# PUBLICATIONS LIST 73

**Bartlesville Project Office**

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*DOE/BC–94/1/SP*

*October-December 1993*

*DATE PUBLISHED–JANUARY 1994*


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### *Quarterly Reports*

**DOE/BC–93/1** **Contracts for Field Projects and Supporting Research on Enhanced Oil Recovery. Progress Review No. 73. Quarter ending December 1992. December 1993. 144 pp. Order No. DE93000136.** Status reports are given for various enhanced oil recovery 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, geoscience technology, microbial technology, field demonstrations in high-priority reservoir classes, novel technology, and environmental technology.

### *General Research*

**NIPER–691** **1992 Annual Report. October 1, 1991-September 30, 1992. National Institute for Petroleum and Energy Research. October 1993. 104 pp. Order No. DE94000103.** This report covers the second full year of research by the National Institute for Petroleum and Energy Research (NIPER) under the DOE's National Energy Strategy-Advanced Oil Recovery Program Implementation Plan. The Plan outlines an intergrated, highly targeted research, development, and demonstration program focusing on near-, mid-, and long-term objectives to maximize the economic producibility of the domestic oil and gas resource and to assure that new and advanced recovery technologies are implemented in the field within the earliest possible time frame. NIPER also performs research for the DOE Advanced Extraction and Processing Technology (AEPT) Program to develop crosscutting tools, techniques, and scientific/technical understanding in both extraction and conversion/upgrading technologies which can be applied to a broad range of petroleum resources. NIPER performs exploratory research to identify and test novel concepts, and fundamental applied research to develop and apply improved technical and scientific understanding to the solution of generic problems. The report covers research accomplishments, publications, and presentations resulting from the FY92 research conducted under 14 Base Program projects, 11 of which were funded under DOE's Light Oil and Heavy Oil Programs, and three funded under the AEPT Program.

### *Chemical Flooding*

**NIPER–698** **NIPER/DOE Chemical EOR Workshop. Final Report. National Institute for Petroleum and Energy Research. October 1993. 96 pp. Order No. DE93000173.** The subject of this report is the Chemical EOR Workshop held on June 23-24, 1993, in Houston, Texas. The objectives of this workshop were to evaluate the potential for chemical enhanced oil recovery (EOR) to recover significant quantities of remaining domestic oil, to assess the role of the DOE and petroleum industry to achieve this potential, and to assess the research needs in chemical EOR. Fifty-six research engineers and scientists from major oil companies, independent oil companies, academic institutes, research institutes, and DOE attended this workshop. Ten papers on the state-of-the-art in chemical EOR technologies and recent field test experience were presented on the first day. Two workshops, one on surfactant/alkali flooding and the other on profile modification/polymer flooding, were held on the second day. It was concluded that chemical EOR has the potential of recovering significant quantities of remaining oil, and it is the only method that has the potential of economically recovering residual oil from reservoirs of shallow and medium depth.

**NIPER–705** **User's Guide and Documentation Manual for "PC-Gel" Simulator. Topical Report. National Institute for Petroleum and Energy Research. October 1993. 196 pp. Order No. DE94000104.** PC-Gel is a three-dimensional, three-phase (oil, water, and gas) permeability modification simulator developed by incorporating an in situ gelation model into a black oil simulator (BOAST) for personal computer application. The features included in the simulator are transport of each chemical species of the polymer/crosslinker system in porous media, gelation reaction kinetics of the polymer with crosslinking agents, rheology of the polymer and gel, inaccessible pore volume to macromolecules, adsorption of chemical species on rock surfaces, retention of gel on the rock matrix, and permeability reduction caused by the adsorption of polymer and gel. The in situ gelation model and simulator were validated against data reported in the literature. The simulator PC-GEL is useful for simulating and optimizing any combination of primary production, waterflooding, polymer flooding, and permeability modification treatment.

**NIPER–710** **Screening of Mixed Surfactant Systems: Phase Behavior Studies and CT Imaging of Surfactant-Enhanced Oil Recovery Experiments. Topical Report. National Institute for Petroleum and Energy Research. November 1993. 128 pp. Order No. DE94000105.** A systematic chemical screening study was conducted on selected anionic-nonionic and nonionic-nonionic systems. The objective of this study was to evaluate and determine combinations of these surfactants that would exhibit favorable phase behavior and solubilization capacity. The effects of different parameters, including (a) salinity, (b) temperature, (c) alkane carbon number, (d) HLB of nonionic component, and (e) type of surfactant, on the behavior of the overall chemical system were evaluated. The current work was conducted using a series of ethoxylated nonionic surfactants in combinations of several anionic systems with various hydrocarbons. Efforts to correlate the behavior of these mixed systems led to the development of several models for the chemical systems tested. The models were used to compare the different systems and provided some guidelines for formulating them to account for variations in salinity, oil hydrocarbon number, and temperature. The models were also evaluated to determine conformance with the results from experimental measurements. The models provided good agreement with experimental results.

**DOE/BC/14880–5** **Improved Techniques for Fluid Diversion in Oil Recovery. First Annual Report. New Mexico Institute of Mining and Technology. December 1993. 284 pp. Order No. DE94000113.** This report describes work performed during the first year of the project, "Improved Techniques for Fluid Diversion in Oil Recovery." This three-year project has two objectives: (1) to compare the effectiveness of gels in fluid diversion with those of other types of processes, and (2) to identify the mechanisms by which materials (particularly gels) selectively reduce permeability to water more than to oil. To establish a baseline for the applicability of gel treatments, previously published field results were examined to determine if they reveal usable guidelines for the selection of candidates for gel treatments. Views of seven gel vendors and experts from eight major oil companies were also surveyed concerning the selection and implementation of gel treatments. After analyzing the literature and the survey responses, criteria were proposed for candidate selection, both for injection wells and production wells.

**NIPER–714** **Surfactant-Enhanced Alkaline Flooding Field Project. Annual Report. National Institute for Petroleum and Energy Research. December 1993. 36 pp. Order No. DE94000111.** The Tucker sand from Hepler field, Crawford County, Kansas, was characterized using routine and advanced analytical methods. The characterization is part of a chemical flooding pilot test to be conducted in the field, which is classified as a DOE Class I (fluvial-dominated deltaic) reservoir. Routine and advanced methods of characterization were compared. Traditional wireline logs indicate that the reservoir is vertically compartmentalized on the foot scale. Routine core analysis, X-ray computed tomography (CT), minipermeameter measurement, and petrographic analysis indicate that compartmentalization and lamination extend to the microscale. An idealized model of how the reservoir is probably structured (complex layering with small compartments) is presented.

*Thermal Recovery*

**DOE/BC/93000174** **Fundamentals of Foam Transport in Porous Media. Topical Report. University of California, Berkeley. October 1993. 76 pp. Order No. DE93000174.** Foam in porous media is a fascinating fluid both because of its unique microstructure and dramatic influence on the flow of gas and liquid. A wealth of information is now compiled in the literature describing foam generation, destruction, and transport mechanisms. Yet there are conflicting views of these mechanisms and on the macroscopic results they produce. By critically reviewing how surfactant formulation and porous media topology conspire to control foam texture and flow resistance, an attempt is made to unify the disparate viewpoints. Evolution of texture during foam displacement is quantified by a population balance on bubble concentration, which is designed specifically for convenient incorporation into a standard reservoir simulator. Theories for the dominant bubble generation and coalescence mechanisms provide physically based rate expressions for the proposed population balance. Stone-type relative permeability functions along with the texture-sensitive and shear-thinning nature of confined foam complete the model. Quite good agreement is found between theory and new experiments for transient foam displacement in linear cores.

**DOE/BC/14899–8** **Drawdown Behavior of Gravity Drainage Wells. SUPRI TR 97. Stanford University Petroleum Research Institute. October 1993. 84 pp. Order No. DE93000175.** An analytical solution for drawdown in gravity drainage wells is developed. The free-surface flow is viewed as incompressible, and anisotropy effects are included. The well is a line source well, and the reservoir is infinitely large. The model is valid for small drawdowns. The uniform wellbore potential inner boundary condition is modelled using the proper Green's function. The discontinuity at the wellbore is solved by introducing a finite skin radius, and the formulation produces a seepage face. The calculated wellbore flux distribution and wellbore pressures are in fair agreement with results obtained using a numerical gravity drainage simulator. Three distinct flow periods are observed. The wellbore storage period is caused by the moving liquid level, and the duration is short. During the long intermediate flow period, the wellbore pressure is nearly constant. In this period the free surface moves downwards, and the liquid is produced mainly by vertical drainage. At long times the semilog straight line appears. The confined liquid solutions by Theis (1935) and van Everdingen and Hurst (1949) may be used during the pseudoradial flow period if the flowrate is low. New type curves are presented that yield both vertical and horizontal permeabilities.

**DOE/BC/94000102** **A Growing-Drop Technique for Measuring Dynamic Interfacial Tension. Topical Report. University of California, Berkeley. October 1993. 52 pp. Order No. DE94000102.** A novel, growing-drop technique is described for measuring dynamic interfacial tension as a result of sorption of surface-active solutes. The proposed method relates the instantaneous pressure and size of expanding liquid drops to interfacial tension and is useful for measuring both liquid/gas and liquid/liquid tensions over a wide range of time scales, currently from 10 ms to several hours. Growing-drop measurements on surfactant-free water/air and water/octanol interfaces yield constant tensions equal to their known literature values. For surfactant-laden, liquid drops, the growing-drop technique captures the actual transient tension evolution of a single interface, rather than interval times as with the classic maximum-drop-pressure and drop-volume tension measurements. Dynamic tensions measured for 0.25 mM aqueous 1-decanol solution/air and 0.02 $kg/m_3$ aqueous Triton X-100 solution/dodecane interfaces show nonmonotonic behavior, indicating slow surfactant transport relative to the imposed rates of interfacial dilation. The dynamic tension of a purified and fresh 6 mM aqueous sodium dodecyl sulfate (SDS) solution/air interface shows only a monotonic decrease, indicating rapid surfactant transport relative to the imposed rates of dilatation. Conversely, an aged SDS solution, naturally containing trace dodecanol impurities, exhibits dynamic tensions which reflect a superposition of the rapidly equilibrating SDS and the slowly adsorbing dodecanol.

**NIPER–722** **Thermal Process for Heavy Oil Recovery. Topical Report. National Institute for Petroleum and Energy Research. November 1993. 76 pp. Order No. DE94000109.** This report summarizes research acitivites conducted in FY93. A major portion of project research during the year was concentrated on modeling and reservoir studies to determine the applicability of steam injection oil recovery techniques in Texas Gulf Coast heavy oil reservoirs. In addition, an in-depth evaluation of a steamflood predictive model developed by Mobil Exploration and Production Company (Mobil E&P) was performed. Details of these two studies are presented. A topical report (NIPER–675) assessing the NIPER Thermal EOR Research Program the past 10 years was written during the fiscal year and delivered to DOE. Results of the Gulf Coast heavy oil reservoir simulation studies indicated that though these reservoirs can be successfully steamflooded and could recover more than 50% of oil-in-place, steamflooding may not be economical at current heavy oil prices. Assessment of Mobil E&P's steamflood predictive model capabilities indicate that the model in its present form gives reasonably good predictions of California steam projects, but fails to predict adequately the performance of non-California steam projects.

**NIPER–661** **Feasibility of Steam Injection Process in a Thin, Low-Permeability Heavy Oil Reservoir of Arkansas — A Numerical Simulation Study. Topical Report. National Institute for Petroleum and Energy Research. December 1993. 112 pp. Order No. DE94000112.** This report details the findings of an in-depth study undertaken to assess the viability of the steam injection process in the heavy oil bearing Nacatoch sands of Arkansas. Published screening criteria and DOE's steamflood predictive models were utilized to screen and select reservoirs for further scrutiny. Although, several prospects satisfied the steam injection screening criteria, only a single candidate was selected for detailed simulation studies. The selection was based on the availability of needed data for simulation and uniqueness of the reservoir. The reservoir investigated is a shallow, thin, low-permeability reservoir with low initial oil saturation and an underlying water sand. The study showed that the reservoir will respond favorably to steamdrive, but not to cyclic steaming. Steam stimulation, however, is necessary to improve steam injectivity during subsequent steamdrive. Further, in such marginal heavy oil reservoirs (i.e., reservoir characterized by thin pay zone and low initial oil

saturation) conventional steamdrive (i.e., steam injection using vertical wells) is unlikely to be economical, and nonconventional methods must be utilized. It was found that the use of horizontal injectors and horizontal producers significantly improved the recovery and oil-steam ratio and improved the economics. It is recommended that the applicability of horizontal steam injection technology in this reservoir be further investigated.

*Geoscience*

**NIPER–713** **Field Guide to Muddy Formation Outcrops, Crook County, Wyoming. Topical Report. National Institute for Petroleum and Energy Research. November 1993. 116 pp. Order No. DE94000106.** The purpose of this report and a similar report containing Almond Formation outcrop data is to provide the data and analyses generated from this research project so that other workers may use and build upon it. The objectives of this research program are to (1) determine the reservoir characteristics and production problems of shoreline barrier reservoirs; and (2) develop methods and methodologies to effectively characterize shoreline barrier reservoirs to predict flow patterns of injected and produced fluids. Two reservoirs were selected for detailed reservoir characterization studies — Bell Creek field, Carter County, Montana that produced from the Lower Cretaceous (Albian-Cenomanian) Muddy Formation, and Patrick Formation of the Mesaverde Group. An important component of the research project was to use information from outcrop exposures of the producing formations to study the spatial variations of reservoir properties and the degree to which outcrop information can be used in the construction of reservoir models. This report contains the data and analyses collected from outcrop exposures of the Muddy Formation, located in Crook County, Wyoming 40 miles south of Bell Creek oil field. The outcrop data set contains, permeability, porosity, petrographic, grain size and geologic data from 1-inch-diameter core plugs drilled from the outcrop face, as well as geological descriptions and sedimentological interpretations of the outcrop exposures. The outcrop data set provides information about facies characteristics and geometries and the spatial distribution of permeability and porosity on interwell scales. Appendices within this report include a micropaleontological analyses of selected outcrop samples, an annotated bibliography of papers on the Muddy Formation in the Powder River Basin, and over 950 permeability and porosity values measured from 1-inch-diameter core plugs drilled from the outcrop. All data contained in this report are available in electronic format upon request. The core plugs drilled from the outcrop are available for measurement.

**NIPER–712** **Reservoir Condition Special Core Analyses and Relative Permeability Measurements on Almond Formation and Fontainebleu Sandstone Rocks. Topical Report. National Institute for Petroleum and Energy Research. November 1993. 32 pp. Order No. DE94000107.** This report describes the results from special core analyses and relative permeability measurements conducted on Almond formation and Fontainebleu sandstone plugs. Almond formation plug tests were performed to evaluate multiphase, steady-state, reservoir-condition relative permeability measurement techniques and to examine the effect of temperature on relative permeability characteristics. The Fontainebleu sandstone was selected for tests because of its uniformity and 100-mD permeability range. In addition to rock tests, a fluid system consisting of propane and 1-bromopropane was designed and evaluated for tests simulating condensate deposition. In condensate systems, liquid and gas phase volumes within the rock are pressure and temperature sensitive. Insufficient time was available to use the fluid in flow tests. Progress was made toward using the PC version of the BOAST simulator, DOE's black oil reservoir simulator, for coreflood history matching. The simulator may be very useful in determining rock relative permeability functions from reservoir-rate displacement tests while accounting for capillary effects.

**NIPER–720** **Investigation of Wettability by NMR Microscopy and Spin-Lattice Relaxation. Topical Report. National Institute for Petroleum and Energy Research. November 1993. 16 pp. Order No. DE94000108.** The wettability of reservoir rock has an important impact on the efficiency of oil recovery processes and the distribution of oil and water within the reservoir. One of the potentially useful tools for wettability measurements is nuclear magnetic resonance (NMR) and spin-lattice relaxation. More recently, using NMR microscopy, NIPER has developed the capability of imaging one- and two-phase fluid systems in reservoir rock at resolutions to 25 microns. Effects seen in the images of fluids within the pore space of rocks near the rock grain surfaces hinted at the possibility of using NMR microscopy to map the wettability variations at grain sites within the pore space. Investigations were begun using NMR microscopy and spin-lattice relaxation time measurements on rock/fluid systems and on well-defined fractional wet model systems to study these effects. Relaxation data has been modelled using the stretched exponential relationship recently introduced. Comparisons of the NMR microscopy results of the model system with the rock results indicate that the observed effects probably do not reflect actual wettability variations within the pore space. The results of the relaxation time measurements reveal that even in the simple model studies, the behavior of two phases is somewhat ambiguous and much more complex and requires more study.

**NIPER–724** **Data from Selected Almond Formation Outcrops — Sweetwater County, Wyoming. Topical Report. National Institute for Petroleum and Energy Research. December 1993. 76 pp. Order No. DE94000110.** The objectives of this research program are to: (1) determine the reservoir characteristics and production problems of shoreline barrier reservoirs; and (2) develop methods and methodologies to effectively characterize shoreline barrier reservoirs to predict flow patterns of injected and produced fluids. Two reservoirs were selected for detailed reservoir characterization studies — Bell Creek field, Carter County, Montana, that produces from the Lower Cretaceous (Albian-Cenomanian) Muddy Formation, and Patrick Draw field, Sweetwater County, Wyoming, that produces from the Upper Cretaceous (Campanian) Almond Formation of the Mesaverde Group. An important component of the research project was to use information from outcrop exposures of the producing formations to study the spatial variations of reservoir properties and the degree to which outcrop information can be used in the construction of reservoir models. A report similar to this one presents the Muddy Formation outcrop data and analyses performed in the course of the study. Two outcrop localities, RG and RH, previously described by Roehler (1988) provided good exposures of the Upper Almond shoreline barrier facies and were studied during 1990-1991. Core from core well No. 2 drilled approximately 0.3 miles downdip of outcrop RG was obtained for study. The results of the core study will be reported in a separate volume. Outcrops RH and RG, located about 2 miles apart were selected for detailed description and drilling of core plugs. One 257-ft thick section was measured at outcrop RG, and three sections 145 ft thick located 490 and 655 ft apart were measured at the outcrop RH. Cross-sections of these profiles were constructed to determine lateral facies continuity and changes. This report contains the data and analyses from the outcrops. The outcrop data set includes 4 measured sections and descriptions of outcrop exposures; grain-size distribution data from image analysis of 30 thin section; permeability and porosity measurements from 25 1-inch diameter coreplugs drilled from the face of the outcrops; and 923 fracture azimuths measured from the outcrop face. This data is available in electronic format from the Department of Energy, Bartlesville Project Office.

**BNL 47046** **Effects of Selected Thermophilic Microorganisms on Crude Oils at Elevated Temperatures and Pressures. 1991 Annual Report. Brookhaven National Laboratory. October 1993. 32 pp. Order No. DE93000172.** During the past several years, a considerable amount of work has been carried out showing that microbial enhanced oil recovery (MEOR) is promising and the resulting biotechnology may be deliverable. In this laboratory systematic studies are being conducted which deal with the effects of thermophilic and thermoadapted bacteria on the chemical and physical properties of selected types of crude oils at elevated temperatures and pressures. Particular attention is being paid to heavy crude oils such as Boscan and Cerro Negro (Venezuela), Monterey (California) and those from Alabama and Arkansas. Current studies indicate that during the biotreatment several properties of crude oils are affected. The oils are (1) emulsified; (2) acidified; (3) there is a qualitative and quantitative change in light and heavy fractions of the crudes; (4) there are chemical changes in fractions containing sulfur compounds; (5)

there is an apparent solubilization of trace metals; and (6) the qualitative and quantitative chemical and physical changes appear to be microbial species dependent. Effects on heavy crude oils are also compared to those on lighter oils such as oils from the Wyoming petroleum reserve. Microbial oil interactions are monitored routinely by a consortium of analytical techniques which are continuously upgraded and are capable of multiparameter analysis. The results generated in fiscal year 1991, describing (1) through (6), are presented and discussed in this report.

**NIPER–703** **User's Guide and Documentation Manual for Microbial Transport Simulator. Topical Report. National Institute for Petroleum and Energy Research. October 1993. 76 pp. Order No. DE94000101.** The microbial transport simulator (MTS) is a three-dimensional, three-phase, multiple-component numerical model that permits the study of the transport of microorganisms and nutrients in porous media. Microbial parameters incorporated into MTS include: microbial growth and decay, microbial deposition, chemotaxis, diffusion, convective dispersion, tumbling, and nutrient consumption. Governing equations for microbial and nutrient transport are coupled with continuity and flow equations under conditions appropriate for a black oil reservoir. The model's mathematical formulations and preparation procedures of data files for conducting simulations using MTS are described.

**DOE/BC/14663–11** **New Microorganisms and Processes for MEOR. Final Report. INJECTECH, Inc. December 1993. 48 pp. Order No. DE94000114.** Oil reservoirs naturally contain inorganic and organic materials which may be exploited through simple mineral supplementation to support the growth of denitrifying microorganisms. The growth and metabolic products from the presence of these microorganisms will aid in the release of oil from the rock matrix and improve crude oil quality and oil field operations. These studies have been successful in defining new microorganisms and processes for MEOR. Materials which may serve as nutritional sources for microorganisms are present in the connate or flood waters or may be added to reservoirs during drilling and production operations of oil fields. These materials include sulfate, carbonate, volatile fatty acids, nitrogen-containing corrosion inhibitors, phosphorous-containing scale inhibitors and trace elements. The experiments show that, with simple minimal mineral supplementation to the flood waters, the increased growth of naturally-occurring microorganisms can contribute to the enhancement of oil recovery and are important aspects of many EOR technologies. Sulfate reducing bacteria (SRB), heterotrophic denitrifying bacteria, and denitrifying *Thiobacillus* species were successfully isolated from oil field waters. The SRB and *Thiobacillus* cultures, as a consortium, can utilize the volatile fatty acids and dissolved carbonates found in these waters and formations. These cultures were shown to feed each other sequentially and survive in mixed cultures. In a reservoir environment, these types of organisms are limited because of the development of an additional microflora containing heterotrophic denitrifying bacteria.

*Fundamental Petroleum Chemistry*

**NIPER–531** **Microcarbon Residue Yield and Heteroatom Partitioning Between Volatiles and Solids for Whole Vacuum Resids and Their Liquid Chromatographic Fractions. Topical Report. National Institute for Petroleum and Energy Research. October 1993. 40 pp. Order No. DE93000171.** Five petroleum resids >1000° F were separated into compound type fractions using liquid chromatography. The coking tendency of each compound type was assessed using the micro-carbon residue (MCR) test (ASTM D 4530). Heteroatom (N, S, Ni, V) partitioning between MCR solids versus volatiles was determined through analysis of the starting fractions and the corresponding MCR solids. The weighted sum of MCR solid yields over all compound types in a given resid was typically in good agreement with the MCR yield of the whole resid. This finding agrees with prior studies indicating coke yield to be an additive property. Sulfur partitioning was also an additive property, was predictable from MCR yield, and was nearly independent of the initial form (sulfide, thiophenic, sulfoxide) present. Nitrogen and nickel partitioning were nonadditive and therefore composition dependent. Partitioning of vanadium into solids was essentially quantitative for all resids and their fractions. MCR solid yield was generally dependent only on H/C ratio. However, there is some evidence indicating secondary dependence on hydrocarbon structure; i.e., that naphthenic rings reduce MCR in proportion to H/C by virtue of their effective hydrogen transfer properties. Deposition of N and Ni into MCR solids over the fractions was often appreciably less than that of the whole resids, thereby indicating that interaction among various compound types was required for maximum incorporation of those elements into coke.

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