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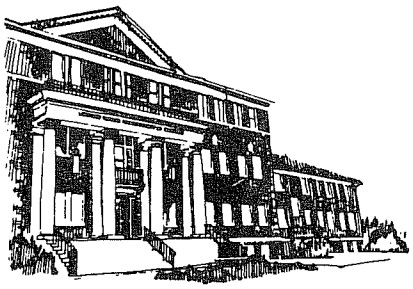

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PREFACE

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Contents

PUBLICATIONS LIST 62

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Quarterly Reports

DOE/BC–90/2 **Activities of the Oil Implementation Task Force. Reporting Period September-November 1990. Contracts for Field Projects and Supporting Research on Enhanced Oil Recovery. Progress Review No. 62. Quarter ending March 31, 1990. Order No. DE90000262.** In Section I, the first report of the Oil Implementation Task Force is summarized. The introduction explains the shift in program direction and the reservoir classification system. Further discussion includes the Tertiary Oil Recovery Information System; field research, development and demonstration, and research support – the characterization of Class 1 reservoirs. In Section II, 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, novel technology, and environmental technology.

Chemical Flooding

NIPER–466 **Critical Factors in the Design of Cost-Effective Alkaline Flooding. Topical Report. National Institute for Petroleum and Energy Research. February 1991. 20 pp. Order No. 91002224.** A review of major alkaline flooding projects highlights the recognized fact that alkali consumption and scale formation are serious deterrents when strong alkalis are used. The review also confirms that there are several mechanisms of oil mobilization besides reducing interfacial tension. Even oils of low acid number may be amenable to alkaline flooding. Moreover, alkalis in a lower pH range – which have minimal reaction with reservoir minerals – can often mobilize oil, especially when enhanced with a low concentration of surfactant. However, the future of alkaline flooding depends critically on improved reservoir analysis, which includes factors that have often been neglected: (1) thorough mineralogical analysis; (2) evaluation of ion-exchange properties; and (3) assessment of carbon dioxide content.

NIPER–488 **Effects of Degree of Hydrolysis and Shear on Gelation Reaction Kinetics and Gel Strength. Topical Report. National Institute for Petroleum and Energy Research. February 1991. 24 pp. Order No. DE91002225.** Gelation tests were conducted to investigate the effect of the degree of hydrolysis on gelation reaction kinetics and gel strength using four low-molecular-weight polyacrylamides (MW = 400,000 daltons), which were 10% (HPAM1-10), 20% (HPAM1-20), 30% (HPAM1-30), and 40% (HPAM1-40) hydrolyzed, and Cr(III) (pH=4.8) and A1(III) (pH=7.0) crosslinkers. Results showed that for polymer/Cr(III) gel systems, samples prepared with a low-molecular-weight polyacrylamide polymer, which was 20% hydrolyzed, gelled at a faster rate and retained higher gel strength than those prepared with a low-molecular-weight polyacrylamide polymer, which was 10% hydrolyzed. Under the screening conditions, no viscosity enhancement was observed in samples prepared with polymers having a degree of hydrolysis equal to or greater than 30%. For polymer/A1(III) gel systems, samples prepared with a low-molecular-weight polyacrylamide polymer, which was 20% hydrolyzed, gelled at the fastest rate and retained the strongest gel strength among the polymer/A1(III) gel systems prepared with four low-molecular weight polyacrylamide polymers, which were 10, 20, 30, and 40% hydrolyzed, respectively. Gelation tests of gel systems in glass bead packs showed that high shear favored the gelation of a gel system that had a fast rate of gelation, but had an adverse effect on the gelation of three gel systems that had a slow rate of gelation. Weak gels were found to be injectable through porous media. Weak gels were degradable under high shear condition and regained viscosity under low shear conditions.

NIPER–498 **Modeling of Asphaltene and Wax Precipitation. Topical Report. National Institute for Petroleum and Energy Research. January 1991. 48 pp. Order No. DE91002217.** Organic deposition has been shown to be a major problem associated with oil recovery by gas flooding. Industry is looking for ways of controlling organic deposition and economic methods that can remedy the problem. A predictive technique is crucial to the solution of this problem, and this research project was designed to focus on the development of a predictive technique. A thermodynamic model has been developed to describe the effects of temperature, pressure, and composition on asphaltene precipitation. The model employs a polymer solution theory for asphaltene-oil solution and treated asphaltene as a polydispersed medium. The proposed model combines regular solution theory with Flory-Huggins polymer solutions theory to predict maximum volume fractions of asphaltene dissolved in oil. The model requires evaluation of vapor-liquid equilibria, first using an equation of state followed by calculations of asphaltene solubility in the liquid-phase. A state-of-the-art technique for C_7+ fraction characterization was employed in developing this model. The preliminary model developed in this work was able to predict qualitatively the trends of the effects of temperature, pressure, and composition. Since the mechanism of paraffinic wax deposition is different from that of asphaltene deposition, another thermodynamic model based on the solid-liquid solution theory was developed to predict the wax formation. This model is simple and can predict the wax appearance temperature with reasonable accuracy. In addition to the modeling work, experimental studies were conducted to investigate the solubility of asphaltene in oil and solvents and to examine the effects of oil composition, CO_2, and solvent on asphaltene precipitation and its properties. This research focused on the solubility reversibility of asphaltene in oil and the precipitation caused by CO_2 injection at simulated reservoir temperature and pressure conditions. These experiments have provided many observations about the properties of asphaltenes for further improvement of the model, but more detailed information about the proper-

ties of asphaltenes in solution is needed for the development of more reliable asphaltene characterization techniques.

NIPER–506 The Effect of Alkaline Additives on the Performance of Surfactant Systems Designed to Recover Light Oils. Topical Report. National Institute for Petroleum and Energy Research. February 1991. 52 pp. Order No. DE91002226. Surfactant flooding is flexible because of the ability to optimize formulations for a wide range of reservoir conditions and crude oil types. The objective for this work was to determine if the addition of alkaline additives will allow the design of surfactant formulations that are effective for the recovery of crude oil, while, at the same time, maintaining the surfactant concentration at a much lower level than has previously been used for micellar flooding. Specifically, the focus of the work was on light, mid-continent crudes that typically have very low acid contents. These oils are typical of much of the midcontinent resource. The positive effect of alkaline additives on the phase behavior of surfactant formulations and acidic crude oils is well known. The extension to nonacidic and slightly acidic oils is not obvious. Three crude oils, a variety of commercial surfactants, and several alkaline additives were tested. The oils had acid numbers that ranged from 0.13, which quite low, to less than 0.01 mg KOH/g of oil. Alkaline additives were found to be very effective in recovering Delaware-Childers (OK) oil at elevated temperatures, but much less effective at reservoir temperatures. Alkaline additives were very effective with Teapot Dome (WY) oil. With Teapot Dome oil, surfactant/alkali systems produced ultralow IFT values and recovered 60% of the residual oil that remained after waterflooding. The effect of alkaline additives on recovering Hepler (KS) oil was minimal. The results of this work indicate that alkaline additives do have merit for use in surfactant flooding of low acid crude oils; however, no universal statement about applicability can be made. Each oil behaves differently with this treatment, and the effect of alkaline additives must be determined (at reservoir conditions) for each oil.

NIPER–507 Surfactant-Enhanced Alkaline Flooding with Weak Alkalis. Topical Report. National Institute for Petroleum and Energy Research. February 1991. 24 pp. Order No. DE91002227. The objective of this project was to develop cost-effective and efficient chemical flooding formulations using surfactant-enhanced, lower pH (weak) alkaline chemical systems. Chemical systems were studied that mitigate the deleterious effects of divalent ions. The experiments were conducted with carbonate mixtures and carbonate/phosphate mixtures of pH 10.5, where most of the phosphate ions exist as the monohydrogen phosphate species. Orthophosphate did not further reduce the deleterious effect of divalent ions on IFT behavior in carbonate solutions, where the deleterious effect of the divalent ions is already very low. When added to a carbonate mixture, orthophosphate did substantially reduce the adsorption of an anionic surfactant, which was an unexpected result; however, there was no correlation between the amount of reduction and divalent ion levels. For acidic oils, a variety of surfactants are available commercially that have potential for use between pH 8.3 and pH 9.5. Several of these surfactants were tested with oil from Wilmington (CA) field and found to be suitable for use in that field. Two low-acid crude oils, with acid numbers of 0.01 and 0.27 mg KOH/g of oil, were studied. It was shown that surfactant-enhanced alkaline flooding does have merit for use with these low-acid crude oils. However, each low-acid oil tested was found to behave differently, and it was concluded that the applicability of the method must be experimentally determined for any given low-acid crude oil.

DOE/BC/14432–5 Interactions of Structurally Modified Surfactants With Reservoir Minerals: Calorimetric, Spectroscopic and Electrokinetic Study. Final Report. Columbia University. March 1991. 44 pp. Order No. DE91002228. The goal of this project was to develop an understanding of the adsorption of structurally modified surfactants and their interactions in the bulk and at the solid/liquid interface. A multi-pronged approach consisting of surface tensiometry, adsorption determination, microcalorimetry and electrokinetics measurement was used in this project to elucidate the effect of surfactant structure, specifically the effect of the position of sulfonate and methyl groups on the aromatic ring of alkyl xylene sulfonates on their adsorption. The study revealed that small changes in the position of the above functional groups have marked effect on their adsorption behavior; particularly the position of sulfonate relative to the methyl groups was found to play an important role. Microcalorimetric studies showed that hemimicellization of the surfactants was entropy driven and that the difference in the adsorption of the surfactants was because of differences in the steric hindrance to the packing of the molecules in the aggregates. The electrokinetic effects of the surfactants was investigated by measuring changes in the zeta potential of the mineral as a result of the surfactant adsorption and the studies indicated that the charge characteristics of the surfactants were not affected by the change in the position of the functional groups.

Thermal Recovery Processes

DOE/BC/14600–3 Large Scale Averaging of Drainage at Local Capillary Control. Topical Report. University of Southern California. February 1991. 44 pp. Order No. DE91002221. Large scale averaging is important for the description of displacement processes in heterogeneous porous media. For immiscible displacement, key objective is the determination of effective (psuedo) capillary pressure and phase permeabilities. Present continuum models rely on volume averaging and homogenization methods, typically under the premise of capillary control. However, such methods are intrinsically unable to provide the local saturation distribution, which is needed for the computation of effective flow properties. In this paper, paralleling pore-level approaches, a percolation method is proposed for the derivation of large scale properties in a drainage process at low flow rates. Percolation concepts are applied to a macroscopically heterogeneous region with a random and uncorrelated permeability distribution. Appropriate modifications of ordinary and invasion percolation, and percolation with trapping are developed for the determination of the large scale averages. Analytical results are also presented for certain simple cases. At conditions of local capillary control, when a local description is possible, the large scale capillary pressure curve is a non-trivial average of the individual curves. Large scale capillary trapping is predicted and a corresponding large scale trapped saturation is calculated. Large scale phase permeabilities are also derived. It is found that capillary heterogeneity renders a system more strongly wet in a macroscopic sense.

DOE/BC/14201–5 Development of Methods for Controlling Premature Oxygen Breakthrough During Fireflooding. Final Report for the Period June 1, 1989 through October 1, 1990. Union Carbide Industrial Gases Inc. February 1991. 104 pp. Order No. DE91002220. The overall objective of this study was to characterize the reservoir mechanisms that cause premature oxygen breakthrough, and develop practical tools for controlling it. The focus was on those conditions most likely to be encountered in moderate-depth to deep reservoirs; candidates included gas override, high-permeability streaks, and water underlie. Mitigation measures were selected based on due consideration of the cost of implementing them and their potential application to a wide range of specific problems. An overriding consideration was practicality for field use.

DOE/BC/91002214 Injection Monitoring with Seismic Arrays and Adaptive Noise Cancellation. Final Report. Lawrence Livermore National Laboratory. January 1991. 32 pp. Order No. 91002214. This report describes the results of a short field experiment conducted to test both the application of seismic arrays for in-situ reservoir stimulation monitoring and the active noise cancellation technique in a real reservoir production environment. Although successful application of these techniques to in-situ reservoir stimulation monitoring would have the greatest payoff in the oil industry, the proof-of-concept field experiment site was chosen to be the Geysers geothermal field in northern California. This site was chosen because of known high seismicity rates, a relatively shallow production depth, cooperation and some cost sharing with the UNOCAL Oil Corporation, and the close proximity of the site of LLNL. The body of this report describes the Geyser field experiment configuration, then discusses the results of the sesmic array processing and the results of the seismic noise cancellation.

Gas Displacement Technology

DOE/BC–91/2/SP **Miscible Applied Simulation Techniques for Energy Recovery – Version 2.0. User's Guide and Technical Manual. Morgantown Energy Technology Center. February 1991. 192 pp. Order No. 91002222.** MASTER was developed on a Digital Computer System (VAX 8650) and was written in standard FORTRAN 77. The simulator should run with minor or no modification on machines designed to handle standard FORTRAN 77. The User's Guide serves as a manual for users of the multicomponent, pseudomiscible simulator, MASTER. In Section 2, "Model Overview," the development history of MASTER and the type of problems that can be simulated are discussed. In Section 3, "Data Preparation and Description," the required format for the input file is shown, while in Section 4, "Interpretation of Model Output," various output formats are shown. In Section 5, "Conventional Model Features," and in Section 6, "Special Model Features," certain options and calculations in the code that the user should know to make the correct choice of variable values and options are discussed. Lastly, Section 7, "Example Problems" validation runs and examples of correct input and output files are presented. The information contained in this manual should be sufficient for the user to complete a successful simulation run with MASTER. The technical manual is divided into six parts. The first section discusses the relation of pseudomiscible simulators to black-oil simulators. The second presents the partial differential equations solved by MASTER and explains the discretization technique. The third section discusses the implicit-in-pressure, explicit-in-saturation (IMPES) solution technique in general terms, and the fourth and fifth sections discuss the IMPES technique as it is applied to saturated and undersaturated blocks, respectively. The sixth section contains closing comments about the simulator. Appendix A discusses calculation of fluid properties and Appendix B discusses the operation of well models in MASTER.

Fundamental Petroleum Chemistry

NIPER-509 **The Thermodynamic Properties of 2, 3-Benzothiophene. Topical Report. National Institute for Petroleum and Energy Research. January 1991. 48 pp. Order No. DE91002218.** Measurements leading to the calculation of the ideal-gas thermodynamic properties for 2,3-benzothiophene are reported. Experimental methods included adiabatic heat-capacity calorimetry, comparative ebulliometry, inclined-piston gauge manometry, and differential-scanning calorimetry (d.s.c.). The critical temperature and critical density were determined with the d.s.c., and the critical pressure was derived. Entropies, enthalpies, and Gibbs energies of formation were derived for the ideal gas for selected temperatures between 260 K and 750 K. These values were derived by combining the reported measurements with values published previously for the enthalpy of combustion, the enthalpy of fusion, and the absolute entropy and enthalpy of the liquid at the triple-point temperature. Measured and derived quantities were compared with available literature values.

NIPER-B06807–26 **Crude Oil and Finished Fuel Storage Stability: An Annotated Review – 1990 Revision. National Institute for Petroleum and Energy Research. January 1991. 92 pp. Order No. DE91002213.** The current update of the 1983 publication is brief and concise in both the narrative discussions and the annotated bibliography. Abstracts are meant to help readers determine the relevance of specific articles. To the extent possible, complete references are provided, as they were derived from the computer printout obtained from the various databases. The lack of uniformity among the citation formatting provided from the databases has made it necessary to provide all references in upper case print while abstracts were rewritten and reworded to avoid any possible copyright infringement. References in each of the subject sections are listed chronologically, starting with the oldest and working up through 1990. Papers covering more than one subject were not relisted under other subject headings to avoid redundancy and a complex numbering system. An alphabetical senior (first) author listing with the page number(s) on which citations can be found is provided at the end of this publication for reader convenience.

Geoscience Technology

NIPER–485 **Imaging Techniques Applied to the Study of Fluids In Porous Media–Topical Report. National Institute for Petroleum and Energy Research. January 1991. 36 pp. Order No. DE91002215.** The dynamics of fluid flow and trapping phenomena in porous media was investigated using a number of rock-fluid imaging techniques. Miscible and immiscible displacement experiments in heterogeneous Berea and Shannon sandstone samples were monitored using X-ray computed tomography (CT scanning) to determine the effect of heterogeneities on fluid flow and trapping. Thin sections were cut from these sandstone samples from areas exhibiting different flow and trapping characteristics. The statistical analysis of pore and pore throat sizes in these thin sections enabled the delineation of small-scale spatial distributions of porosity and permeability. Multiphase displacement experiments were conducted with micromodels constructed using thin slabs of the sandstones. The combination of the CT scanning, thin section, and micromodel techniques enables the investigation of how variations in pore characteristics influence fluid front advancement, fluid distributions, and fluid trapping. Plugs cut from the sandstone samples were investigated using high resolution nuclear magnetic resonance imaging (NMRI). NMRI permitted the visualization of oil, water or both within individual pores. The integration of how small-scale rock heterogeneities influence fluid flow and trapping. The application of these insights will aid in the proper interpretation of relative permeability, capillary pressure, and electrical resistivity data obtained from whole core studies.

NIPER–484 **Selection and Initial Characterization of a Second Barrier Island Reservoir System and Refining of Methodology for Characterization of Shoreline Barrier Reservoirs–Topical Report. National Institute for Petroleum and Energy Research. January 1991. 180 pp. Order No. DE91002216.** Generalization of shoreline barrier reservoir characteristics is a primary objective of this project. The Upper Cretaceous Almond formation in Patrick Draw oil field, southwestern Wyoming, has been selected from 18 primary candidates for comparison with the Lower Cretaceous Muddy formation in Bell Creek field, southeastern Montana. Both oil productive reservoirs selected for broadening geological and engineering understanding of the system represent a combination of "end-member" models of shoreline barriers developed under different hydrodynamic conditions. The hydrodynamic conditions primarily involve changes in sea level and the dominant tide and wave regime of a coastline. The productive Muddy formation in Bell Creek field predominantly consists of fine-grained littoral (intertidal) and neritic (shallow marine) sandstones deposited as shoreface and foreshore facies in a shoreline barrier system, whereas the Almond formation in Patrick Draw field contains two distinct units consisting of fine- to medium-grained estuarine sandstones deposited in a tidal channel/tidal delta environment associated with migrating tidal inlets within a barrier-island coastline and some fine to very fine-grained littoral and shallow neritic sandstones. For broadening comparative aspects of these oil-productive shoreline barrier systems, geologic information on a number of well documented outcrops and several representatives of the Holocene barriers have also been collected.

Resource Assessment Technology

NIPER–513 **Applications of EOR Technology in Field Projects–1990 Update. Topical Report. National Institute for Petroleum and Energy Research. January 1991. Order No. DE91002219.** Trends in the type and number of U.S. enhanced oil recovery (EOR) projects are analyzed for the period from 1980 through 1989. The analysis is based on current literature and news media and the Department of Energy (DOE) EOR Project Data Base, which contains information on over 1,348 projects. The National Institute for Petroleum and Energy Research maintains this data base and analyzes trends in the data. The characteristics of the EOR projects are grouped by starting date and process type to identify trends in reservoir statistics and applications of process technologies. Twenty-two EOR project starts were identified for 1989 and 10 project starts for 1988. An obvious trend over

recent years has been the decline in the number of project starts since 1981 until 1988. An obvious trend over recent years has been the decline in the number of project starts since 1981 until 1988 which corresponds to the oil price decline during the period. There was a modest recovery in 1989 of project starts, which lags the modest recovery of oil prices in 1987 that was reconfirmed in 1989. During the time frame of 1980 to 1989, there has been a gradual improvement in costs of operation for EOR technology. The perceived average cost of EOR has gone down from a $30/bbl range to a low $20/bbl. These costs of operation seem to stay just at the price of oil or slightly above to result in marginal profitability. The use of polymer flooding has drastically decreased both in actual and relative numbers of project starts since the oil price drop in 1986. Production from polymer flooding is down more than 50%. Long-term plans for large, high-cost projects such as CO_2 flooding in West Texas, steamflooding in California, and hydrocarbon flooding on the North Slope have continued to be implemented. EOR process technologies have been refined to be more cost effective as shown by the continued application and rising production attributable to EOR.

Novel Recovery

DOE/BC/14458–1 The Drilling of a Horizontal Well in a Mature Oil Field. Final Report. Rougeot Oil and Gas Corporation. January 1991. 60 pp. Order No. DE91002212. This report documents the drilling of a medium radius horizontal well in the Bartlesville Sand of the Flatrock field, Osage County, Oklahoma. The report includes the rationale for selecting the particular site, the details of drilling the well, the production response, conclusions reached, and recommendations made for the future drilling of horizontal wells. Planning the well was difficult as there is very little publicly available data that provides details of horizontal drilling. The principal source of data was directional drilling vendors. The vendors projected job requirements were drastically different and somewhat contradictory. Vendor job cost estimates varied up to 300%. The well plan called for the placement of a 1,000′ horizontal wellbore at a vertical depth of 1400′. The drill target was 10′ thick and 200′ wide. The spacing of the two rows of producing wells between which the horizontal wellbore is centered is 510′. In June 1990, Rougeot drilled the horizontal well (Wilson 25) attaining 1,050′ of horizontal wellbore at a total cost of $150,532. The drilling problems that occurred were minor and are readily avoidable in the future. The well's productivity was tested with a rod pumping system before any wellbore clean-up or stimulation. The stabilized production rate after three months of production was 6 barrels of oil per day and 0.84 barrels of water per day, providing a very low water cut for this field. This level of oil production is 200 to 600% greater than a typical unstimulated vertical well. The production data for the well indicates that with wellbore clean-up/stimulation and increased wellbore length, future horizontal drilling in the Flatrock field could be economically viable.

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Quarterly Reports

DOE/BC–90/3 **Activities of the Oil Implementation Task Force. Reporting Period December 1990-February 1991. Contracts for Field Projects and Supporting Research on Enhanced Oil Recovery. Progress Review No. 63. Quarter ending June 30, 1990. Order No. DE91002206.** In Section I, discussion continues of efforts to characterize Class 1 reservoirs. Data is being collected, refined, and analyzed to provide criteria for ranking and selection of reservoir classes. In Section II, status reports are given for various enhanced oil recovery and gas recovery projects sponsored by 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, novel technology, and environmental technology.

General Research

DOE/BC–91/6/SP **Opportunities to Improve Oil Productivity in Unstructured Deltaic Reservoirs, Technical Summary and Proceedings of the Technical Symposium. U.S. Department of Energy, Office of Fossil Energy. June 1991. 168 pp. Order No. 91002237.** The symposium was the first in a series of events planned by the Department's Oil Implementation Task Force, under the National Energy Strategy (NES) Advanced Oil Recovery (AOR) Program goal of improving the economic producibility of the domestic oil resource. It was held to obtain public views and comments on the selection of deltaic reservoirs as the focus for DOE's initial program of research, development and demonstration of technology applicable to the needs of the oil operator. **Opportunities to Improve Oil Productivity in Unstructured Deltaic Reservoirs** contains a discussion of DOE's Oil Research and Development Plan, technical presentations on the geological and petroleum production characteristics of deltaic reservoirs, and comments by attendees.

Chemical Flooding

NIPER–502 **Improvement of Sweep Efficiency and Mobility Control in Gas Flooding. Topical Report. National Institute for Petroleum and Energy Research. April 1991. 32 pp. Order No. 91002229.** The application of carbon dioxide or other gases to extract crude oil from depleted reservoirs has been shown to be a technically successful process. However, optimized recoveries are often compromised by poor sweep efficiencies because of low gas viscosities and densities. A new process was investigated that potentially could improve sweep efficiencies by enhancing extractability properties of the injected gas with entrainers. Use of a capillary viscometer to evaluate enhanced viscosities appeared to be the best procedure for evaluating candidate compounds. A mathematical treatment was proposed based on predicting entrainer solubilities and minimum miscibility pressure alterations for carbon dioxide. However, use of many assumptions and approximations limited the effectiveness of this approach to qualitative evaluations. Some 87 compounds were evaluated using this mathematical treatment, and certain monaromatic compounds were identified for further laboratory testing.

NIPER–510 **Modeling of Surfactant Transport and Adsorption in Porous Media. Topical Report. National Institute for Petroleum and Energy Research. April 1991. 42 pp. Order No. 91002230.** This research was designed to investigate the transport and adsorption phenomena of surfactants in porous media using mathematical models. The mathematical models have taken into account the convection, dispersion, capacitance, and adsorption effect on concentrations of surfactants. Numerical methods and computer programs have been developed which can be used to match experimental results and to determine the characterization parameters in the models. The models can be included in foam simulation programs to calculate surfactant concentration profiles in porous media. A flow experimental method was developed to measure the effluent surfactant concentration, which will be used to determine the model parameters. Commercial foaming agent Alipal CD-128 was used in this study. Equilibrium adsorption and surfactant precipitation have been tested. Tracer solutions with a nonadsorbing solute such as dextrose and sucrose were used to determine the dispersion parameters for the experimental sandpack; thus, the adsorption of the surfactant in the test sand can be identified with an adequate model.

DOE/BC/14447–8 **Fluid Diversion and Sweep Improvement with Chemical Gels in Oil Recovery Processes. Annual Report for the Period May 1, 1989-April 30, 1990. New Mexico Institute of Mining and Technology. April 1991. 232 pp. Order No. 91002233.** The objectives of this project are to identify the mechanisms by which gel treatments divert fluids in reservoirs and to establish where and how gel treatments are best applied. Several different types of gelants are being examined, including a monomer-based gelant, several polymer-based gelants, and a colloidal silica gelant. A resorcinol-formaldehyde gel was studied extensively. Insights obtained by studying this relatively simple gel system may be valuable when assessing the performance of more complicated gels in fluid diversion. Experiments were performed to probe the rheology of chromium (III)-xanthan gels and gelants in porous media. Existing theories were applied to explore the influence of diffusion, dispersion, and viscous fingering during placement of gels to modify injection profiles. A mathematical study was performed to characterize gel placement in production wells. This work demonstrates that gelling agents can penetrate to a significant degree into **all** open zones – not just those with high water saturations.

Thermal Recovery

NIPER–495 **Thermal Numerical Simulator for Laboratory Evaluation of Steamflood Oil Recovery. Topical Report. National Institute for Petroleum and Energy Research. April 1991. 160 pp. Order No. 91002238.** A simulator was designed to assist laboratory design and evaluation of steamflood oil

recovery. The model developed is a three-phase, two-dimensional multicomponent simulator capable of being run in one or two dimensions. Mass transfer among the phases and components is dictated by pressure- and temperature-dependent vapor-liquid equilibria. Gravity and capillary pressure phenomena were included. Energy is transferred by conduction, convection, vaporization and condensation. The model employs a block-centered grid system with a five-point discretization scheme. Both areal and vertical cross-sectional simulations are possible. A sequential solution technique is employed to solve the finite difference equations. The model was validated by comparing the simulator results with published data. These initial comparisons showed that the model is capable of predicting qualitatively the performance trends of the published results. Sensitivity studies were conducted with respect to rock and fluid properties, process variables, and time-step size. The study clearly indicated the importance of heat loss, injected steam quality, and injection rate to the process. Dependence of overall recovery on oil volatility and viscosity is emphasized. The process is very sensitive to relative permeability values. Time-step sensitivity runs indicated that the current version is time-step sensitive and exhibits conditional stability.

DOE/BC/14600–7 Long Waves in Parallel Flow in Hele-Shaw Cells. Topical Report. University of Southern California. April 1991. 32 pp. Order No. 91002232. The evolution of fluid interfaces in parallel flow in Hele-Shaw cells is studied both theoretically and experimentally in the large capillary number limit. It shows that such interfaces support wave motion, the amplitude of which for long waves is governed by the KdV equation. Experiments are conducted in a long Hele-Shaw cell that validate the theory in the symmetric case.

DOE/BC/14600–8 Modification of Chemical and Physical Factors in Steamflood to Increase Heavy Oil Recovery. Annual Report for the Period October 1, 1989-September 30, 1990. University of Southern California. April 1991. 188 pp. Order No. 91002234. The study of vapor-liquid flow in porous media continued. Three aspects were addressed: (1) extension of the previous vapor-liquid model for solution gas-drive to a water-liquid vapor (steam) system in a pore network; (2) visualization of steam injection in Hele-Shaw cells and glass micromodels; and (3) macroscopic description of concurrent vapor-liquid flow in porous media. The methodology previously developed for a solution gas-drive process was used to model the phase change and phase growth during a vaporization process driven by a temperature increase. These phenomena are typically encountered in steam injection processes. The model includes nucleation, temperature and heat flux rates, and pore statistics (geometry and topology), but neglects temperature gradients. To include the latter, a variation of gradient percolation was proposed. Conditions are developed that place constraints on the heating rate for the applicability of percolation theory.

DOE/BC/14600–9 Percolation Models for Boiling and Bubble Growth in Porous Media – Topical Report. University of Southern California. May 1991. 36 pp. Order No. 91002241. Analyzed are liquid-to-vapor phase change in single-component fluids in porous media at low superheats. Conditions typical to steam injection in porous media are taken. Nucleation, phase equilibria and their stability, and growth of vapor bubbles are examined. Effects of pore structure are emphasized. It is shown that at low supersaturations, bubble growth can be described as a percolation process. In the absence of spatial gradients, macroscopic flow properties are calculated in terms of nucleation parameters. A modification of gradient percolation is also proposed in the case of spatial temperature gradients, when solid conduction predominates.

Novel Technology

DOE/BC/14203–4 An Innovative Drilling System. Final Report. Petrolphysics. May 1991. 88 pp. Order No. 91002242. An evaluation was conducted to establish that the Ultrashort Radius Radial System was capable of drilling and completing multiple horizontal radials in a heavy oil formation which had a production history of thermal operations; that the horizontal radials would serve as effective conduits for directing steam in specific azimuths and at specific elevations within the producing formation; that radials would help alleviate the deleterious effect of steam override; and that the horizontal radials could be utilized for cyclic production, i.e. for purposes of steam injection as well as for oil production. A site was selected on the west side of the San Joaquin Valley in the Bremer Lease in the Midway-Sunset field. A total of four radials were successfully drilled and completed in April 1989 using the Ultrashort Radius Radial System. Observations from the injection and production results of Bremer RI-53 offset wells and the observation well (Bremer 0-5) document the following conclusions: (1) the steam injected into the radials in RI-53 remained at the elevation as injected for a distance of at least 100 feet from the vertical wellbore; (2) steam override was not observed in Bremer RI-53; and (3) Bremer RI-53 produced oil from a single 30-foot interval at rates equal to or in excess of offset wells having greater than 400-foot gravel packed completions. The production per vertical foot of sand open was about 1.63 barrels per day versus a maximum of .13 barrels per day for a similar stimulated offset producer.

Gas Flooding

DOE/BC/14200–4 Statistically Designed Study of the Variables and Parameters of Carbon Dioxide Equations of State. Final Report. The John Hopkins University. May 1991. 312 pp. Order No. 91002240. The first task of this project was to select an equation of state to calculate the properties of carbon dioxide and its mixtures. In doing this, the equation's simplicity, accuracy, and reliability in representing phase behavior and thermodynamic properties of mixtures containing carbon dioxide with hydrocarbons at conditions relevant to enhanced oil recovery were taken into account. Also determined were the thermodynamic properties that are important to enhanced oil recovery and the ranges of temperature, pressure and composition. After reviewing the technical literature and consulting with experts in both industry and academia, twelve equations of state were chosen for preliminary studies to be evaluated against these criteria. All of these equations were tested for pure carbon dioxide and eleven were tested for pure alkanes and their mixtures with carbon dioxide. Comparing industrial practice and the calculated results with available experimental data, two equations of state – not one, the ALS equations and the ESD equation, were selected for detailed statistical analysis.

DOE/MC/21136–28 Improvement of CO_2 Flood Performance. Final Report for the Period April 1, 1984-March 1, 1991. New Mexico Institute of Mining and Technology. June 1991. 472 pp. Order No. 91002245. The final report is the completion of a six-year research project devoted to the study of processes of oil displacement using dense carbon dioxide. The topics studied have included phase behavior and physical properties of mixtures of crude oil with CO_2, the phenomena involved in the displacement of oil through reservoir rock under oilfield conditions, the influence of stabilized lamella or CO_2-foam on this displacement and the development of computer programs to simulate the displacement. In addition, the occurrence of nonuniformities in the displacement pattern has also been considered. The effect on displacement of permeability heterogeneities in the reservoir have been studied geostatistically and by direct numerical modelling. Displacement nonuniformities that are induced by viscosity and density for the development of two different types of additive for purposes of mobility control of CO_2 floods. One of these is the so called CO_2-foam, formed by simultaneous flow through the formation of dense CO_2 with a water solution of a special surfactant. The second type under development in the project is known as direct thickener, and consists of a polymer that is soluble in dense CO_2 and able to viscosify it.

DOE/MC/22044–15 Improved CO_2 Enhanced Oil Recovery – Mobility Control by In-Situ Chemical Precipitation. Final Report. West Virginia University. June 1991. 132 pp. Order No. 91002243. The objective of this study has been to evaluate the feasibility of chemical precipitation to improve CO_2 sweep efficiency and mobility control. The laboratory experiments have indicated that carbonate precipitation can alter the permeability of the core samples

under reservoir conditions. Furthermore, the relative permeability measurements have revealed that precipitation reduces the gas permeability in favor of liquid permeability. This indicates that precipitation is occurring preferentially in the larger pores. Additional experimental work with a series of connected cores have indicated that the permeability profile can be successfully modified. However, Ph control plays a critical role in propagation of the chemical precipitation reaction. A numerical reservoir model has been used to evaluate the effects of permeability heterogeneity and permeability modification on the CO_2 sweep efficiency. The computer simulation results indicate that the permeability profile modification can significantly enhance CO_2 vertical and horizontal sweep efficiencies. The scoping studies with the model have further revealed that only a fraction of high-permeability zones need to be altered to achieve sweep efficiency enhancement.

DOE/MC/26031–4 Field Verification of CO_2-Foam. Annual Report. New Mexico Institute of Mining and Technology. May 1991. 40 pp. Order No. 91002239. The objectives of this project are to (1) conduct reservoir studies, laboratory tests, simulation runs, and field tests to evaluate the use of foam for mobility control or fluid diversion in a New Mexico CO_2 flood, (2) evaluate the concept of CO_2-foam in the field by using a reservoir where CO_2 flooding is ongoing, characterizing the reservoir, modeling the process, and verifying the effectiveness. By evaluating information from candidate CO_2 flood, a suitable field site in New Mexico, the East Vacuum Grayburg/San Andres Unit, has been identified as appropriate for the proposed work. A sufficient number of Unit Working Interest Owners and the operator of the Unit, Phillips Petroleum Company, has approved the project. The first batch of representative reservoir cores have been received from Phillips Petroleum Company. The laboratory tests will follow assessment of the core material. These tests will consist of both CO_2-foam mobility measurements, and surfactant adsorption tests.

DOE/MC/26253–5 Scale-up of Miscible Flood Processes. Annual Report. Stanford University. June 1991. 240 pp. Order No. 91002244. This report describes recent progress in a research effort to quantify the scaling of interactions of phase behavior of multicomponent mixtures with unstable flow in heterogeneous porous media. Results in three areas are discussed: (1) phase behavior, fluid properties and characterization of crude oils, (2) interactions of phase behavior and flow, and (3) viscous fingering and reservoir heterogeneity. Results are reported in the phase behavior experiments for mixtures of CO_2 with crude oil from the Means field. Detailed analyses of phase compositions are also reported for samples taken during the PVT experiments. Results are given of an investigation of crude oil compositions and phase compositions by gas chromatography combined with mass spectrometry. Those analyses show that molecular weights calculated for single carbon number agree well with the n-alkane molecular weight despite the fact that there is considerable variation in actual carbon number within a cut. The first detailed comparison is reported for displacements with and without volume change as components change phase. The solutions described were obtained by the method of characteristics. Results of experiments and numerical computations that describe the growth of viscous fingers are reported. Both results and simulations show clearly that even mild permeability heterogeneity can have a dramatic effect on the form and location of viscous fingers.

Fundamental Petroleum Chemistry

NIPER–520 Thermodynamic Properties of 9-Methylcarbazole and 1, 2, 3, 4-Tetrahydro-9-Methylcarbazole. Topical Report. National Institute for Petroleum and Energy Research. April 1991. 56 pp. Order No. 91002235. Measurements leading to the calculation of the ideal-gas thermodynamic properties are reported for 9-methylcarbazole and 1, 2, 3, 4-tetrahydro-9-methylcarbazole. For studies on 1, 2, 3, 4-tetrahydro-9-methylcarbazole, experimental methods included combustion calorimetry, adiabatic heat-capacity calorimetry, vibrating-tube densitometry, comparative ebulliometry, inclined-piston gauge manometry, and differential-scanning calorimetry (d.s.c.). Adiabatic heat-capacity and combustion calorimetric studies were reported previously for 9-methylcarbazole. Vapor pressures by comparative ebulliometry and inclined-piston gauge manometry, and heat-capacities for the liquid phase by d.s.c. are reported. Entropies, enthalpies, and Gibbs energies of formation were derived for the ideal gas for both compounds for selected temperatures between 298.15 K and near 700 K. The Gibbs energies of formation will be used in a subsequent report in thermodynamic calculations to study the reaction pathway of the initial hydrogenation step in the carbazole/H_2 Hydrodenitrogenation network.

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Quarterly Reports

DOE/BC–90/4 **Activities of the Oil Implementation Task Force – Interim Report. Contracts for Field Projects and Supporting Research on Enhanced Oil Recovery. Progress Review No. 64. Quarter ending September 30, 1990. Order No. DE91002223.** As in previous reports, Section I describes progress of the classification of reservoirs, and during this particular reporting period, announces the availability of the results of the symposium "Opportunities to Improve Oil Productivity in Unstructured Deltaic Reservoirs" in Dallas, Texas, January 29-30, 1991. In Section II, 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, novel technology, and environmental technology.

Chemical Flooding

DOE/BC/10842–19 **Flow in Porous Media, Phase and Ultra-low Interfacial Tensions: Mechanisms of Enhanced Petroleum Recovery – Final Report. University of Minnesota. July 1991. Order No. DE91002247.** The report summarizes work for the period October 1, 1988 to September 30, 1989 and features 13 major accomplishments of the program during the year. Each accomplishment is described in detail in the report. The major accomplishments of the program from 1985 to 1988 were described in previous reports. The research highlights of the entire four-year program are briefly outlined in this report.

DOE/ID/12846–6 **Gelled Polymer Systems for Permeability Modification in Petroleum Reservoirs – Final Report. The University of Kansas. September 1991. Order No. DE91002254.** The research program described in this report was conducted to improve the performance and predictability of in situ gelation processes designed to increase volumetric sweep efficiency of fluid displacement processes. A principal objective of this research was to develop procedures for design and evaluation of permeability modification processes. Research was conducted in three broad areas: (1) physical and chemical characterization of gelling systems; (2) in situ gelation; and (3) mathematical modeling of in situ gelation. Gelling systems used chromium as the crosslinking agent. Polyacrylamide and polysaccharides gelling systems are studied.

NIPER–535 **The Effect of Alkaline Agents on Retention of EOR Chemicals. Topical Report. National Institute for Petroleum and Energy Research. July 1991. Order No. DE91002246.** This report summarizes a literature survey on how alkaline agents reduce losses of surfactants and polymers in oil recovery by chemical injection. Data are reviewed for crude sulfonates, clean anionic surfactants, nonionic surfactants, and anionic and nonionic polymers. The role of mineral chemistry is briefly described. Specific effects of various alkaline anions are discussed. Investigations needed to improve the design of alkaline-surfactant-polymer floods are suggested.

Thermal Recovery

DOE/BC/91002253 **Cross-Borehole and Surface-to-Borehole Electromagnetic Induction for Reservoir Characterization. Lawrence Livermore National Laboratory. August 1991. Order No. DE91002253.** Audio-frequency cross-borehole electromagnetics (EM) are interesting alternatives to existing techniques for petroleum reservoir characterization and monitoring. With these methods, signals may be propagated several hundreds of meters through typical sand/shale reservoirs and data may be collected at high accuracy with a high sensitivity to the subsurface resistivity distribution. Field systems for cross-borehole and surface-to-borehole EM measurements have been designed and built by Lawrence Livermore and Lawrence Berkeley Laboratories for reservoir evaluation and monitoring. The cross-borehole system uses vertical axis induction coil antennas for transmission and detection of sinusoidal signals. Data are collected in profiles with the source coil moving continuously while its signal is detected by a stationary receiver coil located in a separate well. Subsequent profiles are collected using a different receiver depth and the same transmitter span until a suite of profiles is obtained that cover the desired interval in the borehole. The surface-to-borehole system uses a large diameter surface loop transmitter and a vertical axis borehole receiver. Because of its high signal strength this system operates using a sweep frequency transmitter waveform so that data may be simultaneously collected over several decades of frequency. After extensive local testing these systems were deployed at the British Petroleum test facility in Devine, Texas for further testing and technique evaluation.

DOE/BC/14600–10 **Transient Behavior of Simultaneous Flow of Gas and Surfactant Solution in Consolidated Porous Media. Topical Report. University of Southern California. July 1991. Order No. DE91002249.** The main objective of this research was to investigate the mechanisms of foam generation and propagation in porous media. Results obtained give an insight into the conditions of foam generation and propagation in porous media. The rate of propagation of foam is determined by the rates of lamellae generation, destruction, and trapping. Several of the factors that contribute to foam generation have been studied with Chevron Chaser SD1000 surfactant. Interfacial tension (IF) measurements were performed using a spinning drop apparatus. The IFT of two surfactant samples of different concentrations were measured with dodecane and crude oil from the Huntington Beach field as a function of temperature and time. Results show that foaming agents do not reduce IFT values enough to mobilize residual oil. Foam was used as an oil-displacing fluid. However, when displacing oil, foam was not any more

effective than simultaneous brine and gas injection because of the sensitivity of the surfactant used to oil. Foaming did occur as shown by increased pressure gradients but did not produce a high pressure gradient that was capable of displacing the residual oil. The use of foam increased pressure gradient by a factor of ten and reduced the IFT by a factor of about ten. This resulted in an increase in the capillary number by two orders of magnitude. A series of experiments was performed to study the conditions of foam generation in Berea sandstone cores. Results show that foam may be generated in sandstone at low flow velocities after extended incubation periods. The effect of pregenerating foam before injection into the sandstone was studied. The use of a prefoamer produces small bubbles that enter the core and propagate, causing a more rapid pressure response. However, the effect of injecting a pregenerated foam does not extend far from the injected end of the core. Results show that foam propagates as a front in porous media.

Geoscience

DOE/BC/14448–6 **Outcrop Characterization of Sandstone Heterogeneity in Carboniferous Reservoirs, Black Warrior Basin, Alabama. Topical Report. Geological Survey of Alabama. August 1991. Order No. DE91002251.** This report identifies heterogeneity in Carboniferous strata of the Black Warrior basin on the basis of vertical variations, lithofacies changes, and depositional sequences through lithofacies analysis. Results of lithofacies analysis and depositional modeling were synthesized with existing models of sandstone heterogeneity to propose methods which may improve hydrocarbon recovery in Carboniferous sandstone reservoirs of the Black Warrior basin. A subsurface cross-section network illustrates the correlation of units from the Devonian Chattanooga Shale through the Pennsylvanian Mary Lee cycle of the Pottsville Formation in the Black Warrior basin. This network defines a series of regionally traceable, marker-bound units and depicts the extent and continuity of Carboniferous reservoir sandstone bodies. These cross sections also provide a basis for identifying and correlating subsurface stratigraphic units on the basis of well-log signature and pose new questions regarding the geological evolution of the Black Warrior basin. Outcrops of Lewis, Hartselle, and upper Nason sandstone were examined to characterize lithofacies variation in Carboniferous sandstone reservoirs in northern Alabama.

Microbial Technology

NIPER–508 **Microbial Enhanced Waterflooding Pilot Project, Mink Unit, Delaware-Childers (OK) Field. Topical Report. National Institute for Petroleum and Energy Research. August 1991. Order No. DE91002252.** The first microbial-enhanced waterflood field project sponsored by the U.S. Department of Energy (DOE), Microbial Systems Corp. (MSC), and INJECTECH, Inc. and being conducted in cooperation with the National Institute for Petroleum and Energy Research (NIPER) was initiated in October 1986. One of the major goals of this project was to develop a technology that could be implemented by independent oil producers; thus, the field site chosen for the pilot test was representative of a mid-continent waterflood operation with stripper wells. The methodology for designing and optimizing microbial enhanced oil recovery (MEOR) field technology has yet to be established; however, literature information and experience with MEOR processes indicate that certain procedures are necessary to implement a microbial waterflooding process. The site selected for the project is in the Mink Unit of Delaware-Childers field in Nowata County, Oklahoma. This field is typical of mid-continent reservoirs in the United States. The pilot area consists of four adjacent inverted five-spot patterns drilled on 5-acre spacing. There are 21 injection and 15 production wells on this pilot. Four of the 21 injection wells were treated with NIPER's microbial formulation. Laboratory screening criteria were developed to evaluate microorganisms for this project. Several different microbial formulations were tested in Berea sandstone cores with reservoir fluids to determine oil recovery efficiency. Baseline monitoring of oil production was conducted to establish pre-pilot conditions, and fluid samples were collected on a weekly basis from producing wells. Injectivity and microbial field survivability tests were conducted during the baseline period on two off-pattern wells, and a chemical tracer, fluorecein, was injected into the four injection wells during the baseline period. Tracer was observed in production wells about 1.8 years after injection, which corresponded reasonably well with the breakthrough predicted from simulation studies. Methodologies for field applications of microorganisms in ongoing waterfloods were developed as a result of this project. Results from the field pilot showed that microorganisms could be injected into an ongoing waterflood.

DOE/ID–10326 **Microbial Enhanced Oil Recovery and Wettability Research Program. FY 1990 Annual Report. EG&G Idaho, Inc. Idaho National Engineering Laboratory. July 1991. Order No. DE91002248.** The objective of the multi-year microbial enhanced oil recovery project is to develop microbial enhanced oil recovery (MEOR) systems for application to reservoirs containing medium to heavy crude oils and the design and implementation of an industry cost-shared field demonstration project of the MEOR technology. An understanding of the controlling mechanisms will first be developed through the use of the laboratory-scale testing to determine the ability of microbially mediated processes to recover oil under reservoir conditions and to develop the design criteria for scale-up to the field. Concurrently with this work, the isolation and characterization of microbial species collected from various locations including target oil field environments is under way to develop more effective oil recovery systems for specific applications. The wettability research is a multi-year collaborative effort with the New Mexico Petroleum Recovery Research Center (NMPRRC) at the New Mexico Institute of Mining and Technology in Socorro, New Mexico, to evaluate reservoir wettability and its effects on oil recovery. Results from the wettability research will be applied to determine if alteration of wettability is a significant contributing mechanism for MEOR systems. Eight facultatively anaerobic surfactant-producing isolates able to function in the reservoir conditions of the Minnelusa A Sands of the Powder River Basin in Wyoming have been isolated from naturally occurring oil-laden environments. The isolates have been characterized according to morphology, thermostability, halotolerance, growth substrates, affinity to crude oil/brine interfaces, degradative effects on crude oils, and biochemical profiles.

Fundamental Petroleum Chemistry

NIPER–533 **The Thermodynamic Properties of Benzothiazole and Benzoxazole. Topical Report. National Institute for Petroleum and Energy Research. August 1991. Order No. DE91002250.** Measurements leading to the calculation of the ideal-gas thermodynamic properties are reported for benzothiazole and benzoxazole. Experimental methods included combustion calorimetry, adiabatic heat-capacity calorimetry, comparative ebulliometry, inclined-piston gauge manometry, and differential-scanning calorimetry (d.s.c.). Critical property estimates are made for both compounds. Entropies, enthalpies, and Gibbs energies of formation were derived for the ideal gas for both compounds for selected temperatures between 280 K and near 650 K. The Gibbs energies of formation will be used in a subsequent report in thermodynamic calculations to study the reaction pathways for the removal of the heteroatoms by hydrogenolysis. The results obtained in this research are compared with values present in the literature. The failure of a previous adiabatic heat capacity study to see the phase transition in benzothiazole is noted. Literature vibrational frequency assignments were used to calculate ideal gas entropies in the temperature range reported here for both compounds. Resulting large deviations show the need for a revision of those assignments.

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Quarterly Reports

DOE/BC–91/1 **Contracts for Field Projects and Supporting Research on Enhanced Oil Recovery, Progress Review No. 65. Quarter ending December 31, 1990. October 1991. Order No. DE91002231.** The Oil Implementation Task Force completed activities in June 1991. Efforts continue for selected reservoir classes. A final report highlights the accomplishments of the task force as related to the Department of Energy's National Energy Strategy – Advanced Oil Recovery Program. 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, novel technology, and environmental technology.

General Research

NIPER–527 **Research Needs to Maximize Economic Producibility of the Domestic Oil Resource. Final Report. National Institute for Petroleum and Energy Research and K&A Energy Consultants, Inc. October 1991. 536 pp. Order No. DE92001001.** The purpose of this research was to identify research needs to increase production of the domestic oil resource. The findings of that investigation are summarized in this report. Professional society and trade journals, reports published by the Department of Energy (DOE), dissertations and patent literature were reviewed to determine the state-of-the-art enhanced oil recovery (EOR) and drilling technologies, in addition to the constraints to wider application of these technologies. The impacts of EOR on the environment and the constraints to the application of EOR because of environment regulations were reviewed. A review of EOR field projects showed that management factors contributed to the lower-than-predicted oil recovery in some of the projects reviewed. In projects sponsored by the DOE, achievements and constraints were identified. Recommendations were made for future technology transfer methodology. Finally, several research areas were identified and recommended to maximize economic producibility of the domestic oil resource.

Chemical Flooding

DOE/BC/14447–10 **Fluid Diversion and Sweep Improvement With Chemical Gels in Oil Recovery Processes. Second Annual Report for May 1, 1990 through April 30, 1991. New Mexico Institute of Mining and Technology. November 1991. 208 pp. Order No. DE92001005.** This report describes progress made during the second year of a three-year project. The objectives of this project are to identify the mechanisms required for gel treatments to divert fluids in reservoirs and to establish where and how gel treatments are best applied. Several different types of gelants are being examined. The research is directed at gel applications in water injection wells, production wells and high-pressure gas floods. The work examines how the flow properties of gels and gelling agents are influenced by permeability, lithology and wettability. Other goals include determining the proper placement of gelants, the stability of in-place gels, and the types of gels required for the various oil recovery processes and different scales of reservoir heterogeneity.

Thermal Recovery

DOE/BC/14600–13 **Numerical Construction and Flow Simulation in Networks of Fractures Using Fractals. Topical Report. University of Southern California. November 1991. 36 pp. Order No. DE92001004.** Concepts from the theory of fragmentation and fractal geometry are used for the numerical construction of networks of fractures that have fractal characteristics. The method is based mainly on the work of Barnsley and allows for great flexibility in the development of patterns. Numerical techniques are developed for the simulation of unsteady single phase flow in such networks. Pressure transient response of finite fractals behaves according to the analytical predictions of Chang and Yortsos, provided that there exists a power law in the mass-radius relationship around the test well location. Otherwise, finite size effects become significant and interfere severely with the identification of the underlying fractal structure.

DOE/BC/14600–14 **SUPRI Heavy Oil Research Program. Fourteenth Annual Report for October 1, 1989-September 30, 1990. Stanford University. December 1991. 116 pp. Order No. DE92001011.** Progress was made in five research areas: flow properties, in-situ combustion, steam with additives, formation evaluation and field support.

NIPER–552 **Effect of Wettability on Light Oil Steamflooding. Topical Report. National Institute for Petroleum and Energy Research. December 1991. 24 pp. Order No. DE92001015.** The purpose of this research was to evaluate specific changes in oil recovery by hot water and steam as a function of changes in wettability of porous media/fluid systems. To conduct this research, methodology was needed to determine changes in capillary pressure and wettability with increasing temperature. Laboratory oil recovery experiments using steam in one-dimensional Berea sandstone cores of various wettabilities showed that oil-wet sandstones responded to steam faster than water-wet sandstones, but both attained final residual oil saturations of less than 12%. A series of steamflood experiments was conducted in a two-dimensional model using water-wet, intermediate-wet and oil-wet porous media to investigate the steamflood potential for light oil production after waterflooding. The study evaluated the effects of changes in wettability on steamflooding light oils. New London crude oil (32° API) was used in the study. Comparisons of the oil saturation profiles of the sandpacks indicated higher initial oil saturations in oil-wet sandpacks. However, waterflooding recovered less oil at a slower rate and lower-oil-water ratio from oil-wet

sands. Oil-wet sands showed much higher residual oil saturation after reaching waterflood residual. Steamfloods initiated at this point displaced little oil from water-wet sandpacks. However, significant oil was displaced from oil-wet sandpacks. This study indicated that final oil saturation after steamflooding is independent of initial wettability.

NIPER–554 Evaluation of Surfactants as Steam Diverters/Mobility Control Agents in Light Oil Steamfloods: Effect of Oil Composition, Rates and Experimental Conditions. National Institute for Petroleum and Energy Research. December 1991. 40 pp. Order No. DE92001014. A series of experiments was performed to evaluate the effectiveness of commercially available surfactants for steam-foam EOR applications in light oil reservoirs. The experiments were performed in a 3-ft-long, 1-1/2 in.-diameter cylindrical sandpack of about 1 darcy permeability. The sandpack and injected fluids were preheated to 430° F at 155 psi. The main object of these tests was to investigate the effectiveness of several surfactants in providing mobility control under a variety of conditions expected in light-oil steamfloods. Thus, maximum pressure-rise and foam-bank buildup/decay were noted as operating conditions were changed in a test or in various tests. Tests were performed with various oil types, sacrificial salts, injection rates, injection strategies, vapor-to-liquid fractions (VLF), and steam/N2 ratios (SNR). Key observations are summarized.

Fundamental Petroleum Chemistry

NIPER–514 Determination of Ideal–Gas Enthalpies of Formation for Key Compounds — the 1989 Project Results. Topical Report DIPPR Project 871, American Institute of Chemical Engineers. National Institute for Petroleum and Energy Research. October 1991. 96 pp. Order No. DE91002256. The results of a study aimed at improving group-contribution methodology for estimation of thermodynamic properties of organic and organosilicon substances are reported. Specific weaknesses where particular group-contribution terms were unknown or estimated because of lack of experimental data are addressed by experimental studies of enthalpies of combustion in the condensed phase, vapor-pressure measurements and differential scanning calorimetric (d.s.c) heat-capacity measurements. Ideal-gas enthalpies of formation of (±)-butan-2-ol, tetradecan-1-ol, hexan-1, 6-diol, methacrylamide, benzoyl formic acid, napthalene-2, 6-dicarboxylic acid dimethyl ester and tetraethylsilane are reported. A crystalline-phase enthalpy of formation at 298.15 K was determined for napthalene-2, 6-dicarboxylic acid, which decomposed at 695 K before melting. The combustion calorimetry of tetraethylsilane used the proven fluorine-additivity methodology. Critical temperature and critical density were determined for tetraethylsilane with the d.s.c. and the critical pressure was derived. Group-additivity parameters useful in the application of group contribution correlations are derived.

NIPER–544 Thermodynamics of the Hydrodenitrogenation of Carbazole. Topical Report. National Institute for Petroleum and Energy Research. October 1991. 56 pp. Order No. DE91002255. A thermodynamic analysis based on accurate experimental Gibbs energies of formation was completed for the key hydrogen-consuming steps in the HDN reaction network for carbazole. The results were compared with literature reaction studies. The concept of "crossover temperature" is a valuable tool in the interpretation of literature reaction-study results. Methods of nitrogen removal from aromatic materials are discussed. The removal of nitrogen from heterocyclic aromatic nitrogen-containing compounds with conventional hydrodesulfurization catalysts, temperatures and hydrogen pressures occurs under "thermodynamic control" with unavoidably high hydrogen consumption. The report also concludes that to reduce hydrogen consumption in the HDN of carbazole, pathways via 1, 2, 3, 4, 4a, 9a-hexahydrocarbazole must be followed. Conditions under which these processes are possible are discussed.

NIPER–564 Differentiation of Primary, Secondary and Tertiary Aromatics Amines in Fossil Fuels Using Trifluoroacylation I. Analytical Methodology. National Institute for Petroleum and Energy Research. December 1991. 20 pp. Order No. DE92001013. Analytical methodology to distinguish between primary secondary and tertiary amines has been developed. Trifluoroacetic anhydride, with 4-pyrrolidinopyridine as a catalyst, is used to form di-and mono-trifluoroacylated derivatives of primary and secondary aromatic amines, respectively. Tertiary aromatic amines such as quinoline do not react. GC/MS is then used to analyze the derivatized samples. Retention indices and response factors (relative to 4-fluoroaniline) are reported for >50 pure compounds known or expected to be present in fossil fuel base fractions. Also, results from the analysis of base fractions from mildly hydrotreated SRCII coal liquids and petroleum-derived light cycle oils will be reported.

NIPER–538 Identification of Cross-Formation Flow in Multireservoir Systems Using Isotopic Techniques (Phase I). Final Report. National Institute for Petroleum and Energy Research. October 1991. 44 pp. Order No. DE91002257. This study consists of two phases designed to add quantitative and sometimes unique solutions for undesirable hydraulic communication which results in active fluid flow between productive horizons. Phase 1 of the project revealed that interformational hydrodynamic communication is a common and well-documented phenomenon worldwide. The effectiveness of a continuous trap's seal depends on an equilibrium between the capillary forces holding formation water in pore spaces of the seal and the buoyancy forces of the oil and gas column in a system. Therefore, some seals may leak selectively at changing pressure and temperature conditions with respect to different fluid phases (oil, gas and water). A break in continuity of confining layers, which may be of depositional, erosional, tectonic or physical nature will promote relatively fast interreservoir migration of fluids. Leakage of hydrocarbons between horizons through geologic discontinuities may negatively affect all production stages. It may intensify in reservoirs subjected to high pressures during implementation of secondary and tertiary processes of recovery. Such fluid flow should result in identifiably chemical, isotopic and often thermal anomalies in the area of an open flow path. Carbon-13/12, oxygen-18/16, and protium to deuterium ratios in hydrocarbon and water molecules are best suited for identification of cross-flow. Some other isotopes such as sulfur-34, stontium-87, chlorine-36, and chlorine-37 supplement an array of natural isotopes suitable for solving natural and man-induced fluid communication problems.

Microbial Technology

NIPER–548 Modeling and Laboratory Investigations of Microbial Transport Phenomena in Porous Media. Topical Report. National Institute for Petroleum and Energy Research. November 1991. 24 pp. Order No. DE92001003. Simulation and experimental results on the transport of microbes and nutrients in one-dimensional cores are presented, and the development of a three-dimensional, three-phase, multiple-component numerical model to describe the microbial transport phenomena in porous media is described. The governing equations in the mathematical model include net flux of microbes by convection and dispersion, decay and growth rates of microbes, chemotaxis and nutrient consumption, and deposition of microbes on rock grain surfaces. Porosity and permeability reductions because of cell clogging have been considered, and the production of gas by microbial metabolism has been incorporated. Governing equations for microbial and nutrient transport are coupled with continuity and flow equations under conditions appropriate for a black oil reservoir. The computer simulator has been used to determine the effects of various transport parameters on microbial transport phenomena. The model can accurately describe the observed transport of microbes, nurtrients, and metabolites in coreflooding experiments. Input parameters are determined by matching laboratory experimental results. The model can be used to predict the propagation of microbes and nutrients in a model reservoir and to optimize injection strategies. Optimization of injection strategy results in increased oil recovery because of improvements in sweep efficiency.

DOE/BC/14202–6 **Microbial Enhancement of Oil Production from Carbonate Reservoirs. Final Report for the Period January 1990-May 1991. University of Oklahoma. November 1991. 248 pp. Order No. DE92001007.** The objective of this research was to examine microbial enhanced oil recovery (MEOR) in carbonate reservoirs by reviewing the literature, determining the microbial ecology of carbonate reservoirs, examining the effect of microorganisms on carbonate matrices, documenting MEOR in model carbonate core systems, and constructing a mathematical model for MEOR in carbonates. The literature revealed two common microbial activities as useful mechanisms for MEOR in carbonate reservoirs: acid and gas production. The field trial data showed that microbial activity can affect the properties of an entire reservoir, and that MEOR has been successful in carbonaceous reservoirs. Analysis of the reservoir data from 10 states showed that 7,794 of the 19,297 carbonate reservoirs in the dataset had physical parameters which would allow MEOR. Essentially, a carbonate reservoir which has undergone waterflood would also be a candidate for MEOR.

DOE/BC/14666–5 **Development of Luminescent Bacteria as Tracers for Geological Reservoir Characterization. Final Report. Fairleigh Dickinson Laboratory. October 1991. 52 pp. Order No. DE92001002.** Bioluminescent cultures were acquired and tested for use as biological tracers for reservoir characterization by small independent oil companies. Initially, these bacterial cultures were fastidious to work with, but when their critical growth parameters were finally determined, simple test variations were developed that could be routinely accomplished. The intensity of their luminescence is easily distinguished by the human eye and requires no sophisticated technical knowledge or instrumentation. Cultures were received from culture banks and collected from marine environments. In the laboratory, they were screened using the criteria of optimum growth and luminescence. Three stock cultures proved to grow profusely even when variations were made in nutrient additions, salts, and temperature. These three selected cultures were not inhibited when introduced to formations and formation waters and were not overgrown by other bacteria. Cultures isolated from the Gulf of Mexico were overgrown by indigenous bacteria and, therefore, were eliminated from further screening and adaption. Experiments were performed to: (1) establish growth and luminescencing limitations of selected bacteria in various media, varying salt concentration and temperature; (2) adapt cultures to formation waters; and (3) determine transport limitations of bioluminescent bacteria through representative reservoir cores. The research concludes that bioluminescent bacteria have potential as geological tracers because they adapt easily to oil reservoirs and their luminescence is easily seen and not disputable, proving remarkable candidates for further energy development applications and environmental monitoring.

Geoscience Technology

DOE/BC/14651–5 **Reservoir Characterization of Pennsylvanian Sandstone Reservoirs. Annual Report. University of Tulsa. December 1991. 200 pp. Order No. DE92001012.** The first section of this report describes the methodology for characterizing a reservior in three dimensions. A fractal model was chosen for this project. To test the validity of various methods used for analyzing sampled data, synthetic data with known fractal characteristics were generated and analyzed. R/S analysis and box-counting were the most robust methods for analyzing the sampled data. The next step involved applying these techniques to wellbore data from Pennsylvanian Sandstone reservoirs. To generate a three-dimensional reservoir description, a method of simulated annealing has been proposed. A user-friendly computer program has been developed and has been tested using synthetic and field data. The method produces univariate and bivariate statistics. To scale-up permeability values to grid block level, a new analytical method is proposed. This proposed method calculates an effective permeability tensor for a block containing small scale heterogeneities. It has been partially validated by the use of finite element simulation. The second section describes the progress on investigation of an outcrop. The outcrop is an analog of a Bartlesville sandstone. Data will be collected on the surface of the outcrop as well as by drilling several wells behind the outcrop. The data from the outcrop will then be compared with the cored and logged wells from Glenpool field which also produces from Bartlesville sand. The third section describes the application of geostatistical techniques to infer in-fill potential locations based on the available reservoir and initial potential data.

Environmental

NIPER–546 **Environmental Regulations Handbook for Enhanced Oil Recovery. National Institute for Petroleum and Energy Research. December 1991. 280 pp. DE92001009.** This handbook is a compilation of environmental rules for owners and operators of enhanced oil recovery (EOR) operations. The handbook is a reference tool for use in planning EOR projects. However, federal and state environmental protection laws, rules and regulations are changing constantly. For this reason, current addresses and telephone numbers are given for regional EPA offices, affecting a particular location.

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INDEX

GENERAL RESEARCH

ENHANCED OIL RECOVERY

Quarterly Reports

Chemical Flooding

Thermal Recovery

Gas Displacement Technology

Resource Assessment

Geoscience

Microbial Technology

Environmental

Fundamental Petroleum Chemistry

Novel Technology