records of displacement in micromodels. Topic III is concerned with mobility control in CO_2 floods. While the extent of loss of displacement efficiency due to the low viscosity of CO_2 is variable from field to field, the major goal of research in this area is to develop means for thickening CO_2 where mobility control is needed. Two methods are being studied. The first is "CO_2-foam"—the simultaneous injection of dense CO_2 and surfactant solution. Experimental variables include type of surfactant, surfactant concentration, CO_2/water volume ratio and rock/brine/surfactant compatibilities. The second effort is the development of special polymers to dissolve in the CO_2 and directly increase its viscosity.

Enhanced Oil Recovery—Thermal Recovery

DOE/BC/10830-2 **An Evaluation of the Field Demonstration of the Conventional Steam Drive Process with Ancillary Materials at North Kern Front. Topical Report. Keplinger Technology Consultants, Inc. April 1986. 91 pp. NTIS Order No. DE86000277.** An evaluation of the performance of Petro-Lewis Corporation's North Kern Front Field Demonstration has been completed by Keplinger Technology Consultants, Inc. The primary goal of the operator in this field demonstration project was to evaluate the economic merits of use of ancillary materials in a conventional steam drive to improve sweep efficiencies by reducing injection into "steam channels," thus forcing the steam to enter alternate flow paths. This review was based on information published by the Department of Energy with supplementary information provided by the operator. The test was conducted on two different leases consisting of three contiguous 9-spot pattern on each lease. All of the wells in the test had been cyclically steamed, and continuous steam injection had begun about a year before the test began. Steam injection continued with one of the three patterns on each lease used as a control pattern with no chemical being injected. On the second pattern, a small volume of concentrated surfactant foaming agent, COR-180, was injected directly into the steam line at the wellhead every week; and on the third, a small volume of a mixed solution of concentrated COR-180 and concentrated CMC polymer was injected into the steam line every week. Several tests were incorporated into the project operation to aid in interpretation of results. These tests included: (1) injection wellbore profiles in some injection wells before, and at various times after, chemical injection; (2) injection well to producing well tracer surveys in each pattern before, at six months, and at two years after chemical injection; (3) carbon/oxygen (C/O) logs at various times after chemical injection in the monitor well located one-third of the distance between the injector and producer; and (4) comparison of open hole logs in the monitor well to the same logs in a post project monitor well drilled about 10' from the monitor well. Data and analyses are presented in this report suggesting that the ancillary material in the steam drive at North Kern Front did not affect the project oil recovery. This was a surprising result, since other laboratory and field tests indicate ancillary materials can divert steam flow and contribute to increased oil recovery. Further study revealed the reason for lack of success: the test area was overwhelmingly influenced by influx of water and oil from outside. A critique is given of the several evaluation methods attempted in this project to aid in the interpretation of future tests.

Resource Assessment Technology

DOE/BC/10744-8 **Reservoir Characterization For Numerical Simulation. Final Report. The University of Texas at Austin. June 1986. 233 pp. NTIS Order No. DE86000285.** This report discusses the accomplishments of a research project which focuses on quantitative reservoir description. The report is divided into four major areas: (1) a proposed reservoir description scheme; (2) a generalized statistical approach; (3) the connection between geology and statistics; and (4) how statistical descriptions affect fluid flow. The use of power transformation to describe distribution functions is proposed in Section III. The transformation is theoretically motivated from a series or parallel arrangement of permeability layers and can be shown to encompass all of the single-population distributions which characterize permeability. The power of the transformation can be determined only from the original data. Also included in this section is the central tendency estimation and correlation which are both improved when the power transformation is used. In two actual reservoir settings, fluvial and eolian sandstones, permeability was found to be controlled by stratification type and the primary depositional mode. The last section discusses two aspects of fluid displacements: the importance of the correlogram and volume averaging. Correlation in permeability can be used to classify mixing in displacements as flux, dissipative or capatitative dominated. The work on volume averaging shows that stabilized average fractional flow curves exist and can be used to lump point properties into grid block averages.

NIPER-64 **State-of-the-Art Report Summarizing Techniques To Determine Residual Oil Saturation and Recommendations on the Requirements for Residual Oil Saturation Research and Development. Topical Report. May 1986. National Institute for Petroleum and Energy Research. 45 pp. NTIS Order No. DE86000282.** Declining domestic reserves and development of improved methods for oil recovery have increased the need to know the remaining oil reserve or residual oil saturation (ROS) in reservoirs. Residual oil saturation is the remaining oil saturation after waterflooding. The amount of residual oil left behind is one of the most important parameters critical to the selection of an enhanced oil recovery process. There are a variety of engineering methods to estimate residual oil saturation. An investigation was conducted on the residual oil saturation measurement techniques developed during the last 15 years. Knowledge of precise ROS measurements is required for EOR project planning. The following residual oil saturation techniques are discussed: core analyses, well logging, backflow tracer tests, material balance and well testing, newly developed gravity log methods, and interwell residual oil saturation measurements. Several aspects left to be improved in both instrumentations and data interpretation on pressure coring, back-flow tracer tests, well logging, material balance calculations, well testing, and interwell ROS measurements are presented. A nuclear magnetism log-inject-log method is proposed in which the need for porosity measurement for determining residual oil saturation is eliminated.

Enhanced Oil Recovery—Microbial

DOE/BC/10508-36 **Bacteria Transport Through Porous Media. Annual Report, December 31, 1985. University of Southern California. March 1986. 90 pp. NTIS Order No. DE86000274.** Initial studies in microbial enhanced oil recovery at the University of Southern California demonstrate the great potential MEOR has for the future. It is perhaps the youngest of the conventional EOR processes under various stages of development, but it has gained acceptance as being a technically viable alternative to the other EOR processes. With a large percentage of original-oil-in-place (70%) being left in the reservoir after waterflooding, a great deal of effort has gone into the development of EOR processes. The DOE-sponsored university research programs in MEOR began in 1979 and have been the focal point of many of the developments that have launched MEOR from its infancy to its current status as an acceptable and viable alternative

process. At present, however, many problems need to be resolved before MEOR can be successfully applied on a commercial scale. Transport of bacteria in reservoirs is one such problem that has been studied in our laboratories for the past few years. The problem of the transport of bacteria is linked closely with the success or failure of a bacterial injection process and its ability to enhance oil recovery. The injection and penetration of bacteria into a reservoir is the most problematic and crucial of the steps in any MEOR process. Its study, therefore, is critically important to the implementation of any MEOR program.

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Enhanced Oil Recovery—Chemical Flooding

DOE/ET/13070-79 El Dorado Micellar-Polymer Demonstration Project, Seventh Annual Report, September 1980-August 1981. Cities Service Co. June 1982. 588 pp. NTIS Order No. DE82015391. This project is aimed at determining the economic feasibility and the associated benefits and problems of improved oil recovery using the Union Oil soluble-oil-flood micellar-polymer process. During this project year, polymer solution was injected into two patterns. Produced and injected fluid analyses continued, and samples were collected from an observation well during the passage of the oil bank and analyzed. A radial flow simulator was used to match the field performance at this well, and results of the match were used to explain the observed field performance; comparisons are made to laboratory data. Documentation of the geology of the 650-ft. Sand formation has continued. The information and interpretations should be useful in understanding fluid flow within the reservoir, in accurate modeling of the reservoir, and for evaluation of the project performance.

Enhanced Oil Recovery—Carbon Dioxide

DOE/MC/08333-3 Feasibility and Economics of By-Product CO_2 Supply for Enhanced Oil Recovery, Final Report. Vol. 1: Technical Report; Vol. 2: Appendices. Science Applications, Inc. January 1982. Vol. 1: 228 pp. NTIS Order No. DE82004814. Vol. 2: 554 pp. NTIS Order No. DE82005815. This report provides an analysis of the technical and economic feasibility of using by-product sources of CO_2 for enhanced oil recovery. The report includes a comprehensive survey of existing and future by-product sources in the conterminous United States. The potential demand for CO_2 was determined for the four regions where reasonably good data were available: Permian Basin, Williston Basin, Appalachian Basin, and Los Angeles Basin.

DOE/MC/08341-35 Target Reservoirs for CO_2 Miscible Flooding, Task Two: Summary of Available Reservoir and Geological Data, Task Two Final Report, Vol. 2: Rocky Mountain States Geological and Reservoir Data. Gruy Federal, Inc. January 1982. Part 1: 82 pp. NTIS Order No. DE82004826. Part 2: 306 pp. NTIS Order No. DE82004829. Part 3: 338 pp. NTIS Order No. DE82004827. Part 4: 290 pp. NTIS Order No. DE82004828. This report for Task Two summarizes existing reservoir and geological data on carbonate reservoirs located in west Texas, southeast New Mexico, and the Rocky Mountain states. It is contained in two volumes; this volume, in four parts, is a summary of reservoir data for fields in the basins of the Rocky Mountain states. Part 1 contains the reservoir selection procedure, geology, and reservoir data summary. Data are included on the following fields: Part 2–Williston Basin and Sweetgrass Arch Fields, ANTELOPE-Madison through KUROKI-Madison; Part 3–Williston Basin and Sweetgrass Arch Fields, LIGNITE-Madison through WOLF SPRINGS-Amsden; Part 4–Paradox, Uinta, Eastern Utah Overthrust, Big Horn, Wind River, Powder River, Red Desert, and Great Divide Basins, CACHE-Ismay through WERTZ-Madison. Order by report number–DOE/MC/08341-35–and specify the Part Numbers that you wish to receive.

DOE/MC/08341-39 Field Project to Obtain Pressure Core, Wireline Log, and Production Test Data for Evaluation of CO_2 Flooding Potential. Gruy Federal, Inc. May 1982. 278 pp. NTIS Order No. DE82012437. Pressure coring and associated logging and testing programs are planned for selected wells to provide data on *in situ* oil saturation, porosity and permeability distribution, and other data needed for resource characterization of fields and reservoirs in which CO_2 injection might have a high probability of success. This report presents detailed information on the first such project at the Bennett Ranch Unit well No. 310, Wasson (San Andres) Field, Yoakum County, Texas. Porosity and water saturation, as determined by extensive core and log analyses, agreed well in intervals where cores were successfully retrieved under pressure. Core and log data were useful in determining the residual oil saturations, and production data confirmed the validity of oil saturation determinations.

Drilling

DOE/BC/10079-48 Experimental Determination of Solids Friction Factors and Minimum Volumetric Requirements in Foam and Mist Drilling and Well Cleanout Operations, Final Report. University of Tulsa. September 1982. 354 pp. NTIS Order No. DE82020945. The objectives of this study were: (1) to present a semi-empirical model for predicting frictional losses due to the solid phase in solids-foam slurry flow, (2) to develop a theoretical model for predicting pressure drops across bits for foam, and (3) to utilize these models to predict minimum volumetric requirements for foam drilling operations, taking into consideration the settling velocities of drilled particles. A theoretical model for predicting pressure drop across bit nozzles for foam and mist flows is proposed. It accounts for the compressibility of foams but assumes negligible pressure losses due to friction and changes in elevation. A model was also developed for predicting minimum volumetric requirements.

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GENERAL RESEARCH

Quarterly Reports

DOE/BC-85/4 **Contracts for Field Projects and Supporting Research on Enhanced Oil Recovery. Progress Review No. 44. Quarter ending September 30, 1985. September 1986. 101 pp. NTIS Order No. DE86000292.** Status reports are given for various enhanced oil and gas recovery projects sponsored by the Department of Energy. The field tests and supporting research on enhanced oil recovery include chemical flooding, gas displacement, thermal/heavy oil, resource assessment, extraction technology, and microbial technology.

Enhanced Oil Recovery – Carbon Dioxide

DOE/MC/16426-19 **Mobility Control for CO_2 Injection. Final Report for the Period May 15, 1981-January 31, 1986. New Mexico Institute for Mining and Technology. August 1986. 138 pp. NTIS Order No. DE86000293.** A mobility control test of CO_2-foam performed in Pennzoil's Rock Creek Field of Roane County, West Virginia, is described in this final report. Test results showed that it is possible to inject dense CO_2 and surfactant solution simultaneously into a regular injection well. The reduced injectivity can be interpreted as due to the reduced mobility of CO_2-foam as an injection fluid with an apparent viscosity about 2½ times that of water. Another test result of some interest is that the simultaneous injection of surfactant with the CO_2 was successful in retarding the formation of viscous fingers and early breakthrough of CO_2 into a producing observation well only 75' away. A total of 8000 reservoir barrels of dense CO_2 were injected (simultaneously) with about 2500 bbl of surfactant solution with no massive CO_2 breakthrough experienced at the observation well. Details are given on related research and operating projects, on the design of all features of this test, on the chronology of injection and sampling, and on the test results. In addition, three extensive appendices give descriptions of related computer calculations of expected flooding patterns, of results to be expected from the Point Dilution Method (an operational test which was not performed due to an unavoidable change in field plans), and in the distribution of tracer concentration in the formation after a period of radial flow from the injection well.

DOE/MC/16551-19 **Enhanced Oil Recovery By CO_2 Foam Flooding. Final Report for the Period October 1, 1981-December 31, 1985. New Mexico State University. September 1986. 210 pp. NTIS Order No. DE86000300.** Significant progress has been made in developing a commercial method of reducing the mobility of carbon dioxide in enhanced oil recovery processes. Experiments on gas mobility control, conducted in linear sand-pack models, show only a general correlation with the static foam test. The static test, which utilizes a blender to generate foam from an aqueous surfactant solution, is useful mainly for studying the effects of pH, temperature, salinity, and crude oil on the relative foamability of any given surfactant. In general, surfactants that produce reasonable quantities of foam in the blender test also impart some degree of mobility control to gas during two-phase flow. The best mobility control additives, however, are those which produce only modest volumes of foam. In addition, the best additives spontaneously produce a viscous foam under flow conditions and rates typical of petroleum reservoirs. Three basic chemical structures show the most promise for gas mobility control: (1) ethoxylated adducts of C_8-C_{14} linear alcohols; (2) sulfate esters of ethoxylated C_9-C_{16} linear alcohols; (3) and low molecular weight copolymers of ethylene oxide and propylene oxide. Each of these three types is compatible with normal oil field brines, unaffected by the presence of crude oil, and stable under conditions common in a petroleum reservoir. Additive stability is of real concern. Limited experimentation suggests that only the sulfate esters might degrade at an unacceptable rate. This could limit their application to lower temperature reservoirs, below about 130 F. No degradation was noted for structures 1 and 3 in aging tests lasting two weeks at 125 F. Computer simulation of mobility controlled CO_2 floods provide mixed results. For an immiscible CO_2 flood, reducing CO_2 mobility by a factor of 10 increased overall recovery by 20%. More importantly, incremental oil production was more than doubled during the early phase when only CO_2 was injected. It was not possible within the time frame of this project to model miscible CO_2 mobility lowering without generating spurious effects on the reservoir oil phase.

Enhanced Oil Recovery – Thermal Recovery

DOE/SF/11564-15 **Foams in Porous Media–SUPRI TR-49. Topical Report. Stanford University Petroleum Research Institute. 26 pp. NTIS Order No. DE86000290.** This is a chronological survey showing the development of foam flow, blockage and use in porous media, starting with laboratory studies and eventually getting into field tests and demonstrations. It is arbitrarily divided into five-year time periods. Since the first literature search on selective blocking of fluid flow in porous media was completed by the author in 1978 (SUPRI TR-3), new information has been added to the literature as a result of continued research in this area.

DOE/SF/11564-16 **Pressure Transient Analysis of Wells With Horizontal Drainholes–SUPRI TR-51. Topical Report. Stanford University Petroleum Research Institute. July 1986. 115 pp. NTIS Order No. DE86000291.** This study is the result of the need to understand pressure transient analysis for horizontal drainholes. Analytical solutions for the transient pressure response of a uniform flux horizontal drainhole in an anisotropic reservoir of finite thickness are presented. The solution also applies for a reservoir with multiple drainholes in a vertical array. The analytical solution is developed using instantaneous source functions, Green's functions and the Newman product method. The solution shows that there are two possible types of transient pressure behavior depending on

the length of the drainhole relative to the height of the reservoir. If the drainhole is short, flow is characterized by three flow periods: an initial radial flow perpendicular to the drainhole axis, a transition flow period, and a pseudo-radial flow period. If the drainhole length is long relative to the reservoir height, the initial radial flow period ends instantaneously for all practical purposes. The transient pressure behavior here is identical to that of a uniform flux vertical fracture and is characterized by early time linear flow followed by a transition period and late time pseudo-radial flow. It is demonstrated that the pressure transient response for multiple drainholes is identical to the single drainhole solution if dimensionless variables are defined relative to the number of drainholes. Consequently, the pressure response of a uniform flux vertical fracture can also be approximated by several short drainholes. The solution for infinite conductivity drainholes is also suggested by analogy to the infinite conductivity vertical fracture solution. Log-log type curves are presented for various drainhole radii and can be used in the conventional manner to determine reservoir characteristics including directional permeability or drainhole half length. Short and long time approximations are presented along with appropriate time limits. Finally, conditions for greater productivity than with vertical wells or hydraulic fractures are presented.

DOE/SF/11564-17 Thermal Injection Well Falloff Testing–SUPRI TR-33. Topical Report. Stanford University Petroleum Research Institute. August 1986. 66 pp. NTIS Order No. DE86000286. Several case histories are presented from both in situ combustion and steamflood projects. An investigation for each case history shows the information that may be obtained from pressure transient tests. Pressure transient testing of the injection well is useful in evaluating and controlling the performance of thermal recovery projects. Field case histories from which the swept volume could be determined from pressure transient tests at thermal injection well were studied. Knowledge of the swept volume permits calculation of important economic parameters including the fuel concentration in a combustion test and heat loss in a steamflood. In an earlier study, a pressure transient model of a two-region reservoir was solved analytically and results demonstrated that in principle, both the permeability-thickness and the swept volume may be determined from a pressure transient test. A typical falloff curve consisted of an initial semilog straight line, a transitional period, and finally, a second semilog straight line. The transition period was found to contain a pseudosteady-state Cartesian straight line whose slope was related to the swept volume. Several sets of field test data were examined to verify the existence of the Cartesian straight line. In order that the swept volume may be calculated from the slope of the Cartesian straight line, the average reservoir pressure and temperature in the swept zone must be estimated. The average pressure is the early-time flattening of the pressure curve on a semilog graph. The average temperature in a steamflood can be estimated from the average pressure, but average temperature must be calculated for combustion. One method of calculation involves a heat balance which includes both the heat generated by combustion and the heat loss to the overburden.

DOE/SF/11564-18 An Experimental Study of Recovery From A 2-D Layered Sandmodel–SUPRI TR-53. Topical Report. Stanford University Petroleum Research Institute. August 1986. 124 pp. NTIS Order No. DE86000288. The study of the effect of flow rate on the recovery of oil by waterflooding is reported. The model consists of a two-dimensional, layered sand which allows visual observation, and three communicating layers of equal thickness of water-wet sand with the permeability ratio of 2:4:1 from top to bottom. Three white mineral oils of viscosity 15, 30, and 150 centipoise have been used for immiscible liquid/liquid displacement under constant pressure drops covering a range of flow rates. The changes in flow regimes in the various layers are observed with respect to the variations in pressure drop across the model. The effects of capillary imbibition, gravity segregation, and viscous pressure gradient are observed and an attempt is made to quantify the crossflow. Crossflow of oil from the tight layers to the most permeable layer increases the intermediate recovery of oil for a given volume of water injected. Oil recovery increases with a decrease in flow rate and also with a decrease in oil viscosity. Slow flow rates produce higher recovery but may not be feasible in the field for economic reasons. Most of the crossflow of oil into the permeable layer occurs just behind the flood front and produces a secondary oil bank soon after breakthrough. A sequence of slow flow rate followed by a fast flow rate is shown to improve the recovery of oil for a given volume of water injected, and this occurs within a reasonable experimental time-frame. Slow flow rate is continued to the time of breakthrough to take advantage of the crossflow, and then the flow rate is increased and maintained for the remaining life of the waterflood. The slow flow rate is set from a criterion of stable displacement in the most permeable layer based on Peters' stability analysis (1981), and the fast flow rate is based on the maximum pressure the model can take. The effect of variation in interfacial tension on the displacement behavior is also studied. Interfacial tension is reduced from 45.0 to 0.5 dyne/cm by the addition of a surfactant to the injected flood-water. These ranges of interfacial tension are not sufficiently low to increase oil recovery from interfacial effects. The low interfacial tension flood produced less oil than a waterflood for the same volume of injected fluid. This results from the reduced capillary imbibition which is important for oil recovery from a stratified reservoir. Also, the injectivity of the surfactant solution probably decreased due to emulsion forming and plugging of pore channels.

DOE/SF/11564-19 Transient Pressure Analysis in Composite Reservoirs with Rectangular Discontinuities–SUPRI TR-54. Topical Report. Stanford University Petroleum Research Institute. August 1986. 128 pp. NTIS Order No. DE86000289. The objective of this research was to determine by using numerical simulation if the pseudosteady-state method presented by Eggenschwiler et. al. (1980) can be applied to a long and narrow, rectangular swept-zone. Two simulators were developed to generate transient pressure responses for a reservoir with a rectangular discontinuity. Cases with different width to length ratio (W/L) for the inner-zone were simulated for a mobility ratio of 200. The reservoir has a square geometry with closed outer boundaries. Sufficiently large distance was provided between the well and reservoir boundaries to prevent boundary effects during the time of interest. Results were analyzed with the pseudosteady-state method to find inner zone volumes. Results from the analysis indicate that pseudosteady-state flow does not exist for the inner zone for low W/L ratio cases. The curvature of the Cartesian plot of the pressure responses increases as W/L ratio decreases. For cases with W/L ratio below 0.4, the curvature becomes significant and many straight lines can be drawn through segments of the data. For cases with W/L ratio below 0.1, there is clearly no pseudosteady-state flow, and the Cartesian plot of pressure versus time is a continuous curve. It is found that swept-zone volume calculations are extremely sensitive to the slope of the pseudosteady-state straight line, if one exists. If the distance between the burning front and the well is not approximately equal in all directions, the slope will usually be too flat, and the volume calculated will be too large. A comparison between Cinco's type curve for a finite conductivity fracture and a case with an extremely low W/L ratio was also performed. The results show a favorable match. However, for a rectangular burned zone to behave like a fracture at early time, the dimensions of the burned zone must be similar to that of a fracture.

Enhanced Oil Recovery – Microbial Technology

DOE/BC/10508-37 Bacteria Transport Through Porous Media. Annual Report, December 31, 1984. University of Southern California. September 1986. 170 pp. NTIS Order No. DE86000299. The transport of bacteria is linked closely with the success or failure of a bacterial injection process and its ability to enhance oil recovery. The injection and penetration of bacteria into a reservoir is the most problematic and crucial of the steps in any MEOR process. Its study, therefore, is critical to the implementation of any MEOR program. During the past four years, the following progress has been made from the study of bacterial transport in porous media: (1) spores together with nutrients were found to penetrate deep into formations with rather low permeability; (2) prediction of deposition rate based on known properties of rock and cells has been made; (3)

modification of the rock surface as well as the bacterial surface by chemical methods for facilitating transport was demonstrated; (4) bacterial transport through Berea sandstone by chemotaxis alone was first shown (without external pressure); (5) surfactant-producing aerobe Bacillus subtilis and acid- and solvent-producing anaerobe Clostridum actobutylicum were found to effectively displace residual heavy crude remaining after secondary waterflooding; (6) an approach of colloidal chemistry was adopted to predict the rate of attachment of cells suspended in a laminar flow; (7) the effect of molasses-pyrophosphate mixture on bacterial transport and oil recovery efficiency was studied; (8) experiments were conducted to investigate the bacteria-phage-rock interaction for the lytic control of bacteria in MEOR processes.

PROCESSING AND THERMODYNAMICS

Processing

NIPER-56 **Upgrading of Heavy Crudes: Probable Reactions of Problem Components During Hydrotreating. Topical Report. National Institute for Petroleum and Energy Research. September 1986. 39 pp. NTIS Order No. DE86000296.** The trend in increasing use of heavy crudes is expected to continue as is the need to increase the production of distillates from these heavy crudes. Hydrotreating is widely used as a pretreatment of heavy crude to allow more profitable and efficient downstream processing. This report addresses the problem components in heavy crude and their probable reactions during hydrotreating. It was found that there is a significant gap between model compound studies and kinetic studies of heteroatom removal for process design. This gap is in the understanding of the actual chemistry involved in the hydrotreating of heavy crude feedstocks. Problem compounds addressed include nitrogen compounds, organometallics, sulfur compounds, oxygen compounds, polynuclear aromatics, and asphaltenes.

NIPER-65 **Storage Stability and Compatibility of Heavy Fuel Oils. Topical Report. National Institute for Petroleum and Energy Research. September 1986. 33 pp. NTIS Order No. DE86000297.** The increasing use of low-quality crudes in refinery feedstocks has been paralleled by increasing problems in both processing and product quality. Lower product quality is evidenced by increased problems with product stability and compatibility. Problem components increase with increasing boiling point and are highest in the residual fractions. This project has the specific goal of determining the types of components causing problems in the utilization of residual fuel oils and then using this information to provide practical test methods that will be useful as screening techniques for predicting stability and compatibility problems. Three baseline (nonproblem) fuels and three fuels which have exhibited instability or incompatibility problems are being analyzed in an effort to determine the compound types responsible for the observed problems.

Thermodynamics

NIPER-159 **Assessment of Thermodynamic Data and Needs, Including Their Economic Impact, For Development of New Fossil Fuel Refining Processes. National Institute for Petroleum and Energy Research. September 1986. 95 pp. NTIS Order No. DE86000298.** A survey of the present data base and future data needs for thermodynamic properties of substances related to the future refining of heavy petroleum, shale oil, tar sands, and coal liquids, is presented. Examined in the report are the past economic effects of accurate and precise thermodynamic data on the efficiency of the petroleum industry and projects in the utilization of alternate fuels. Also examined are the differences between the liquid fuels from heavy petroleum, shale, tar sands, and coal, and those that are presently handled by the petroleum industry. Problem areas in the processing of heavy petroleum, shale oil, tar sands, and coal liquids, are high hydrogen requirements, the need to remove large amounts of heteratoms, the presence of metals, and yield reduction due to coke formation. Current processes for the production of oil from shale and coal are energy intensive and uneconomic. This report details the use of thermodynamic data in the design and operation of possible processes to address these problems. The report examines the range of thermochemical and thermophysical properties needed for efficient design and operation of processes in the extraction and processing of heavy petroleum, shale oil, tar sands, and coal. It outlines the development of key data on pure compounds and selected mixtures to serve as a basis for prediction of the thermodynamic properties of the wide range of substances found in the alternate fuels. The interrelationship between thermodynamics, kinetics, and catalyst selection and development are addressed. The thermodynamic study of organometallic compounds will have far reaching implications in the whole field of catalysis. The major differences between light and heavy petroleum, shale oil, tar sands, and coal liquids are outlined, and problem compounds highlighted. In conclusion, the report suggests that sustaining a well-founded, well-funded effort is needed to give the industry a firm foundation on which to build the refinery operations of the future, and this will require more than a simple extension of the scope and ranges of existing data bases. A five-year plan for thermodynamic research in fossil energy accompanies the report and prioritizes the tasks necessary to obtain the relevant thermodynamic data and derive the corresponding correlations necessary for the continued highly efficient and economic production of energy from our sources of fossil fuels.

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Enhanced Oil Recovery – Chemical

DOE/BC/00048-29. Selection of Reservoirs Amenable to Micellar Flooding, Final Report, October 1978-December 1982. Gary Energy Corp. and Intercomp. Resource Development and Engineering, Inc. August 1983. 154 pp. DE84000578. A chemical flood predictive model (CFPM) for micellar-polymer processes was developed. It is applicable to waterflooded sandstone reservoirs and is based on an analysis of all available laboratory and field data. The CFPM also can be used to select the better micellar-polymer prospects in Mid-Continent and California regions and to aid in the design and development of micellar-polymer floods.

DOE/BC/10321-12 Improved Polymers for Enhanced Oil Recovery Synthesis and Rheology–Fifth Annual Report. University of Southern Mississippi. October 1981-September 1982. 219 pp. DE83017371. Investigations of new, more effective systems involving polymers for enhanced oil recovery have been continued. Synthesis, characterization, and rheological studies of random copolymers have been made to serve as models in studying fundamental mechanisms in EOR. Mathematical models, new calibration functions, analytical methods, and data acquisition techniques for aqueous size exclusion chromatography have been developed. Quasielastic light scattering techniques have been applied to the study of hydrodynamic volume concepts. Preferential and overall solvation studies of acrylamide/sodium acrylate and acrylamide/sodium-2-acrylamido-2-methylpropane sulfonate copolymers were made. Phase behavior of model polymers in mono- / and multivariate electrolytes at different polymer and salt concentrations were determined as a function of temperature.

EXTRACTION

Enhanced Oil Recovery–General

CONF-821199 Proceedings of Forum on Subsidence Due to Fluid Withdrawals. U.S. Department of Energy and the Ministry of Energy and Mines of the Republic of Venezuela. August 1983. 146 pp. An international conference on subsidence was held Nov. 14-17, 1982, at Checotah, Okla. This report contains the presentations and discussions on the key issues of (1) the state of the art of compaction and subsidence, (2) the problems of subsidence and their definition, and (3) recommendations for research.

DOE/ET/14010-1 Enhanced Oil Recovery in the Gulf of Mexico. Lewin and Associates. January 1983. 422 pp. This project was designed to identify reservoirs in the Gulf that are geologically, technologically, and economically amenable to enhanced oil recovery (EOR). Reservoirs containing 56% of the Gulf's oil-in-place were studied individually. A subset of reservoirs, accounting for about 20% of the overall resource, was assessed in detail using engineering and economic models. The results indicate that the EOR potential could be up to 4.4 billion barrels in known reservoirs. Technological performance could have a great effect on the EOR potential, especially the ability to recover oil from zones of the reservoirs previously unswept by conventional operations. The rapid decline of many fields in the Gulf will lead to the abandonment and removal of platforms, which would economically prevent recovery of substantial portions of the EOR potential. Therefore, collaboration by industry and government research and development agencies is needed to realize the offshore Gulf potential.

DOE/BC/10355-1 Environmental Regulations Handbook for Enhanced Oil Recovery –1983 Update. Spears and Associates. October 1983. 204 pp. DE84002003. This handbook is a guidebook of environmental laws and regulations which are particularly significant for enhanced oil recovery (EOR) operations. It was prepared to aid owners and operators of EOR projects. The handbook does not, however, detail environmental laws and rules governing conventional oil and gas exploration, drilling, and production. The previous publication was DOE/BC/00050-15, August 1980.

DOE/BC/10116-26 Flow in Porous Media, Phase Behavior and Ultralow Interfacial Tensions: Mechanisms of Enhanced Petroleum Recovery. 1982 Final Report. University of Minnesota. May 1984. 424 pp. DE84009783. This report summarizes 16 major accomplishments of research performed on the basic mechanisms on enhancing petroleum recovery at the University of Minnesota. Abstracts of 45 publications which were written during the year as a result of this research program are included in the appendix of the report. The original focus of the research program was to improve petroleum recovery through surfactant-based chemical flooding processes. The program has since become multi-directional producing research that pertains not only to petroleum recovery but to other energy-related technologies as well.

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GENERAL RESEARCH

NIPER-164 **FY87 Annual Research Plan. National Institute for Petroleum and Energy Research. October 1986. 230 pp. NTIS Order No. DE86000303.** The National Institute for Petroleum and Energy Research or NIPER entered its fourth year of operation under a cooperative agreement with the U.S. Department of Energy (DOE) and IIT Research Institute. This annual research plan describes the work planned for the upcoming year. NIPER's research program is organized three different ways: (1) The DOE funds a $5 million base program for long-range, high-risk research that industry is not willing to perform; (2) a second optional program cost-shares research on petroleum and substitute fossil fuels between DOE and contributing participants. For FY 1987, the DOE maximum share will be $1 million and the remainder will be sponsored by other government agencies and industrial participants; (3) the third program, Work-for-Others, allows NIPER to solicit work from the private sector and others. This Annual Report only covers the base and optional programs.

NIPER-173 **Screening and Laboratory Flow Studies for Evaluating EOR Methods. Topical Report. National Institute for Petroleum and Energy Research. November 1986. 85 pp. NTIS Order No. DE87001203.** Selecting and implementing an EOR method requires several steps. Initially, with knowledge of reservoir properties and formation fluid characteristics, a technical screening guide is consulted, followed by crude oil characterization, injection water studies, and reservoir rock property characterization. After selection of candidate methods, basic stat tests are carried out. Methods which appear to be promising are then subjected to flow studies in porous media where a semirealistic environment is introduced. The data resulting from these tests are often used as input variables for numeric computer simulators which have provisions for considering properties such as reservoir heterogeneity – properties which are practically impossible to simulate physically on a laboratory scale. Pilot projects demonstrate the viability of the selected method. Finally, assuming success at the lower screening levels, an EOR project is implemented fieldwide. Economic evaluations may be conducted throughout all screening levels. This report addresses only some of these screening steps. Technical screening guides, crude oil and reservoir rock characterization, and injection water studies are discussed, but economics and basic laboratory screening tests are not covered. Applied flow studies, selection of appropriate porous media, and experimental configurations for each EOR method are described.

Enhanced Oil Recovery—Chemical Flooding

DOE/BC/10830-4 **A Review and Statistical Analysis of Micellar-Polymer Field Test Data. Topical Report. Keplinger Technology Consultants, Inc. November 1986. 27 pp. DE87001202.** A statistical analysis study has been made of 21 micellar-polymer field test projects to evaluate the significance of key parameters upon performance. In this study, the term micellar-polymer is used to describe surfactant recovery processes of which the most common are the water phase low tension and the soluble oil. The micellar slug is usually followed by a drive slug containing a polymer for mobility control. The data include 10 projects that were used in a previous study and 11 other well-documented projects which have been completed recently. A major effort in this study was to collect and convert the data into a consistent form which would allow for statistical analysis. The study was conducted by correlating oil recovery efficiency and various parameters with a linear regression analysis using the least squares method. The accuracy of a particular correlation is expressed in terms of the "correlation coefficient" and the "confidence limit" which are discussed in this report. The study indicates three significant correlations. The most important of these is the correlation showing that oil recovery is inversely related to the log of the reservoir connate water salinity. This suggests that prior flooding with a water near the design salinity or use of preflushes to adjust salinity and remove hardness have, at best, been only partially effective. A second correlation showed that oil recovery increased as the pattern size was decreased. This is attributed to the higher frontal velocities and to the reduced tendency of slug breakdown in smaller patterns. Low oil cuts at the beginning of the micellar-polymer floods indicated that higher recovery efficiency could not be attributed to infill drilling. The third correlation showed the expected result that oil recovery is related to the quantity of surfactant used. This quantity is the product of the surfactant slug volume (Vps) and the concentration of surfactant (Cs).

Enhanced Oil Recovery—Thermal Recovery

DOE/ET/12059-8 **The "200" Sand Steamflood Demonstration Project. Eighth Annual Report for the Period June 1983-June 1984. Santa Fe Energy Company. October 1986. 23 pp. NTIS Order No. DE86000304.** The joint venture project between Santa Fe Energy Company and the U.S. Department of Energy was initiated in July 1975 to test an enhanced steamflooding technique in the Midway-Sunset Field, Kern County, California. The Demonstration Project was initiated in the "200" Sand Pool to demonstrate the operational, recovery, and economic aspects of steamflooding a typical heavy oil reservoir which responds unfavorably to cyclic stimulation. This pool contains approximately 50 million barrels of oil-in-place in a structure that lies between 400 and 700 feet in depth. This project was conducted in two phases. The first phase was a pilot test consisting of four 2.35 acre inverted seven-spot steam drive processes, which were not fully developed with producers. As a result of the response shown by the pilot, the second phase was implemented in 1980-81 by expanding the pilot area to a total of 14 fully developed 2.35 acre inverted seven spot patterns. The steamflood project consists of 42 producing wells and 14 injection wells. Based on prediction and actual performance here and in other heavy oil reservoirs, steamflooding is considered the most promising thermal recovery technique for this reservoir.

DOE/ET/12059-9 **The "200" Sand Steamflood Demonstration Project. Ninth Annual Report for the Period June 1984-June 1985. Santa Fe Energy Company. October 1986. 23 pp. NTIS Order No. DE86000305.** This joint venture project between Santa Fe Energy Company and the U.S. Department of Energy was initiated in July 1975 to test an enhanced steamflooding technique in the Midway-Sunset Field, Kern County, California. Steamflooding is conducted in Midway-Sunset Field reservoirs which respond favorably to cyclic steam stimulation. A number of heavy oil pools have not been adequately developed because of poor cyclic steam performance. The Demonstration Project was initiated in the "200" Sand Pool to demonstrate the operational, recovery, and economic aspects of steamflooding a typical heavy oil reservoir which has unfavorable response to cyclic stimulation. This pool contains approximately 17 million barrels of oil-in-place in a structure that lies between 400 and 700 feet in depth. This project is being conducted in two phases. The first phase was a pilot test consisting of four 2.35 acre inverted seven-spot steam drive patterns, which were not fully developed with producers. As a result of the response shown by the pilot, the second phase was implemented in 1980-81 by expanding the pilot area to a total of 14 fully developed 2.35 acre inverted seven-spot patterns. The steamflood project consists of 42 producing wells and 14 injection wells. Based on prediction and actual performance here and in other heavy oil reservoirs, steamflooding is considered the most promising thermal recovery technique for this reservoir.

DOE/SF/11564-20 **SUPRI Heavy Oil Research Program. Ninth Annual Report for the Period October 1, 1984-September 30, 1985. SUPRI TR-52. Stanford University Petroleum Research Institute. October 1986. 201 pp. NTIS Order No. DE86000301.** The Stanford University Petroleum Research Institute or SUPRI was established in 1976 with the primary purpose of pursuing enhanced oil recovery research. SUPRI has five overall research objectives: (1) Flow Properties Study – to assess the effects of temperature and pressure on relative permeability to oil and water, capillary pressure and electrical resistivity in petroleum reservoirs; and to correlate the data obtained in the laboratory with those at reservoir conditions. (2) In-Situ Combustion – to evaluate the different parameters affecting combustion field projects, including the study of the reaction kinetics of combustion in the presence of reservoir matrix and crude oil. (3) Steam Injection with Additives – to develop a process allowing mobility control in steam drives in order to reduce gravity override and channeling of steam, primarily by use of surfactants/foams. (4) Reservoir Definition – to improve the techniques of well-to-well formation evaluation such as tracer tests, pressure transient tests, and well logging, and to facilitate the interpretation of such tests. (5) Field Support Services – to provide technical support in design and monitoring of enhanced oil recovery field experiments.

DOE/SF/11564-21 **A Study of Heat Transfer During Steam Injection And Effect of Surfactants on Steam Mobility Reduction. SUPRI TR-55. Topical Report. Stanford University Petroleum Research Institute. October 1986. 160 pp. NTIS Order No. DE86000302.** A system of differential equations describing the temperature in the insulation and the heat frontal movement in a cylindrical core during steam injection is derived and solved in Laplace space. The real-time solution is obtained by using the Stehfest algorithm. The solution shows that movement of the heat front is strongly dependent on the heat transfer coefficients at the inner and outer boundaries. Experimental results of steam injection are shown at pressures varying from 0.11 to 1.42 MPa (16 to 206 psia). The apparent thermal conductivity of the insulation as a function of temperature was obtained by comparing experimental data with an analytic solution. When the pressure of the steam zone changed during a run, it was found that changes of volumetric heat content in the heated core and the insulation may be treated as though they were changes in heat injection rate. The method of succession of steady states can also be used to approximate the heat frontal movement for cases of variable pressure. For displacements using Kaydol as the in-place oil, the initial oil saturation had little effect on irreducible oil saturation. A method for approximating the steam swept volume is presented using an adjustment to the Marx and Langenheim equation and a new definition of the critical time. This method improves the approximation of the steam swept volume. The steam mobility can be reduced by alternate injection of steam and surfactant slugs. The steam mobility decreased with an increase of surfactant concentration and with an increase in the slug sizes of the surfactant solutions. The number of surfactant slugs required to obtain the maximum mobility reduction was found to be a function of surfactant concentration and backpressure. The addition of nitrogen in the injected steam further reduced the steam mobility, with very little effect seen at concentrations of nitrogen above about one mole percent.

NIPER-180 **Using Micromodels to Study Steam Displacement Processes in Porous Media. A Literature Review and Topical Report. National Institute for Petroleum and Energy Research. October 1986. 37 pp. DE87001201.** An experimental system for studying high-temperature displacement processes in micromodels is discussed. Although no attempt to date has been made to investigate steam EOR processes in micromodels, experiments in micromodels at elevated temperatures should provide qualitative information on the effects of temperature on important process variables. Micromodels have been successfully used to observe various displacement processes at low temperatures and pressures and to understand fluid transport mechanisms within porous media. Previous research on physical pore model studies was reviewed, and the advantages and limitations of various techniques used are discussed as well as techniques used in the design, construction, and operation of the models. Finally, the possible use of micromodels to study the fluid displacement process at high temperatures and moderate pressures, such as those commonly encountered in steamflood enhanced oil recovery projects was examined.

Resource Assessment

NIPER-119 **Design and Operation of the Three-Phase Relative Permeability Apparatus (X-Ray/Microwave System). Topical Report. National Institute for Petroleum and Energy Research. October 1986. 36 pp. NTIS Order No. DE86000306.** This work is concerned with measurements of three-phase relative permeability to improve understanding of multiphase flow behavior in porous media which will also aid in predicting hydrocarbon recovery and production rates by secondary or tertiary (EOR) methods. To measure three-phase relative permeability, capabilities are required for accurately determining fluid saturation in core samples. Since three fluid phases are involved, the measurement of the existing saturation of two of the phases is sufficient to establish the relative content of all three phases. In this report, procedures for designing and calibrating a combined x-ray and microwave absorption technique are presented. The x-ray absorption technique is used to measure oil saturation, whereas the microwave absorption technique is used to measure water saturation. By scanning the core along its length using the x-ray/microwave apparatus, the fluid distribution along the length of the core can be obtained. The saturation distribution obtained may also be used to improve the estimation of three-phase relative permeability from unsteady-state or displacement runs. The x-ray/microwave scanning table is also described. As part of the development work in this project, three-phase flow relative permeabilities were measured at steady-state condition using conventional (volumetric, gravimetric, and resistivity) techniques for fluid saturation determination and compared fluid saturation obtained by the x-ray/microwave technique.

PROCESSING AND THERMODYNAMICS

Processing

NIPER-152 **Detailed Analysis of Polar Compounds in Wilmington Gas Oil and Hydrotreated Products. Topical Report. National Institute for Petroleum and Energy Research. December 1986. 70 pp. NTIS Order No. DE87001205.** This study focused on determining the composition of the feedstock and products from hydrotreating a distillate of a representative heavy crude, Wilmington. The ultimate objective was to attain an understanding of the compound types and reaction mechanisms con-

tributing to instability, incompatibility, corrosiveness, catalyst poisoning, and other problems exhibited by some crude oil feedstocks, intermediate process streams, and final products resulting from the processing of lower quality fossil fuel feedstocks. State-of-the-art upgrading procedures have proven to be inadequate for removal of many of the chemical compound types that cause problems in the processing sequence or adversely affect the quality of the end products. These problems include process stream/product instability or incompatibility, corrosiveness, and catalyst poisoning. Before new approaches can be intelligently developed to remove the problem components, it is necessary to know what compound types are causing the observed problems.

Thermodynamics

NIPER-139 **Thermodynamic Properties of Real and Synthetic Fluid Mixtures Derived From Fossil Substances. Topical Report. National Institute for Petroleum and Energy Research. October 1986. 26 pp. NTIS Order No. DE86000307.** Methanol is one of the key low-molecular weight materials which are derived from fossil sources. In 1984, methanol ranked 18th among all chemicals produced in the United States with a total of about four million tons. Production and usage is expected to increase in the future as more is used as an additive in gasoline. The pressure-volume-temperature (PVT) properties of methanol have been studied by a number of investigators but the most important work was done by Machado and Streett on the liquid phase from 298 to 489 K, pressures to 1040 bar and on vapor and liquid by Zubarev, and by Bagdonas from 413.15 to 573.15 K and pressures to 200 bar. The present work is intended to fill in the gaps in these works and to take needed data in the vicinity of the critical point at 512.64 K. The decomposition of methanol at high temperatures has been noted often. The experiments were designed to retard decomposition by confining the sample in a quartz vessel to reduce catalyzed decomposition, by keeping the sample in the liquid phase at higher pressures whenever possible, by keeping the sample at high temperatures only long enough to make the measurements and then cooling to a lower temperature, and by taking the measurements as rapidly as possible. Some decomposition was noted at temperatures above 423.15 K and some adjustments were made to the data.

NIPER-188 **Thermochemical and Thermophysical Properties of Organic Nitrogen Compounds Found in Fossil Materials. Status Report. National Institute for Petroleum and Energy Research. November 1986. 115 pp. NTIS Order No. DE87001204.** This report is the first comprehensive compilation of thermochemical and thermophysical property data on organic nitrogen compounds present in alternate fossil fuels. Removal of these compounds during processing is necessary for the production of stable and environmentally acceptable products. Data on 24 organic nitrogen-containing compounds are reported. The data are combined to give ideal gas phase thermodynamic properties for 18 of the compounds. Statistical thermodynamic calculations for six of the compounds are given and a comparison of statistically calculated values (including those previously published) and the calorimetric values obtained from this work is made. The thermodynamic equilibrium conditions necessary for the removal of the nitrogen atom from the molecules can be determined from the results. In conclusion, future research in this area is discussed.

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PROCESSING

DOE/BETC/IC-82/4. Waste Lubricating Oil: An Annotated Review, 1982 Revision. Faye O. Cotton. October 1982. 278 pp. The 1980's have brought a deluge of information on used oil recycling dealing with numerous new processes, legislation, planned community and state programs, solutions to disposal problems (including utilization of by-products), new tests and analyses to determine quality, and new additives. To assist those interested in the waste oil situation, this bibliography of information available to the public was compiled and updated. It is not complete, as new information becomes available almost daily, but these references serve as a starting point for those who wish to update their knowledge in this area.

DOE/BC/10525-8. Mechanisms of Syncrude/Synfuel Degradation—Second Annual Report, Oct. 1, 1982-Sept. 30, 1983. Naval Research Laboratory, May 1984, 111 pp. Polar compounds have been isolated from two different shale sources by acid extraction and silica gel adsorption. The identification of the extract components was accomplished by combined gas chromatography/mass spectrometry. Accelerated storage-stability tests employing these polar extracts as dopants indicated a range of activities with respect to the promotion of insolubles formation. Extracts comprised of nitrogen bases exhibited moderate activity. The greatest activity was found for highly polar extracts.

DOE/BC/10562-5. Used Lubricating Oil Re-Refining Demonstration Plant Data Acquisition, Topical Report I: Environmental Considerations. Booth Oil Co. January 1983. 116 pp. In 1978, Booth Oil decided to design and build a new re-refining facility. This report describes the environmental laws, regulations, and other considerations that were addressed. It details the work performed in assessing the theoretical and actual air emissions from the facility and describes the plant's wastewater treatment system.

Enhanced Oil Recovery—Chemical

DOE/SF/01424-45. Big Muddy Field Low-Tension Flood Demonstration Project, Fourth Annual Report, April 1981–March 1982. Conoco, Inc. September 1982. 124 pp. The goal of this project is to provide data for commercialization of the process for the Big Muddy Field and similar Wyoming and Colorado fields. During 1981, about two-thirds of the low-tension slug was injected. The effect of the slug on oil production was noted by August 1981, after only a few months of continuous injection. By the end of the year, the oil cut had increased from 0.6% to more than 2%. Injection rates were less than predicted. The viscosity of the slug was reduced from 20 to 14 centipoise in an attempt to improve injectivity. Laboratory studies showed that the reduced viscosity should still give adequate mobility control without reducing oil recovery. Following the viscosity reduction, the injection rate continued to decline from about 65,000 barrels per month to about 50,000 barrels per month by the end of 1981.

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