NIPER/DOE Chemical EOR Workshop

Final Report

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CHEMICAL EOR WORKSHOP

Holiday Inn – Hobby Airport, Houston, TX
June 23-24, 1993

ABSTRACT

A Chemical EOR Workshop was 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 Department of Energy (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.

Opening remarks were given by Alex Crawley from DOE Bartlesville Project Office and Thomas E. Burchfield of the National Institute for Petroleum and Energy Research (NIPER). The keynote address was delivered by Donald Juckett, Acting Deputy Assistant Secretary for Gas and Petroleum Technology. 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. It is recommended that funding of support research in chemical EOR be continued and sustained to provide continuity and expertise for future advanced oil recovery technologies.

INTRODUCTION

In the 60's and early 70's, chemical flooding (polymer flooding, profile/permeability modification treatment methods and surfactant/alkali flooding) was considered to be the most versatile process applicable to many of the waterflooded reservoirs in the U.S. Its application is still expected to recover a significant portion of the Nation's remaining oil. The combined remaining mobile and immobile oil is estimated to be 341 billion barrels, 242 billion barrels of which are immobile oil and 99 billion barrels of mobile oil (DOE, 1990). The National Petroleum Council (NPC, 1984) estimated that chemical EOR techniques have the potential to produce 0.4 billion barrels oil at a crude oil price of \$20 per barrel using implemented technology (DOE, 1990). The attractive feature of this technology is its versatility; it can be used to recover mobile and immobile oil, and

Thomas and Ali, 1992 considered surfactant/alkali flooding "the only process that has been demonstrated successfully in the field as a tertiary recovery process for low pressure, depleted oil reservoirs". Surfactant/alkali processes were widely applied between 1970 and 1984. A total of 101 projects were started during this period (Pautz et. al, 1992), that included both DOE cost-shared and industry funded projects. A number of these projects started in the 1970's were technically successful, however the majority of them produced less oil than predicted. The lackluster performance of some of these projects was attributed to several factors. These factors were identified as lack of adequate reservoir characterization, inaccurate mathematical reservoir models as well as technical and management constraints (Tham and Dauben, 1991).

In the early 1980's a few projects (Exxon's Loudon, Marathon's M1, and Shell's White Castle) overcame many of these constraints and resulted in the production of oil at a cost comparable to the market price prevailing at the time (DOE, 1991). The precipitous oil price drop in 1986 curtailed much of the plans for further testing and expansion, including attempts to improve the process performance. Research in the area of chemical flooding also diminished significantly. In the recent past, most of the papers in this area were published by researchers from Europe and Asia, where a number of field tests and laboratory research projects are still in progress. There exists a genuine need for the U.S. to continue or even intensify research activities in chemical flooding research in order to maintain its technical lead in this area. This need arises not only to develop economic oil recovery methods in the immediate future, but also to have optimized technologies in place capable of recovering the significant amount of immobile oil in the Nation's reservoirs when crude oil becomes a more valuable commodity either through a change in economic climate or depletion of oil supplies.

The recent restructuring of the petroleum industry, with the accompanying layoffs and retirements, dealt another blow to any attempt to revive the research efforts in chemical flooding. Some of the major oil companies have even closed down their entire production research facilities as part of their cost cutting/reduction strategy. With the departure of these experienced research personnel, engineers, and geoscientists, there is a grave concern that the many years of valuable experience and lessons-learned will be lost forever. This is of special concern since a significant fraction of the Nation's resources are now in the hands of independent producers, and this fraction continues to increase as shown in figure 1. Unfortunately these independent producers do not have the financial and personnel resources to redevelop or implement this essential technology.

FIGURE 1. – Fraction of oil resource owned by independent producers.

The current thrust of the U. S. DOE's Advanced Oil Recovery Program (AORP) strategy is directed towards applications of advanced techniques within the near- and mid-term time frame. Much of the work involves field applications to demonstrate and transfer these state-of-the-art technologies to petroleum producers, especially the independent producers, in an effort to slow down the decline in domestic petroleum production and to reduce the rate of well abandonment. The long-term strategy of the Program is focused on developing advanced oil recovery technologies to recover the remaining oil from the Nation's aging reservoirs. The results of the NPC study showed that of the different advanced technologies, chemical EOR techniques have the most potential for improved oil recovery from these difficult reservoirs.

In an effort to evaluate the current needs of the petroleum industry, particularly in the area of chemical flooding, a workshop was sponsored by the DOE in order to address several important issues and to obtain input from selected industry experts regarding the following areas:

- (1) assessment of the potential for chemical EOR, under the current and foreseeable crude oil price, to recover the remaining oil from domestic reservoirs;
- (2) determination of the role of the DOE and the petroleum industry in advancing chemical EOR technology;
- (3) identification and proposal of new research areas that can improve the efficiency and economics of chemical EOR; and
- (4) identification and evaluation of the different mechanisms for retaining the expertise in chemical EOR of experts that are leaving the chemical EOR areas.

The central theme of the workshop was to determine the potential of chemical EOR, its future applications, current technical trends and field applications, research and development (R&D) needs, and feedback on the focus of DOE's research priorities. The workshop was held in Houston, on June 23-24, 1993 at the Holiday Inn-Hobby Airport. The agenda of the workshop is given in appendix II. The total number of attendees to the workshop was fifty-six. This group comprised a mix of key representatives from major and independent oil companies, chemical companies, services and operating companies, research institutions, academia, consultants, and the DOE. Several technical talks were presented by respected industry experts in the area prior to the actual workshop/discussion session. The highlight of the workshop was the luncheon keynote speech delivered by Donald Juckett, Acting Deputy Assistant Secretary For Gas and Petroleum Technologies, Office of Fossil Energy, for the Department of Energy.

This report provides a summary of the important topics discussed by the two main workshop groups. One group focused on surfactant flooding technology while the other was geared toward polymer flooding and profile/permeability modification treatments. Recommendations from these two workshop panels regarding the four input areas of interest to the DOE are also presented. Extended abstracts of the technical presentations, and descriptions of DOE funded chemical EOR projects are included in Appendix I. Biographical sketches for those giving the technical presentations are provided in Appendix II. Appendix III includes the agenda for the workshop, and Appendix IV lists the workshop attendees. Letters of recommendation from chemical EOR research personnel have been included in Appendix V. A report of Texaco's Lignin Surfactant Technology, that was discussed at the workshop, is included in Appendix VI.

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OPENING REMARKS

Alex Crawley, Program Coordinator of the Advanced Extraction and Processing Technology Program, U.S. DOE Bartlesville Project Office (BPO), welcomed the scientists and engineers attending the workshop. He expressed regrets that Thomas Wesson, Director of the DOE's BPO, could not attend the workshop due to health reasons.

Reviewing the oil production by chemical EOR since the early 1980's, he pointed out that it is much below the original 1984 NPC predictions. In view of the reduction in chemical EOR research efforts by petroleum companies, he felt that now is the opportune time to reexamine the potential of chemical EOR technology, and to determine whether DOE should make any changes to its program. He concluded by encouraging the attendees to examine critically the economic and technical issues to arrive at an assessment of the potential of this technology, and to make recommendations for future development of the DOE chemical EOR research program.

Thomas E. Burchfield, Director of Energy Production Research, NIPER, echoed Mr. Crawley's message and extended his welcome to the attendees.

KEYNOTE SPEECH

Donald Juckett, Acting Deputy Assistant Secretary for Gas and Petroleum Technology, U.S. DOE, presented the keynote speech. He traced the history of DOE from its establishment after the oil embargo of 1973 to the present. He also discussed the recent reorganization of the Department of Energy and the increase in emphasis on oil and gas programs (especially the gas program). The development of the current Advanced Oil Recovery program with the near-term objective of arresting well abandonment was described. He also discussed the recent increase in the budget of the oil program with its emphasis on targeted field (class) projects. The budget for the supporting research program will be reduced, however, as the major portion of the budget is applied to the class projects. The supporting research budget has the possibility of returning to the original level or even increasing after the increase in funding for the targeted field projects subsides.

He was pleased that the attendees are meeting to discuss the topics of the workshop, and that he will be interested to learn about the recommendations of the workshop.

SURFACTANT/ALKALI FLOODING WORKSHOP

Moderator – Jerry F. Casteel

Summary

Surfactant and alkali-surfactant flooding are versatile and flexible processes that are suitable for mobilizing residual oil. While it has been shown that steam flooding is not economical for recovering waterflooded reservoirs with low oil saturations, and the cost effectiveness of CO₂ in waterflooded reservoirs has not been demonstrated, recent field tests indicated that either surfactant or alkali-surfactant flooding can recover residual oil economically (although the rate of return is not as high as other investment opportunities available to petroleum companies) even at an oil price of \$20/bbl. In many cases, reservoir conditions dictate these as the only methods that can be used to recover immobile oil in the U.S. Many of the problems that plagued previous surfactant and alkali-surfactant field tests have been solved during the past decade. Robust processes that are cost-effective using large slug-size, low cost alkali-surfactant processes have been demonstrated in field tests. There is a need, however, to convince petroleum companies of the economic viability of these processes and to overcome the negative impacts of the failed field tests of the 1970's. For this purpose, additional field testing – preferably larger size demonstration projects – is required. Pending this development, continued and sustained funding of supporting research in chemical EOR is recommended to provide continuity and expertise in the event changing economic or political conditions call for application of these methods.

Potential Recovery Using Chemical Flooding Techniques

A recent analysis using reservoir data in the DOE TORIS (Tertiary Oil Recovery Information System) Database (figure 2) has been used to estimate potential recoverable reserves based on application of different Enhanced Oil Recovery (EOR) methods. The analysis estimates potential reserves based on the application of implemented (available now) techniques and advanced (need more development) potential for different crude oil price levels. As crude oil prices increase, development and application of advanced techniques become economically viable.

The EOR methods have been classified as Advanced Secondary Recovery (ASR) methods, chemical flooding, gas flooding, and thermal methods. ASR includes polymer-enhanced waterflooding, profile modification, infill drilling, etc., which targets mobile oil. These areas are under discussion in the Polymer Flooding/Profile Modification

FIGURE 2. – Additional ASR/EOR Potential.

Workshop and are part of chemical flooding process. Chemical flooding also includes processes that cause some reduction in interfacial tension between water and oil. These types of chemical flooding target immobile oil. In many cases, chemical flooding potential includes reserves not recoverable by gas flooding and thermal recovery methods.

Members of the workshop felt that many of the technical problems in surfactant/alkali flooding have been solved, and that many of the constraints are a result of unfavorable experience from previous field pilots and current depressed economic conditions. The consensus of the members of the workshop was that the estimate for recoverable reserves from implemented chemical methods in the recent DOE study is overestimated for the lower ranges of crude oil prices (\$16 and \$20/bbl). However, at the higher ranges of crude oil prices, estimates for implemented technology may be too low. Some chemical recovery techniques such as alkaline-surfactant-polymer (ASP) methods would easily be implemented if the investment risk was reduced by higher oil prices. For advanced methods, workshop member also felt that recoverable reserves are over-

estimated at price levels below \$30/bbl. Even if chemical costs are reduced and separated from the price of oil and crude oil prices rise, there will not be incremental oil from advanced chemical methods unless fluctuations in oil prices are eliminated. Management will not take the risk to support the investment if oil prices are subject to sudden reductions.

One of the problems of predicting producible reserves is defining what constitutes implemented and advanced technology. Implemented technology for a large oil company may be advanced technology for an independent and may be extremely advanced for a small independent oil company. Applications exist, however, such as the ASP process, which are relatively inexpensive and robust which can now be considered implemented rather than advanced technology. DOE support in the future may best reside in providing support such as funding of field projects to build confidence in the technology.

The TORIS oil recovery projections differ from those of the 1984 NPC. The NPC study projected very little recovery from chemical technology based on the oil prices that occurred during the late 1980's. At the time of the NPC study, ASP and low-tension polymer processes were not developed. In addition, the categories included in chemical flooding have changed. Furthermore, there has been a big change in operation of U. S. fields since the 1984 study. Ownership of the fields is becoming fragmented and, more and more, are going from the major oil companies into the hands of independent operators. The impact of infill and horizontal drilling is not reflected in the NPC projections. In light of these changes, the committee members feel that a new study should be conducted. They felt that the analysis based on the TORIS data may not be detailed enough.

In summary, the potential oil recovery using chemical methods is large. An updated assessment study that includes the impact of advancements in the technology since 1984 would be helpful to provide a better understanding of the recovery potential. This will help define and identify the range of applications for the technologies that have advanced, particularly within the last decade. However, a number of difficulties that exist outside of technical considerations such as fluctuating oil prices, complexity in application methods, management reluctance to risk investments, and changing ownership of the nation's oil field will require high crude oil prices before that oil becomes a significant part of domestic oil production. With the change in ownership of domestic oil fields from the major oil companies to the Independents, the information and technology must be adapted and scaled to the needs of the Independents.

The Role of the DOE and the Petroleum Industry

It is expected that up to 70% of the old oil fields in this country will be abandoned by the end of the century. Once the infrastructure of field waterflooding projects has fallen apart, it may never be economical to reopen the field and inject chemicals. The equipment costs may just be too high. In addition, independent operators do not have the in-house expertise to plan, conduct, and monitor many types of EOR projects. Information dissemination and access to expertise are critical requirements to encourage application of chemical EOR technology.

Workshop members felt that a DOE chemical flooding program is essential. Downsizing by the major oil companies has reduced their research effort significantly. If efforts to recover domestic oil are to be continued, the DOE program will provide the major impetus. Funding of University programs is important to continue development of advanced techniques; and funding of technology transfer programs is also critical to get information into the hands of field operators.

The workshop participants also felt that the DOE program in place is underfunded for development of advanced technology. The available money for supporting research is directed toward the Class field demonstration projects. These class projects do not presently require an advanced research element. The DOE should require at least some advancement in the technology and not just provide a subsidy for field work.

There is a separation between the research "idea" people and the field people. A great deal of support was generated for DOE to conduct forums or workshops to get the field and research people together. These might be used as opportunities to get these different groups together to discuss technology advances and include advanced elements in responses to the class Program Opportunity Notices (PON's). If chemical processes can be included in the PON's, improvements may be made in pre- and post-flood interpretation and evaluation that will reduce the reluctance of operators to continue to apply this technology.

Specific suggestions where the DOE support would be most beneficial include the following:

- Give more time to respond to the class field project proposals (PON's) to allow research personnel to convince operating units to include chemical EOR projects in the responses.

- Provide funding for diagnostic purposes (e.g., observation wells, tracer tests) during field tests. This will provide much needed data for pre- and post- test evaluation.
- Encourage (or fund) more chemical EOR field tests.
- Conduct forums to bring people with the technology expertise and field operators together. This may also encourage inclusion of chemical EOR projects in PON responses.
- Disseminate information to operators, including PON announcements, new technologies, etc.

In summary, DOE support for chemical flooding research and technology transfer is extremely important. This support should include elements to continue advancement of the technology and to encourage field application with support to obtain sufficient information for interpretation and dissemination of results.

Research Needs

A number of research areas will have near- and mid-term impact on production of the domestic oil supply using chemically enhanced oil recovery methods. The workshop members suggested the following areas:

- Use of horizontal or fractured injection or production wells in conjunction with chemical EOR to produce line drive chemical floods. Drill horizontal well from existing wells to reduce drilling costs.
- Determine if an abandoned oil field can be reopened in the future to apply chemical EOR. Topics of interest include technological questions such as reversible plugging techniques and economic questions such as the cost of replacing the infrastructure.
- Investigate application of chemical EOR processes in fractured reservoirs, including surfactant-aided imbibition technology.
- Investigate the use of foam mobility-control in addition to polymer mobility control for surfactant flooding.
- Additional studies for large slug/low-concentration processes. These processes help economics by reducing large, up front chemical costs in addition to producing significant amounts of incremental oil.

- Additional studies for large slug/low-concentration processes. These processes help economics by reducing large, up front chemical costs in addition to producing significant amounts of incremental oil.
- Provide PC-based, user-friendly chemical simulators and horizontal-well models. This would be especially helpful for Independents who do not have the in-house expertise to run larger, more complicated versions of the simulators.
- Provide a portfolio of processes for different applications. This would help the independent operator evaluate and become familiar with possible tertiary methods to increase oil production.
- Study chemical EOR processes in carbonates. Not all carbonates are amenable to CO₂ flooding. Chemical flooding may be the only advanced EOR method applicable to some carbonate reservoirs.
- Ultimate success of chemical processes may require combination or co-deployment of processes. Investigations to determine synergistic application of processes as occurs with alkaline-surfactant methods or interference such as precipitation of some polymer-surfactant mixtures should be conducted.
- Chemicals for drilling fluids.
- Chemicals for completion fluids.
- Investigation of low-tension polymer flood (LTPF) applications.
- Investigation of alkaline-surfactant-polymer (ASP) applications.
- Use of chemicals to increase injectivity or well stimulation treatments can be extremely economical. These practices may also increase the life of a field and prevent complete abandonment. Additional studies in this area and technology transfer to smaller independents is important.
- Studies in scale up of chemical EOR processes to improve application.
- Further studies in reservoir characterization are required to maximize application potential of chemical flooding techniques.

- Support investigations to produce and/or develop surfactants and polymers with improved properties. Determine the bottlenecks that prevent evaluation or production of chemicals that are now or have been available.
- Remote sensing and monitoring of chemical EOR field tests, and controlling the process as the field tests are in progress.

Retaining the Expertise in the Oil Industry

Discussions in the workshop that focused on retention of the expertise in chemical flooding particularly in view of the changing nature of the industry included summarizing the comprehensive knowledge already amassed in the area and imparting the knowledge to active field operators.

A comprehensive document with the history, chemical development, field experience, and pitfalls of chemical flooding should be developed. It should describe where we were and where we are now. A significant amount of information on prior projects has not been fully published. A number of smaller, more recent applications of chemical methods should be of interest to independent producers.

Focused workshops that bring together experts in the field could be used to discuss innovative ideas like the application of horizontal drilling to chemical flooding. These ideas should be documented and discussed with field operators.

The development of databases would be a step toward transferring information to independent operators. A database of consultants could be used by independent operators looking for expertise in certain areas. A database of field projects including specific field, process and operator information would capture much of the prior experience in the area. A database or repository of core would provide access to information without requiring drilling of new wells. Access to records of field histories, even waterfloods, is very scarce. There is no requirement in this country to provide even certain basic information about a field. This makes it even more difficult to identify and plan chemical flooding projects. As fields change hands, information can easily be lost. Efforts to assemble data before it is completely lost would help in the future application of chemical flooding technology.

PROFILE MODIFICATION/POLYMER FLOODING WORKSHOP

Moderator – G. Paul Willhite

Potential Recovery Using Chemical Flooding Techniques

Much of the discussion of the potential for application of profile/permeability modification and polymer-augmented waterflooding revolved around the field-related constraints, both technically and economically, imposed by the present state of the petroleum industry. Everyone was in agreement that the potential did exist, and that the important matter at hand would be the means by which the technology can be more widely applied and be profitable for end-users at the same time. Acceptance of the technology within the industry was considered a very important factor in this process. One of the methods highlighted in the discussion is in the area of permeability/profile modification or conformance control. The majority of the members of the workshop felt that this type of treatment could be routinely utilized within the industry to alleviate reservoir-specific problems commonly encountered during production. Both the majors and independents would greatly benefit in the advancement of these methods. The potential for this type of treatment could be further expanded to include combinations with other EOR processes such as chemical, gas, and thermal flooding. Information compiled by the DOE supports the contention of the applicability of this technology to a vast number of our domestic oil reservoirs.

The Role of the DOE and the Petroleum Industry

The hurdle that remains to be overcome is the need for acceptance within the industry that this type of treatment is necessary to improve their production operations. The ability to deliver a technology that is packaged as having a high probability of success and at the same time be cost-effective and easy to apply, is critical. In order for the industry, particularly small independent operators to accept this technology, a sufficient amount of information will be necessary to provide details of successful field demonstrations. One stumbling block in this avenue is the lack of what one would refer to as "detailed" information.

Members of the workshop agreed that the documentation on applications was done, for the most part, by the majors as well as the service companies who conducted them. The documentation and information gathered by these companies are often used only

internally and are not available in the open literature, except for a limited quantity of references in publications such as the Society of Petroleum Engineers Journal (SPEJ).

The DOE can be instrumental in providing these companies some means (e.g., tax incentives) to publish this information and provide them to the general public. Independent work by other operators was seldom, if ever, documented. The ability to pull all available information from both sides of the industry is important in providing a viable "success story" for end users to evaluate.

Not all field applications of the technology can be categorized as successes. Successful field applications are also often coupled with some failures. In order to account for some of the variances in applications resulting in these failures, a realistic risk assessment also needs to be conducted to provide some degree of cushion or confidence limit for management and/or field operators to assess their application needs. Disseminating this information to receptive members of the industry is therefore very important.

The ability to timely place this information in the hands of field operators facilitates acceptance of the technology. The DOE already provides some of this much needed vehicle for technology transfer. Continued efforts in this area are very important. Instilling a degree of cooperation among the DOE, majors, independents and academia was also viewed as vital in promulgating a level of acceptance of this technology within the petroleum industry. Researchers and service companies need to be aware that input from field operators is important in the planning, design and development of any treatment method. Independents often do not have the technical expertise and personnel to tackle issues pertaining to complicated treatment applications. The thrust of the discussion here focuses on the need for making the technology as simple and as easy to understand and implement as possible.

Other important factors considered by members of the workshop include the need for better reservoir description or characterization as well as the timing of the implementation of technology early in the productive life of the field. The need for improved reservoir characterization was well emphasized as a critical piece of information in designing treatments that would be effective, both technically and economically. Information on the type of formation problem that could be encountered provides input in the design of treatments, whether the solution would be near-wellbore remediation or in-depth/penetrating diverting treatments (DTs).

The need to implement the technology early in the life of the field provides a sufficient target resource for oil recovery to justify the cost of the treatment. More often than not, the situation calls for the treatment of already marginal wells that would also significantly drive the economic prospects of the project down. Management needs to be convinced on the idea that early treatment improves the possibility of accessing/contacting more of the oil that remains in ground. Here again management's acceptance of the technology plays an important role. The ability to gain a profit in any investment is the prime motivating factor prior to any company management's commitment to implement any project. The capability to develop a simple, easy to use, and cost effective treatment method will be necessary to gain this commitment.

The overall consensus from members of the workshop was that the technology does have a niche in terms of providing the industry much needed tools in extracting valuable petroleum resources that otherwise would not have been recoverable. Emphasis on the need for acceptance within the industry, dissemination of information on the technical successes, as well as development of a cooperative attitude within the industry was viewed as important factors in breathing back life to our dwindling domestic petroleum production.

Summary of the Role of DOE and the Petroleum Industry

- Consensus on applications of technology as to when and where it can be utilized.
- Need to survey previous projects for both laboratory and field applications, with the resulting information published in a major report/presentation.
- Instilling a spirit of cooperation among the DOE, the major oil companies, the independent producers, the researchers, and academia - with particularly emphasis on establishing teamwork between the field operators and the service providers.
- Develop a methodology for reservoir problem identification - with consideration for establishing a correct perception of the technology at field level.

Research Needs

The following areas were identified during the workshop as having the most potential in advancing the state-of-the-art in ASR methods: These items are listed without considerations for any ranking or priority.

- Establishment of guidelines on matching the appropriate gelling system with the reservoir problem that needs to be solved - whether fractures and/or matrix problems.
- Development of chemical systems for permeability modification that are non-toxic and environmentally acceptable.
- Evaluation of corrosion problems associated with the use of polymers.
- Development of more cost-effective treatments and establishment of methodology for control and reduction of chemical costs.
- Continuation of efforts on technology transfer in order to inform field operators.
- Establishment of screening criteria on selecting candidate applications and development of standard operating procedures (SOPs) on how projects should be documented.
- Determination of optimal chemical treatment formulations and establishment of treatment guidelines.
- Evaluation of the use of sacrificial agents to mitigate chemical treatment losses and improve slug propagation.
- Identification of different injection methods and strategies to alleviate propagation and injectivity problems under restrictive conditions.
- Development of user-friendly computer simulator for ease of use in field evaluation.
- Development of improved methods for reservoir characterization and evaluation.
- Development of chemical systems applicable to harsh reservoir conditions - (e.g., temperatures > 300° F, possibly for steam/thermal flooding applications).
- Development of methodology for evaluation of treatment placement and sizing or scale-up of treatment.
- Development of recyclable polymers in an effort to reduce chemical cost component.

- Determination and evaluation of the effect of crossflow and the effectiveness of treatment depth (e.g., near-wellbore vs. in-depth, how deep is deep enough?).
- Develop a database system to compile available information on gel systems and field-scale treatments.
- Development of inexpensive means of diagnosing reservoir-specific problems.
- Establishment of guidelines and procedures for scale-up from laboratory to field projects.
- Evaluation of improved treatment alternatives (e.g., surfactant-based, polymeric-surfactants, associated polymers, biopolymers and others).

Key Research Areas

Of the above-mentioned topics, five items were selected by members of the workshop as key topics for DOE-funded research.

- Establishment of guidelines and procedures for scale-up from laboratory to field projects.
- Development of methodology for evaluation of treatment placement.
- Development of methodology for sizing or scale-up of treatment.
- Establishment of screening criteria on selecting candidate wells.
- Areas including (1) evaluation of gel formulations; (2) educating field operators; (3) environmentally acceptable chemical systems; (4) chemical systems for application at elevated temperatures; (5) inexpensive methodology of diagnosis and evaluation pre- and post-treatment performance.

Retaining the Expertise in the Oil Industry

The current global economic climate has placed a significant burden on every industry in both domestic and international markets. Over the past decade, the petroleum industry has been hardest hit by the downturn and instability of oil prices, leading to a significant decrease in profits and dictating cut-backs in operations costs. An off-shoot of these cut-backs includes shifting/reassignment of personnel to different work areas as

well as mass staff-reduction and downsizing efforts. Research, Design, and Development (RD&D) as well as Exploration and Production (E&P) efforts for most major oil companies have also been considerably reduced. The primary focus of today's major oil companies has been towards foreign oil production and majority of the domestic oil leases has slowly being transferred to the independent producers. Along with these cost-minimization efforts come significant amount of loss in terms of the technological expertise that has been built-up through the years, one area in particular is chemical flooding.

A discussion was undertaken by members of the workshop to identify possible avenues of documenting/retaining the knowledge and experience base that has been established through the research and field work that have been conducted. The following suggestions were made:

- Provide DOE-funded employment for former/retired industry experts as visiting professor/consultants to conduct seminars and short-courses by in the area of chemical EOR.
- Encourage publication and presentation of more technical papers. Particular emphasis is made on encouraging the publication of key company reports and data on EOR that have originally been set aside for use internally only. Inducements such a DOE-sponsored tax credit was suggested as a means of encouraging these companies to release these valuable information and establishing an EOR archive of information.
- Establish a directory of EOR experts/consultants on categorized EOR areas.

APPENDIX I

PRESENTATIONS

Chemical Flooding – Will it Survive?

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Large scale testing of surfactant flooding began in the mid-1960's. In some tests, relatively concentrated surfactant solutions with mobility design were injected and followed by polymer solutions of tapered polymer concentration to maintain mobility control. Marathon Oil Company's effort with concentrated surfactant systems lead to the 219-R project and the joint Marathon/DOE sponsored M-1 project initiated in 1977. Both projects utilized crude oil sulfonate manufactured at the Robinson refinery. Oil recovery from the 219-R project ultimately reached 32% of oil-in-place at the beginning of the project. Sulfonate arrived at production facilities at the same time as mobilized oil indicating that an oil bank had not been formed. Also oil/water separation problems were severe throughout the life of the project. Dehydrating oil added significant cost to the project.

Oil recovery from the M-1 project was about half what had been anticipated from laboratory work and field test experience. Again, oil/water separation was problematic and expensive. Low recovery was attributed to poor areal and vertical sweep efficiency. Two and a half acre spacing did not overcome the effect of reservoir heterogeneity. After tax rate-of return did not meet corporate guidelines for project investment. As a result, and with falling oil prices in the mid 80's, surfactant flooding efforts were redirected.

As with the rest of the industry, efforts turned to dilute systems of large volume that avoided heavy front-end capital investment. Early field test results have been encouraging. However, a number of improvements in surfactant flooding will be needed before this technique finds widespread application. A variety of new surfactant are needed that are insensitive to salt and heat.

Other avenues of chemical flooding included injection of polymer and crosslinked polymer solutions. Marathon selected polyacrylamide for field application. In order to improve the economics of micellar/polymer flooding, efforts were initiated in the early 70's to reduce the cost of the mobility control polymer. Poor injectivity (corefloods and field test) was attributed to the existence of microgels. Field manufacturing of polymer was developed to avoid the drying step and reduce cost. Relief from the Windfall-Profit-

Tax was obtained by initiating polymer floods in Wyoming and Texas. Significant reserve additions were attributed to these polymer floods. The next logical step in chemical flooding, a result of low oil prices, was the development of gels for conformance improvement. Gels have now been used in several of Marathon's reservoirs to improve waterflood sweep.

The potential for recovery of oil by chemical means remains large. However, private industry cannot afford the risk with minimal economic return. Significant incentives will be needed to apply surfactants for oil recovery. Failure in field applications was due, in large part, to poor mobility control. New thoughts are needed on controlling flood fronts and how dilution of injected fluids by reservoir fluids occurs. Better reservoir description will be needed prior to process application.

Can Horizontal Injection (and Production) Wells Save Chemical Flooding?

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Many engineers and company managers have been disappointed in the results of chemical EOR field projects, with the possible exception of gel treatments. Both economic and technical reasons have been given for the poor or marginal results of the past few years (see Jacques Bosio, SPE President, JPT, Dec. 1992, p. 1337). In an effort to understand the disappointing results, the chemical flooding economics and displacement mechanisms were compared with those of the more successful thermal recovery and CO₂ flooding field projects. It was shown that the costs of the large volumes of injected steam and CO₂ are much less on a reservoir volume basis than the costs of the injected chemicals. In addition, many of the more successful projects have benefited from higher initial oil saturation (especially the thermal projects) and the presence of a continuous oil phase during much of the displacement process. Therefore, ways must be found to lower the costs of the injectants and to target reservoir areas that have higher oil saturation wherever possible. Horizontal wells can help achieve both of these objectives.

Horizontal injection wells are now being tried for thermal recovery, and plans are underway for their use in CO₂ flooding. However, some of the greatest improvements with horizontal wells may come from applications in surfactant (low-interfacial-tension)

flooding and polymer flooding. A favorable configuration of horizontal injection and production wells is shown in figure A1. In theory, horizontal-well waterfloods of 5-spot patterns in homogenous formations can achieve near-perfect sweep efficiency and much faster flooding rates (compared to vertical-well patterns) in thin formations and at wide spacing. In stratified reservoirs, the performance of horizontal wells will be affected by their vertical placement, especially in reservoirs with barriers to vertical flow. The horizontal-well advantages also decrease markedly for very thick formations and closer spacing. This wide-spacing and thin-formation advantage is shown for sweep efficiency in figure A2. Figure A3 shows that the use of horizontal wells can increase the injection/production rates several fold with no increase in injection pressure. Thus, polymer flooding should be feasible at somewhat higher (and more economic) rates because of the higher injectivity, and the chemicals will spend less time in the reservoir for a given volume swept. Therefore, the chemical stability problems in high-temperature reservoirs will be less severe with horizontal-well patterns. In addition, lower fluid flux at the sandface (see figure A4) will lessen the probability of mechanical degradation of some polymers.

For surfactant flooding, the microscope displacement efficiencies will be increased because of the higher capillary numbers possible (up to a tenfold increase) with the faster flooding rates of horizontal wells, as shown in figure A5. The higher capillary numbers can also permit the use of lower (and less costly) surfactant concentrations while still maintaining good displacement efficiency.

FIGURE A1. - Five-spot pattern with horizontal injection and production wells.
from Taber and Seright (1992)

FIGURE A2. - Comparison of sweep efficiencies for vertical wells versus horizontal wells (parallel and opposed in a five-spot pattern, unit mobility ratio).
from Taber and Seright (1992)

The overall economics of any EOR project can be improved because of the faster oil production rates and shorter project life with horizontal wells compared to regular vertical-well patterns. For new projects, fewer horizontal wells at wide spacing should lower the overall drilling costs and still improve the recovery efficiency. For older projects, horizontal infill wells (or kickoffs from existing wells) could reach higher oil saturation and thus improve displacement efficiency.

FIGURE A3. – Comparison of injection rates for the wellbore for horizontal versus vertical wells.
from Taber and Seright (1992)

FIGURE A4. – Comparison of fluid velocities at horizontal wells relative to vertical wells.
from Taber and Seright (1992)

FIGURE A5. – Potential for improved oil recovery from faster flooding rates with horizontal injection and production wells. Original figure with calculated capillary number values (and definitions of symbols) from Stegemeier (Ref. No. 78, data from Refs. 48, 52, and 77) See Taber and Seright (1992) for these references.

Reference

Taber, J. J. and Seright, R. S.: "Horizontal Injection and Production Wells for EOR or Waterflooding," *Proc. of the SPE Permian Basin Oil and Gas Recovery Conference* (March 1992); *Proc. of the SPE/DOE Eighth Symposium on Enhanced Oil Recovery*, Tulsa (April 1992); and *Proc. of the Rocky Mountain Regional Meeting*, Casper, WY (May 1992).

Observations About Surfactant Flooding and Future Implications

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Surfactant flooding has been the subject of research and development for about thirty years. There have been a large number of field tests of the process during this time period. Although the results of many of the early field tests were below expectations, those performed during the past decade were for the most part considered technically successful, yet the process has not become commercial. This is an attempt to summarize some of the more important reasons why this is the case. The focus is on classical surfactant flooding (which uses both injected surfactants and polymers) rather than some of the more recent innovations such as low tension polymer flooding or alkaline/surfactant/polymer (ASP) processes. There are in fact some commercially successful ASP field applications and the reader should be acutely aware of the differences between these various forms of chemical flooding as well as others such as polymer flooding, which is also practiced commercially on a limited basis.

Some of the major reasons that surfactant flooding is not a commercial process at this time are as follows:

1. High costs even excluding chemicals. These costs include new wells, workovers, new facilities, the cost of money associated with the high front end cost of the chemicals, taxes, royalties and operating costs including the treatment of injected and produced fluids.
2. High risk and uncertainty compared to alternative E&P projects worldwide.
3. Negative perception of technology by oil company managers.
4. High level of expertise required to design and operate a successful project.

5. Limited range of field experience under many conditions e.g. in carbonates, at high temperature, in fractured reservoirs, offshore, at large well spacing, with horizontal wells, and with moderately heavy crudes. By contrast, more than 100 field pilots have been done in sandstone reservoirs without these characteristics.
6. High sensitivity of process to reservoir characteristics such as permeability variations.
7. Lack of standard, large scale source of proven, effective surfactants and polymers at competitive prices. This situation is somewhat analogous to the lack of large supplies of low cost carbon dioxide gas for enhanced oil recovery prior to the installation of pipelines during the early 1980's for this purpose.
8. Lack of standard, accurate, fast, robust commercial reservoir simulators of the process that could be used by engineers to design and optimize large field projects. Although chemical flooding simulators have been developed and their accuracy and usefulness demonstrated, this technology has not moved to the commercial sector with the same degree of maturity that it has with commercial simulators used for thermal and gas enhanced oil recovery processes.
9. All of the other factors that negatively impact oil production in the United States e.g. high uncertainty in crude prices, environmental regulations and fears, downsizing and abandonment of oil properties by major oil companies, very old wells in many cases, very mature waterfloods with high water cuts in many cases and many other similar factors.

If this were not bad enough, there is now almost no research and development underway in the domestic oil company research laboratories to address these problems and only a very low level of research elsewhere such as at the universities, and what little research there is either does not or cannot address all of these problems effectively. Both past and current research has mostly focused on better and lower cost chemicals. This research has been very successful. Some examples of these successes include the development of surfactants that work well at very high salinities and temperatures and an understanding of how to tailor these surfactants to yield ultra-low interfacial tensions under a wide range of conditions. Although the costs of making these synthetic surfactants is high, they are about twice as efficient as before, so their cost per barrel of oil recovery is much better than before. Although the actual costs will vary over a wide range depending on many variables such as retention levels, chemical (surfactant and polymer) costs on the order of \$5 per barrel are possible with these very efficient surfactants. Such costs were previously considered adequately low for commercial

purposes and are on the same order as current costs of carbon dioxide for enhanced oil recovery. This implies that the other factors listed above are indeed the current problem and must be addressed as a whole if surfactant flooding is to have any reasonable chance of commercial success in the United States.

The current economics of an onshore surfactant flooding candidate in the United States will be used to illustrate the problem. This oil reservoir is owned and operated by Conoco and the economics were done by Conoco. This oil reservoir is typical of those that have been identified by the U.S. Department of Energy using the TORIS system as surfactant flooding candidates and are typically not candidates for any other enhanced oil recovery process and thus subject to abandonment. The total amount of oil in such reservoirs in the U.S is very large. The oil recovery was calculated using the University of Texas chemical flooding simulator UTCHEM calibrated by Conoco's laboratory and field data. Figure A6 shows the oil recovery for two of the many cases studied. For case 8, only 0.5 PV of 0.5% surfactant was needed to recover 55% of the remaining oil in this reservoir after waterflooding. The cost of the chemicals for this case is only about \$5 per barrel of incremental oil recovery. This is a very favorable result, yet we will see that the process is still not profitable under these conditions and current and projected oil prices. Figure A7 shows the internal rate of return for the base case and several perturbations of it. The base case does not become profitable until \$27 per barrel and does not produce a 15% rate of return until \$40/Bbl. With a 50% reduction in chemical costs, \$24/Bbl is needed to produce a 15% rate of return. With both a 50% reduction in chemical costs and a 20% increase in oil production, \$20/Bbl is needed to produce a 15% rate of return.

FIGURE A6. – Oil Recovery from an oil reservoir using surfactant flooding.

FIGURE A7. – The internal rate of return for the base case and several perturbations.

Although a reduction in the chemical costs is desirable and if sufficient could make this project marginally attractive, it is equally clear that other cost reduction factors should be considered for this or other similar projects. One obvious candidate is the use of horizontal wells. Preliminary studies at the University of Texas indicate that using horizontal surfactant injectors and vertical oil producers can reduce the project life by a factor of about two. This should improve the economics provided the wells can be drilled at a cost only slightly more than vertical wells. This is because of the high front end cost factor in surfactant flooding. Some improvement in sweep efficiency may also be possible with horizontal wells but will depend on reservoir characteristics such as vertical permeability in a sensitive way and make accurate reservoir characterization and reservoir simulation even more important to the success of the process than is true now.

This brief summary does not allow all of the factors impacting the economics of surfactant flooding to be discussed and potential solutions explored. However, it should be clear that all of the costs of operating surfactant flooding need to be examined, not just the chemical costs. Furthermore, much more needs to be done to decrease the risk associated with the process and to communicate the potential of the process to those in important decision making roles in the United States. Unless all of these factors are

effectively addressed at the same time and before abandonment of many of the stripper wells in the old fields that are surfactant flooding candidates, the future of surfactant flooding in the United States is not very bright despite its technological successes and despite the lack of suitable alternatives.

Laboratory and Field Performance of a Surfactant/Alkali Flood

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In 1984, at the Fourth DOE/SPE Symposium on Enhanced Oil Recovery, the author discussed the beneficial effect of adding cosurfactants to alkaline floods. In the 1986-1990 period, Shell Oil Company conducted two of a three-part field test of the cosurfactant-enhanced alkaline flooding process. That work, in the White Castle field, was discussed in 1992 at the Eight DOE/SPE Symposium on Enhanced Oil Recovery. In this talk, laboratory predictions are compared with field results with emphasis on obtaining quantitative data on oil production, alkali consumption and surfactant retention. Lessons from the field work are provided.

The principal difference between the onshore reservoir used for the field test and the offshore target reservoirs is a 45 degree difference in dip. Results of a laboratory study of the effect of dip angle on oil recovery are presented. In that study, 16 cosurfactant-enhanced alkaline sandpack floods were run with high and low values of the four variables: flow rate, viscosity, permeability and dip. As would be expected, tertiary oil recovery depends less on dip the higher the flow rate, the higher viscosity of the displacing fluid, and the lower the permeability of the sand. The effect of dip on oil recovery in these laboratory floods correlates with the effect of dip on the direction, relative to the axial direction of the sandpack, of the total force vector acting on oil trapped by capillary forces.

An outgrowth of that study is a surfactant flooding technique, called "Surfactant-Induced Drainage," in which tertiary oil is recovered by injecting a surfactant solution into watered-out producing wells located near the top of steeply dipping reservoirs or thick reservoirs with high vertical permeability. Surfactant-Induced Drainage requires no polymer.

It is argued that formulating an surfactant/alkali flood should allow the sequence: determine reservoir characteristics, select the alkali, select the concentration of alkali,

select the concentration of surfactant, select the surfactant, select the method and extent of mobility control. Surfactant retention in the White Castle field test, 0.026 meq/100g of rock, supports the method used to select the concentration of surfactant. Two principal mechanisms of alkali consumption, mixing with formation brine and cation exchange, were minimized by the large preflood used at White Castle. Actual total alkali consumption, 0.433 meq/100g of rock, agreed well with the amount predicted to occur from hydrogen ion exchange, dissolution of silica, clay transformation, and conversion of petroleum acids to soaps.

Results of a polymer injectivity test suggest that polyacrylamide can be injected without significant degradation through 3/4-inch perforations into a one-darcy sand at rates up to 32 barrels per day per square inch of perforation.

**Alkaline - Surfactant - Polymer Flood of the West Kiehl, Minnelusa Unit, Alkaline -
Surfactant - Polymer Flood of a Oily Waste Super Fund Site and Alkaline -
Surfactant - Polymer Flood of the David Pool**

Malcolm J. Pitts
Surtek, Inc.

The co-injection of an interfacial tension agent (alkali, alkali plus surfactant or surfactant) and a mobility control agent (polymer) is done to improve oil recovery from porous media by increasing the three oil recovery efficiency factors simultaneously according to the following equation.

$$N_p = E_{VI} E_A E_D \frac{S_{oi} V_p}{B_o} \quad (1)$$

The value of each of the efficiency factors (E_{VI} , E_A , E_D), the initial amount of the oil present (S_{oi}), the pore volume of the oil zone (V_p), and the oil formation volume factor (B_o) dictate the amount of oil (N_p) that is produced from an oil bearing porous media. E_{VI} and E_A are the vertical and areal contact efficiency factors and their product is the volumetric sweep efficiency. Polymer or a mobility control agent is added to the injected solution to improve E_{VI} and E_A . E_D is the efficiency with which oil is removed from each pore contacted by the injected fluid. The initial oil saturation and the waterflood residual oil saturation are dictated by the relative permeability curve. Increasing E_D reduces the waterflood residual oil saturation. Alkali, surfactant, or a combination of alkali and surfactant are added to the injection fluid to improve E_D .

An alkaline-surfactant-polymer flood was initiated in September 1987 in the Minnelusa Lower "B" sand at the West Kiehl Unit. The reservoir volume affected by fluid injection or the gross swept pore volume of the West Kiehl Unit is 1,294,800 barrels (205,857 m³). The alkaline-surfactant-polymer flood oil recovery efficiency in the gross swept area as of March 1993 is 55.9% OOIP or 499,218 barrels of oil (79,396 m³). Projected ultimate production from the Unit is 570,840 barrels of oil (90,756 m³) or 63.9% OOIP. The projected primary plus waterflood oil recovery at the West Kiehl Unit is 39.9% OOIP. Comparative Minnelusa Field oil recovery efficiencies for a waterflood in the Hamm Unit and a polymer flood in the OK Field are 28.5% OOIP and 45.6% OOIP. A total of 197,786 incremental barrels of oil (31,495 m³) are projected for the West Kiehl Unit at a incremental cost of \$393,458 or \$1.99 per incremental barrel of oil (\$12.49/m³). No injected chemical production has been observed as of December 1992. No changes in the Hall plot slopes have been observed suggesting that alkali plus surfactant plus polymer injected without damage to the Minnelusa formation.

The 1989 an alkaline - surfactant - polymer solution was injected into an alluvium contaminated with wood treating oil. The composition of the solution was 0.825 wt% Na₂CO₃ plus 0.650 wt% NaHCO₃ plus 1.4 wt% Makon 10 (ethoxylated nonyl phenol) plus 1,500 mg/l Flocon 4800M. pH of the injected solution was 9.2 with a viscosity of 54 cP at 60°F, formation temperature. Delivery and production of fluids was accomplished using three 4-inch horizontal wells spaced 60 feet apart in parallel and located at the alluvium-bedrock contact. Prior to the chemical injection, water was injected for 1.7 pore volumes and recovered 58.4% of the initial oil saturation. Injection of the 3.0 pore volume of Na₂CO₃-NaHCO₃-Makon 10-Flocon 4800M recovered an additional 35.1% of the initial oil saturation or 84.3% of the waterflood residual oil saturation. No additional oil recovery was observed with the injection of 1.0 pore volume of Na₂CO₃-NaHCO₃-Flocon 4800 as a pre-flush.

An alkaline-polymer flood initiated in the David Pool February 1987 after a primary production history from 1969 to 1978. A waterflood was initiated in 1978 followed by an alkaline-polymer flood in June 1987. Projected primary plus waterflood oil recovery is 45.8% OOIP. Primary plus waterflood plus alkaline-polymer oil recovery is extrapolated to be 66.5% OOIP for a projected recovery of 1,745,000 bbls (277,790 m³) of incremental oil. The effect on the oil production as a result of alkaline-polymer solution injection was most pronounced in the interior producing wells which were surrounded by injection wells, changing from 125 bbls/day (20 m³/day) at the end of the waterflood to 440 bbls/day (70 m³/day). The oil cut decline was arrested, going from a minimum of

20% to the current oil cut of about 50%. Estimated chemical cost per incremental barrel of oil is \$1.16 (\$7.31/m³). No injection problems or production scale problems were observed at David Pool.

Permeability Modification – A Chemical Technology with Potential for Independent Oil Operators

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Abstract

Permeability modification has high potential as chemical technology for the independent operator producing stripper wells and marginally profitable waterfloods. Independent operators have constraints such as limited capital, unavailable reservoir data, and limited technical personnel. Permeability modification can be applied within the limit of these constraints. It has low up front capital cost, technical staff requirements are not large, it is scalable, and the data required for proper design is minimal compared to many other chemical technologies. In general, economics are favorable not only because of increased oil production but also because of a lowered water oil ratio with reducing operating expenditures. Reduction in operating expenditures increases the economic limit on stripper wells and marginally profitable waterfloods.

This paper reviews one field case history utilizing a permeability profile modification treatment and how guidelines were placed on the technology to increase its potential use among independents. Also discussed is the future in permeability modification by the Tertiary Oil Recovery Project (TORP) at the University of Kansas.

Background:

Most Kansas oil fields are mature with many producing oil fields in the late waterflood stages near the economic limit due to high water-oil ratios (WORs). Many of these waterfloods have been plagued with low volumetric sweep efficiency. In many instances, poor performance is thought to be a result of water moving rapidly through high permeability channels or through fractures. In other instances, water breakthrough may be related to permeability contrasts between different layers, which may or may not be in vertical communication in the reservoir.

Fractures in a reservoir may be either natural or induced. Induced fractures are often the result of over-pressuring the formation at some point in the life of a project. When these type of problems exist, uncrosslinked polyacrylamides' ability to develop resistance to the flow of water is not sufficient to correct the problem. The addition of low concentrations of metal ions to the polymer solution will bond the polymer molecules to one another, greatly increasing the resultant gel's ability to develop resistance to the flow of water. Depending on the concentrations of polymer and crosslinking agent and the rate the crosslinking agent is made available to the polymer solution, a wide range of permeability adjustment is possible. This type of technology has been identified as permeability modification treatments or conformance-improvement-treatments (CIT's). It has been found that when the gel polymers are properly placed in the targeted problem area, the fluid flow changes will improve oil recovery and, in many cases, reduce operating costs due to reduced water cycling.

Permeability modification has been a chemical technology which has been in existence for many years. In recent years success has been relatively high at 80%, however historical success rates with crosslinked polymer treatments have been less than 50% with two thirds or more of the failures resulting from improper application. Most failures with in-situ gel polymer are caused by one or more of the following problems; 1) improper placement of the gel polymer within the wellbore, 2) improper selection of candidate well, 3) lack of knowledge of the wellbore integrity, 4) lack of adequate preparation of the wellbore prior to job, 5) limited time allotted to implement the treatment, and 6) understanding the injection well profile before and after treatment.

Identifying potential technologies

Before any technology has potential, there must be a need for the technology. The major step involved in identifying potential chemical technologies is determining the operators reservoir and production needs. Needs are determined by defining the operators' problems and the constraints in implementing a possible solution. Therefore the following steps must be conducted to determine a potential technology, 1) problems must be identified, 2) possible technologies as solutions must be matched with each problem, 3) operators constraints in implementing the possible technology must be determined, and 4) guidelines must be placed on the implementation of the technology to make it suitable for implementation.

In Kansas, six problem identification workshops were conducted, and it was found that channeling in waterfloods was the major reservoir problem for independents, especially when the waterfloods are near their economic limit. Operators have a variety of constraints when implementing technology such as limited capital, unavailable reservoir data, and limited technical personnel. As a result, permeability modification was identified as a possible solution and the following guidelines were placed on the technology:

- 1) the technology must be scalable to any problem size. This increases the usage by smaller operators with smaller channeling problems because of the low up-front costs.
- 2) the technology must be easily understood and implemented. The technology must not require a large degree of technical knowledge to implement.
- 3) the technology cannot require large amounts of reservoir data to design. In most cases, channeling problems can be located and quantified through use of present day tests and do not require a large degree of reservoir data. Calculations and tests that are applicable are (1) material balances calculations between injection and production wells, (2) water-oil ratio versus cumulative oil production curves, and (3) tracer tests.
- 4) the technology cannot require special high cost equipment. The equipment must be equipment built from everyday oil field equipment or easily accessible by the operator.
- 5) the technology must lower operating costs by reducing water production. When breaking down operating costs, it was found that four out of five categories were affected by high water production.
- 6) the technology must be demonstrated with a large degree of success. Operators need to see the technology successfully implemented in fields similar to their fields to increase confidence in the technology.

It is quite easily determined that permeability modification falls under these guidelines and can be a high potential technology for the independents.

New Albany Field

The New Albany field in Elk County is a typical, shallow southeastern Kansas reservoir, producing from the Wayside sandstone (Schoeling, et. al., 1989). The project pattern is an inverted five spot. The producing sandstone, at a depth of 600 ft, is 20 ft

thick. The operator started a waterflood on the lease in 1983. Despite high injection rates, the reservoir could not be pressured up, indicating a possible channeling problem. The tracer indicated a severe channeling problem between the injection well and one of the producing wells. The producing WOR was about 30 and climbing, causing high lifting costs and poor economics.

A 50 bbl gel treatment was designed with the objective of sealing the fracture system. The gel solution was the Cr(III)/polyacrylamide system with sodium dichromate and thiourea used. The injection well responded immediately with a 300% decrease in injectivity index. Oil production on the lease increased from about 6 to 10 B/D as shown in Figure A8. Payout time was about 1 month on a basis of \$10/bbl of incremental oil and \$12/bbl of polymer injected.

The producing WOR on the lease could be estimated only from metered injection water. The produced water was recycled into the metered injection well at steady-state conditions with no makeup water. The producing WOR responded favorably, as shown in Figure A9.

The oil production declined to near the pretreatment rate over a period of about 1 year, as presented in Figure A8. The assumption was that the original gel treatment either had broken down or had been slowly displaced. A second gel treatment of the same composition, but with twice the volume, was implemented with excellent results. Production again nearly doubled with a payout time of about 1 month based on the same

FIGURE A8. – New Albany field (Cook II lease) oil production.

FIGURE A9. – Cook II lease WOR vs. cumulative oil production

economic parameters used in the first payout-time calculation. Approximately 8 to 12 months after the treatment, the production declined, as noted in Figure A8, but this production drop was caused by operations problems and wellbore plugging. Water-injection rate was down for about 8 to 9 months, causing the premature drop in oil production. After wellbore cleanup, oil production returned to the previous post-treatment rate.

As of August 1990, approximately 8,000 bbl of incremental oil had been recovered as a result of the two polymer gel treatments. In the treatment, 225 lbm of polyacrylamide was used. Recovery efficiency is over 30 bbl of incremental oil per 1 lbm of polymer to date. The waterflood exponential decline rate used in figure A8 was 25%, which is the average rate for similar waterfloods in the area.

Future Research

TORP has been researching three areas of research in the gel polymer technology. They include: 1) continued study on the chromium - polyacrylamide systems, 2) a polysaccharide system which has a gelation time that is a function of pH, and 3) selecting new environmentally safe crosslinking systems.

Technology Transfer Recommendation of DOE

Technology transfer can be broken down into three types which differentiate the goals involved in the transfer of a technology. These types of technology transfer are technology development, technology acceptance, and technology application. "Technology development" centers on the scientist who is conducting the research, and who makes the results available in publications in professional journals. "Technology acceptance" requires shared responsibility between development and application personnel. The goal is to ensure that the technology is accepted, or at least understood, by someone who has the knowledge and the resources to apply and/or use the technology. "Technology application" is also shared responsibility between the development and application personnel, however the goal is to apply the technology and show a profit in the marketplace.

Each of the three levels of technology transfer are very important. As presented in Figure A10, the first level is the development of the technology and without this level, neither of the two higher levels are needed. Therefore an optimum technology transfer program must have all levels of technology transfer to be effective. The key is to develop a program which is efficient in networking the technology developers (researchers) to the technology users. To facilitate this goal, technology users must be linked more directly and actively to the development of the technology.

FIGURE A10. – Technology transfer at three levels of involvement.

It is recommended that the Department of Energy concentrate on training and assistance of university laboratories, in technology acceptance and technology implementation. For instance, develop resource centers in which technical personnel can work with oil operators in technology acceptance and implementation.

Conclusions

Permeability Modification is a potential chemical technology for the independent operator. The technology is adaptable for the independent operator. It has been successfully implemented by independent operators with very favorable economics.

Before chemical technologies can be successfully implemented, they should be matched with identified problems the domestic operators have and adapt them to fall within the constraints of the independent operator.

References:

Schoeling, L. G., Green, D. W. and Willhite, G. P., "Introducing EOR Technology to Independent Operators," Journal of Petroleum Technology, December 1989.

Chemical-EOR Diverting Treatments for Improving Sweep and Reducing Water Production

Robert D. Sydansk
Marathon Oil Company

Chemical-EOR diverting treatments for promoting sweep efficiency and reducing water production constitute a technology that has recently proven itself in a number of instances to be both technically and economically attractive. Unfortunately, these diverting treatments have at times not been recognized as a bona fide chemical EOR technology. When applied as sweep-improvement treatments, this chemical EOR technology has been shown in the field to be able to generate, in a number of instances, relatively large volumes of incremental oil production in a profitable manner. Large volumes of incremental oil production per pound of chemical injected and/or per barrel of treatment fluid injected have been obtained.

Diverting treatments are applied for the purpose of improving sweep efficiency during oil-recovery operations where the poor sweep arises from reservoir

heterogeneities. The primary mechanism by which diverting treatments operate involves permeability reduction in the high-permeability flow paths and the promotion of favorable flow diversion — as opposed to improving sweep efficiency resulting from viscosity enhancement of drive fluids and the improvement in associated mobility ratios. Water shutoff treatments fall within the scope of diverting treatments. A partial list of chemical technologies that can be employed in conjunction with diverting treatments includes: 1) gels (inorganic and organic [polymer and monomer based]), 2) selected polymers alone, 3) resins, 4) microfine cement, 5) inorganic precipitates, 6) foams, 7) polymer-enhanced foams, and 8) foamed gels.

Diverting treatments for improving sweep efficiency are applicable in conjunction with all forms of secondary and tertiary oil-recovery operations. Diverting treatments for improving sweep are especially needed and applicable in conjunction with gas flooding being conducted in reservoirs suffering from fracture conformance problems. Diverting treatments for improving sweep have been referred to as conformance, conformance-improvement, conformance-control, profile modification, and permeability-modification treatments. Especially attractive are sweep-improvement diverting treatments which are applied to fracture conformance problems involving vertical fractures and the treatment of associated areal conformance problems. Thus, diverting treatments for improving sweep efficiency encompass treatments for both areal and vertical conformance problems. As such, diverting treatments are not limited to profile modification treatments.

Diverting treatments applied as water shutoff treatments can be used to reduce operating, lifting, water-handling, water-treating, and water-disposal costs — in turn, leading to more profitable oil-recovery operations and the possibility of extending the lives of certain marginal reservoirs. Reduced water production can alleviate environmental concerns and help meet existing and future environmental regulations relating to water production. Water shutoff treatments can be used to promote incremental oil production and to reduce operating costs in conjunction with primary oil recovery operations.

Diverting treatments for improving sweep are a chemical EOR technology that provides a means to help attain a series of goals that the DOE and the oil industry hold in common. Diverting treatments are an emerging technology that can, and will likely, have a significant impact in the near and intermediate term by generating significant amounts of incremental oil production in an economically attractive manner from identified,

proven, well-defined, and maturing U. S. reservoirs. Such treatments should be applicable as a means of extending the economic life of a number of mature oil reservoirs which are approaching their economic limit and abandonment. Since diverting treatments are often relatively small volume and inexpensive treatments and are usually available from service companies, they will be attractive to small independent operators, as well as major oil companies. After application of a diverting treatment, the reservoir is normally returned to the conventional oil-recovery operations which were in place prior to the treatment. The volume of oil mobilized by the conventional oil-recovery flood after the application of a diverting treatment can be large. Such incremental oil production is usually obtained from fields where the full infrastructure for the oil-recovery operations is already in place.

Selected field results were reviewed to illustrate successful applications of chemical-EOR diverting treatments for improving sweep and reducing water production. The generation in a profitable manner of substantial volumes (3,700,000 STBO gross) of incremental oil production resulting from the application of 29 Cr^{III}-carboxylate/acrylamide-polymer gel treatments, which were applied to fractured reservoirs under waterflooding in Wyoming's Big Horn Basin, were reviewed. Nine of these gel treatments were applied as injection-well treatments in a single field to either the Embar carbonate formation or the Tensleep sandstone formation. For these nine injection-well treatments, the average treatment cost was \$34,000 and projected ultimate incremental oil production per treatment, on the average, is 320,000 stock tank barrels — yielding the average reservoir development cost for the incremental oil production to be \$0.11 per barrel. Recently reported field results involving the successful application of Cr^{III}-carboxylate/acrylamide-polymer gels as conformance-control treatments in conjunction with CO₂ flooding were briefly discussed. B. R. Anderson of Amoco reported in *SPE EOR Field Reports* (Volume 17, Number 2, pages 3725-3728) that for the Amoco, Wertz field, Tensleep reservoir, CO₂ miscible tertiary flood, "In total, eight polyacrylamide gel treatments with Marathon's [Cr^{III}-carboxylate/acrylamide gel] process were completed. Results have been favorable both technically and economically Successful conformance modifications allow recovery of previously unswept zones." It was also noted that these gels have been used as gas shutoff treatments in a major Alaskan reservoir to reduce excessive gas production and, in turn, have at times rendered substantial increases in oil production. An overview was presented of the performance of a series of 16 Cr^{III}-carboxylate/acrylamide-polymer gel water shutoff treatments which were applied as production-well treatments in fractured reservoirs. The average water

production per well was reduced through application of these 16 treatments from 4,020 BWPD prior to the treatments to 1,150 BWPD following the treatments. The treatments resulted in gross water-production reduction of 46,000 BWPD.

It is recommended that chemical-EOR diverting treatments for improving sweep and reducing water production be pursued and promoted by the DOE as a technology for generating incremental oil production in the near and intermediate term from identified, proven, and mature U.S. reservoirs and as a technology to help extend the economic lives of certain U.S. oil reservoirs nearing abandonment. It is further recommended that the DOE fund development, especially in academia, of improved chemical-EOR diverting-treatment fluid systems and application techniques. Proper problem diagnosis, candidate selection, and treatment-fluid placement remain significant problems. These are areas in which fruitful additional development work should be conducted in order to help insure more widespread application of successful chemical-EOR diverting treatments. It is also recommended that chemical-EOR diverting treatments be included as a bona fide EOR technology category for inclusion in any future government EOR incentive programs.

OFPG Field Experiences with Well Treatment Gels

L. A. Burkholder and J. A. Sutphen – OFPG Inc.

M. A. Gruenenfelder

OFPG Inc. (formerly Oil Field Products Division of Pfizer Inc.) has been involved in the treatment of over 1,200 wells since our formation in 1982. Approximately 800 of these have been injection wells for water profile control and 400 production wells for water shutoff. Through these two approaches, a very large percentage of incremental oil can be recovered. Gel systems are available for fractured and matrix formulations of any lithology and temperatures to 260°F. Some formulations are selective in placement and required no mechanical isolation, saving significantly on treatment costs. Timely and appropriate application of these technologies can reduce or delay the decline of older fields and, as a precursor to chemical flooding, improve the performance of those technologies. This presentation will discuss the gel technologies available, well treatment limitations, typical costs associated with treatments, and actual field experiences of OFPG Inc. Emphasis will be put on design considerations, lessons learned, and typical results of these past experiences, as well as guidelines for future applications.

Mobility Control Projects for the North Burbank Unit

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Phillips Petroleum Company

The North Burbank Unit (NBU) is a large sandstone reservoir located in northeastern Oklahoma. The NBU field covers some 18,000 acres and contained 671 million barrels of original oil in place (OOIP). Primary production from the field began in the 1920's and waterflooding began in the mid 1950's. Expansion of the pilot waterflood project in the southern end of NBU did not recover as much oil as originally projected until directional permeability trends associated with joints and natural fractures in the reservoir were recognized and pattern configurations changed to account for this directional permeability. The northern portion of NBU, in addition, also exhibits a high degree of vertical heterogeneity. Due to the poor waterflood sweep efficiency resulting from the high degree of areal and vertical heterogeneity, polymer flooding was recommended in the northern portion of the unit to improve horizontal and vertical conformances and to increase displacement efficiency. Consequently, a 1440 acre fresh water polymer flood project was instituted in the Block A area of NBU in 1980. The polymer flood project area encompasses 84 producing wells and 36 injection wells. For the project, 20 production and injection wells were re-drilled and 29 wells worked over or converted to re-establish the 20-acre staggered line drive used for the original waterflood pattern. Six water disposal wells were also drilled to dispose of the produced brine as the Block A project utilized fresh water for the injection fluid.

The Block A polymer flood project utilized the sequential injection of polymer-aluminum citrate-polymer to build resistance to the flow of water in the formation. Polymer was injected at a concentration of 500 ppm prior to aluminum citrate injection; the polymer after aluminum citrate injection was injected initially at 500 ppm and then decreased sequentially to 250 and 50 ppm concentration before injection of fresh water and then brine postflush. A total of 4.17 million active lb. of a high molecular weight polyacrylamide was injected into the 36 project injection wells (42 percent pore volume slug), along with 4.02 million lb. of aluminum citrate solution (116,000 lb. of active aluminum ion). Total polymer injected per well was on the order of 116,000 lb. per well.

The sequential injection of polymer/aluminum citrate/polymer was effective in increasing the resistance to the flow of water in the project area. A decrease in injection rate and a wellhead pressure increase were recorded at most project injection wells. Pressure falloff tests conducted before and during polymer injection showed that polymer

injection was effective in reducing in-situ fluid mobility. The target injection rate into the project area was 63,000 BWPD, but the actual injection rate only averaged 45,000 BWPD due to the lower injectivity of the polymer solution as compared to fresh water.

Production response to the Block A fresh water polymer flood project was very favorable. The oil production rate increased from a pre-project rate of 15,900 BOPM to a peak of 35,500 BOPM after polymer injection was initiated and the producing water-oil ratio (WOR) decreased from over 100 (pre-project) to less than 50 before starting to rise again. The oil production rate started to increase before polymer injection because of the drilling of 20 new wells and workovers on another 29 wells; however, the producing WOR did not respond until after polymer was injected. Incremental oil recovery from the project was estimated to be 2.66 MM STB (4.5 % OOIP) by decline curve analysis when the shutdown of producing wells during continued waterflooding is accounted for. Incremental oil recovery was also estimated using a plot of producing WOR versus cumulative oil production. The producing WOR was extrapolated to an economic limit of 150 both for continued waterflooding and for polymerflooding. The difference in cumulative oil recovery between polymerflooding and continued waterflooding was 2.54 MM STB, which compares very closely to the value of incremental oil recovery determined from decline curve analysis.

The interior producing tracts, Tracts 41, 42, and 43, exhibited the greatest response to polymer injection and produced 62 percent of the incremental oil recovery, whereas the six exterior producing tracts produced only 38 percent of the incremental oil. Incremental oil recovery by well could be correlated to pore volume and degree of confinement by polymer injection. Total project oil recovery was estimated to be approximately 4.3 MM STB (7.3 percent OOIP). Problems with disposal of producing brine caused total fluid production rates in some producing wells to be curtailed. Production response to polymer injection would have been greater if all producing wells had been operated in the pumped off condition.

The Block A fresh water polymer flood project was both a technical and economic success. Even though the Block A area only accounts for 8 percent of the total unit area, it currently produces 40 percent of the unit production. The successful EOR project in the Block A area has extended the producing life of the marginally economic North Burbank Unit and increased ultimate oil recovery from the reservoir.

Even though the Block A project was successful, total costs of \$14.20 were required to produce a barrel of oil. This includes the cost to drill and workover wells, chemical costs and total operating costs. In an effort to reduce the cost to recover a barrel of incremental oil, Phillips Petroleum Company is implementing a microbial EOR (MEOR) process and a brine polymer flood process. The MEOR process was designed to improve sweep efficiency by means of in-depth permeability modification which results from in-situ microbial growth and polymer production. The process utilizes the sequential injection of nutrients essential for microbial growth in order of decreasing retention in the formation. The nutrients combine in-depth to form a complete growth medium. Two stages of sequential MEOR nutrient injection and one stage of nutrient co-injection have been completed in a single injection well pilot in NBU. Pressure falloff/injectivity tests have been conducted periodically on the MEOR pilot injection well and have indicated some reduction in in-situ fluid mobility due to the MEOR process.

A brine polymer flood pilot is also being conducted this summer in NBU. Polyacrylamide dissolved in brine will be co-injected with a metallic ion crosslinker to build flow resistance to injected water in the fractures and high permeability streaks and divert injected fluids to less flooded regions with higher oil saturations. The crosslinkers which have been tested in the laboratory include compounds of zirconium and titanium. If the brine polymer flood pilot is successful, the process will be extended to a 160 acre pilot with 4 injection wells and 12 production wells before being expanded to the remaining portion of the unit which is amenable to mobility control EOR processes. Using produced brine as the polymer solvent makes polymerflooding less expensive as fresh water does not have to be acquired and treated and produced brine from the polymer flood project area can be injected rather than disposed of. The use of produced brine rather than fresh water also reduces operating problems (reduced corrosion, producing wells can be pumped off more easily, etc.). Phillips remains vitally interested in EOR for this large secondary recovery unit with approximately 361 MM barrels of oil remaining.

The Current Status of the Mobility Controlled Caustic Flooding (MCCF)

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Improved Petroleum Recovery Consultants

The Mobility Controlled Caustic Flooding (MCCF) is an improvement over the traditional Caustic Flooding in which the early breakthrough of the injection chemicals is avoided and the emphasis is placed upon the improvement of the injection profile and the volumetric sweep efficiency. Other differences between Caustic Flooding and MCCF are stated in the excerpts from the MCCF brochure given on the last page. In this process, alternate slugs of two dilute solutions, first of highly alkaline soluble silicate, and then of calcium chloride, separated by a water spacer, are injected in the reservoir.

Upon in-situ contact with some crude oils, a part of the alkaline silicate:

- 1) produces a surfactant that is very effective because the nearby water has been "softened" by the silicate,

- 2) drastically reduces the surfactant adsorption loss and thus prolongs the surfactant life and effectiveness. The surfactant lowers the interfacial tension and helps mobilize and produce the residual oil by improved displacement efficiency.

Another portion of the silicate then reacts with the calcium chloride slug to produce a non-sticking mobility reducing fines which reduces the water mobility by: 1) reducing the water permeability through a brush heap effect, and 2) by increasing the effective water viscosity by making water behave non-Newtonian, much in the same manner that the blood cells make the blood behave non-Newtonian and increase the blood serum viscosity. Furthermore, the low interfacial tension causes the formation of an emulsion which could become stabilized by the fines and also improve the mobility ratio by increasing the displacing fluid viscosity.

In the past, the MCCF process has been used in two California fields, two Texas fields and one field in Siberia. Recently it was also used in Oklahoma and Texas.

The first California field test consisted of two MCCF injection wells surrounded by eight production wells in an 18 gravity oil reservoir with an irregular well pattern separating the injection/production wells by 200-300'. The nine month test was trouble free, sealed the thief zones between injection and production wells and produced 15,000

bbl of incremental oil at a chemical cost of \$18,000.00 or about \$1.20 per bbl incremental oil.

The second California test was done in a 420 acre 22 gravity oil reservoir with 16 injectors and 22 producers. Again the thief zones were sealed and 400,000 bbl. of incremental oil at a chemical cost of \$268,000 or less than \$1.00 per bbl incremental oil.

The two Texas tests were in a 34 gravity oil reservoir, one was a 92 acre secondary project and the other a 97 acre tertiary one. The combined production decline of 60% was leveled off and the injection profiles were drastically improved.

The Siberia (1000 miles east of Moscow) test has not been reported, but the Petroleum Engineer International recently reported that a similar test in Kazakstan has changed the production from 90% water to 90% oil in Guilfaks field.

Recently, the MCCF process was re-applied to the Texas field to study the mechanism of the process by injecting the chemicals in one well as a design phase while conducting many reservoir characterization tests before and after MCCF including 3D seismic, log inject log, pressure falloff, pulse tests, tracer tests and injection profile surveys. After two-months of MCCF chemical injection, the injection profile increased by 445%, but as soon as the injection of the unfiltered salt water containing particulate sticking matter was resumed, the injection interval was decreased. A very interesting side feature of the test was that the pulse test revealed an unexpectedly large 60:1 directional permeability which is highly detrimental, even to the waterflood.

A current field test in an Oklahoma 29°API oil field is being carried out to test the precipitate recycle concept. In this concept, the divalent cations of the injection water are first removed to improve the surface activity for the emulsion formation in the ground. Then the required calcium chloride is made by reacting the precipitate with HCl. This aspect of the process makes it very unique, but also inexpensive, because it uses HCl, which is a by-product of caustic productions anyway, instead of purchasing calcium chloride; and by not having to use a water softener which requires salt water disposal, the process becomes more environmentally friendly. The LACT average shipment increased by 10% from 400 BOPD to 440 BOPD shortly after the start of the test in late '92 and continued to the writing of this report in June 1993.

The test of the precipitate recycle was highly successful even though the existing field equipment was cannibalized to make the needed facilities to economize.

Thus far, the results of the MCCF trials have been both gratifying in producing inexpensive incremental oil, and puzzling for the lack of uniform results from uniform treatments! *We need to better understand the mechanism of the process and its limitations.*

The MCCF process is most applicable to the highly heterogeneous poor water floods having and adverse mobility ratio of greater than 2 and Dykstra Parson's permeability variation of greater than 0.7 based on our current knowledge, there are no depth or temperature limitations.

Although the MCCF process and the precipitate recycle concept have been field tested, more research work in the following areas could help optimize the process and improve its acceptance by the operators of the stripper wells. If successful, this process has the potential of decreasing national dependence on imported oil by increasing its oil production from the watered-out and virgin reservoirs very economically.

1. Further evaluate the mechanism and better establish the limitations and potential of the process.
2. Expend the application using other chemicals that could produce non-sticking fines for mobility control.
3. Develop software to simulate the MCCF process for the design of field-wide projects.
4. Initiate small and large demonstration projects using the following concepts:
 - The present MCCF
 - The precipitate recycle
 - Extension of MCCF
5. Help Independent Oil Companies apply the process to stripper wells.

Final Note:

This type of process could have the potential of decreasing the national dependence on imported oil by reconciling the environmental as well as the energy demand by increasing the oil production from the watered-out and virgin reservoirs by an inexpensive and yet environmentally friendly method.

U.S. DOE's Chemical Enhanced Oil Recovery Research Program

Jerry Casteel
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Presented at the Chemical EOR Workshop
June 23-24, 1993

INTRODUCTION

The Department of Energy's Enhanced Oil Recovery Research program is changing. The emphasis of Research and Development has been broadened to include near-term research from almost exclusively long-term, high risk research. This new direction will be to fund projects which will have significant impact on oil recovery in the near-term and mid-term application. Long-term research will, however, still play an important role in the overall research program.

The Bartlesville Project Office will play a significant role in implementing the new Enhanced Oil Recovery programs toward achieving the new goals and objectives of the National Energy Strategy. The role of the Bartlesville Project Office in domestic Chemical Flooding Enhanced Oil Recovery programs will be presented in this paper to place in perspective what DOE has done in past and what DOE is currently doing in Chemical Flooding Enhanced Oil Recovery.

BARTLESVILLE PROJECT OFFICE

History of the Bartlesville Project Office

The federal petroleum research facility at Bartlesville was established in 1918 as Petroleum Experiment Station. This facility has undergone several name changes and administered by under several departments. Summarized below is the progression of these changes.

Date	Name	Bureau/Department
1918-1936	Petroleum Experiment Station	Bureau of Mines/Department of Interior
1936-1959	Bartlesville Petroleum Experiment Station	Bureau of Mines/Department of Interior
1959-1971	Bartlesville Petroleum Research Center (BPRC)	Bureau of Mines/Department of Interior
1971-1975	Bartlesville Energy Research Center (BERC)	Bureau of Mines/Department of Interior
1975-1977	Bartlesville Energy Research Center (BERC)	Energy Research and Development Administration (ERDA)
1977-1983	Bartlesville Energy Technology Center (BETC)	Department of Energy (DOE)
1983-1993	Bartlesville Project Office (BPO)	Department of Energy (DOE)
1993-	Bartlesville Research Facility ?	Department of Energy (DOE)

The Bartlesville Project Office (BPO) was formed when the Bartlesville Energy Technology Center was defederalized in 1983. The facility is operated by the IIT Research Institute for the U.S. DOE under a cooperative agreement. The operation of the facility is being changed to a Management and Operation (M&O) contract beginning October, 1993 with BDM, Oklahoma as the M&O contractor to DOE.

Mission of the Bartlesville Project Office

The lead mission assignment of the Bartlesville Project Office is the implementation of Fossil Energy Research in Enhanced Oil Recovery (EOR) subprograms for light and heavy oil, the Advanced Extraction and Processing Technology (AEPT) subprogram and the Tertiary Oil Recovery Information System (TORIS) subprogram.

The mission of the Bartlesville Project Office is:

- (1) to assist in program formulation;

- (2) to develop and execute implementation plans for research that will advance oil production technology for the currently unrecoverable petroleum resource base;
- (3) to implement technical research projects which develop environmentally acceptable processes and improve fundamental understanding of novel concepts in EOR and geoscience;
- (4) to implement cross-cutting geoscience research along with other fundamental chemical, physical, and thermodynamic studies;
- (5) to implement transfer of EOR/AEPT technology to the scientific and technical user community.

Program Responsibilities of the Bartlesville Project Office

The responsibilities of the Bartlesville Project Office are:

- (1) to formulate and execute implementation plans for the national petroleum research program which plays a critical role in the effort to arrest the decline of domestic oil production and to reduce oil imports;
- (2) to be the Lead Center in Enhanced Oil Recovery for light and heavy oil, Advance Extraction Process Technology, Tertiary Oil Recovery Information Systems and a major portion of the Department of Energy's petroleum research;
- (3) to contribute to the Decentralization Concept;
- (4) to monitor, coordinate and evaluate petroleum research projects with other Energy Technology Centers, Project Offices, Site Offices, National Laboratories, universities, private contractors, foreign governments and international organizations.

FEDERAL OIL RESEARCH PROGRAM FOR MAXIMIZING PRODUCIBILITY

Evolution of Federal Oil Research Program

In 1974, immediately after the oil embargo of 1972-1973, the Federal EOR Research Program was established with the concept that technology need only to be

demonstrated to gain widespread application. Twenty-seven cost-shared field demonstration projects were conducted to "prove" the technology. The results from these demonstration gave mixed results. The reasons for the successes and failures experienced in the field could not be adequately explained because of limited technical understanding of the EOR process and the complexity of the reservoir.

During 1976-80, the Tertiary Incentive Program granted price relief to over 400 projects designed to increase oil production. The research program was focused on residual oil and specific EOR techniques and processes. Analysis of the resource base was initiated to identify the most promising types of reservoirs and to estimate overall EOR potential.

The target and scope were expanded during 1981-89 to include Discrepancy Analyses — comparing predicted results to actual field results. This became central to technology assessment and resource analysis since both cost-shared and incentive projects failed to produce significant oil. The National Petroleum Council, in cooperation with the Department of Energy, released a major assessment of Enhanced Oil Recovery in 1984.

Current EOR Program

Beginning in 1990, the Federal Oil Research Program seeks to maximize U.S. oil producibility through an integrated and interdisciplinary program. Two Class Program Opportunity Notices (PON) have been issued: Class 1, Delta/Fluvial-Dominated and Class 2, Shallow Shelf carbonates.

The PONs incorporate near-term, mid-term, and long-term goals into the EOR program. The goals are:

- (1) near-term (1-5 years)
to maintain access to resources in danger of abandonment and increase domestic production;
- (2) mid-term (5-10 years)
to maximize recovery from high potential reservoirs;
- (3) long-term (over 10 years)
to improve our understanding of the oil resource and technologies for extracting to resource.

The first of these goals shows that future research will include near-term research with more immediate application.

ENHANCED OIL RECOVERY PROGRAMS MANAGED BY THE BARTLESVILLE PROJECT OFFICE

Over the past 18 years, DOE and its predecessor, the Energy Research and Development Administration (ERDA), have funded projects relating to Enhanced Oil Recovery. The following summarizes projects which were managed by BPO and its predecessors BERC and BETC.

BPO Categorization of Enhanced Oil Recovery

Enhanced Oil Recovery at BPO is divided into an integrated program consisting of six (6) major categories.

1. Chemical Flooding
2. Gas Flooding
3. Thermal Recovery
4. Novel Technology
5. Geoscience
6. Microbial EOR (MEOR)

There is also a Technology Transfer section having a mandate to transfer technology by publishing reports, progress reviews, and sponsoring technical conferences, symposia and meetings. Additionally, the technical staff is available for discussion with the public and private sectors.

DOE funding for chemical EOR projects (1974-1993) is summarized below by process and contractor. Also the current funding is shown for the chemical flooding program.

Summary of Funding for Chemical Flooding EOR Projects (1974 – 1993)

Type	Number	Funding
Alkaline	4	\$5,493,403*
Enhanced/Surfactant	3	\$2,214,000
Polymer	18	13,116,283*
Surfactant	50	\$65,005,101*
Total	75	\$85,828,787*

* Including cost shared demonstration projects

Funding by Types of Chemical EOR Contractors:

Type	Number	Funding
Government/City	2	\$8,133,829*
Government/Foreign	1	\$0
Industry	16	\$46,967,016*
NIPER	8	\$10,828,000
National Laboratory	1	\$781,500
Small Business Innovative Research (SBIR)	1	\$48,000
University	46	\$19,070,442
Total	75	\$85,828,787

* Including cost shared demonstration projects

Current Chemical Flooding EOR Projects

There are currently 12 Chemical Flooding EOR projects, the funding levels, and the principal investigator and the length of the funding period are as shown below:

Contractor	DOE funding	Total funding
New Mexico Institute of Mining and Technology (Seright – 3 years)	\$604,000	\$1,304,000
University of Kansas (Willhite– 3 years)	\$704,000	\$1,311,000
University of Southern Mississippi (McCormick – 3 years)	\$846,000	\$890,000
Illinois Institute of Technology (Wasan – 3 years)	\$450,000	\$565,000
Columbia University (Somasundaran – 3 years)	\$602,000	\$602,000
University of Texas at Austin (Pope – 3 years)	\$766,000	\$1,054,000
Surtek (Pitts – 3 years)	\$493,000	\$493,000
Surtek – Heavy oil (Surkalo –1 year)	\$296,000	\$296,000
NIPER – BE4A (Gall – 1 year)	\$640,000	\$640,000
NIPER – BE4B – Heavy oil (French – 1 year)	\$200,000	\$200,000
NIPER – BE4C (Gao – 1 year)	\$240,000	\$240,000
NIPER – SGP41 – Heavy oil (Burchfield – 1 year)	\$618,000	\$1,260,000
Total Chemical Flooding	\$6,459,000	\$8,855,000

SUMMARY

The new Federal Oil Research Program, based on current policies and recent assessments of the oil industry and national needs builds upon the predecessor program but envisions a more comprehensive and timely approach. Its goal is to maximize the economic producibility to the domestic oil resource. The program will implement a highly targeted research, development, and demonstration (RD&D) plan in collaboration with the states and industry, focusing on the reduction of technical and economic constraints on producibility to produce the enormous potential of the resource remaining in known domestic reservoirs. The main purpose of the Workshop is to help determine where and what chemical flooding processes to implement in the Federal EOR program.

APPENDIX II BIOGRAPHICAL INFORMATION

Jerry F. Casteel

Jerry F. Casteel is a Project Manager in the Bartlesville Project Office of the Department of Energy's Office of Fossil Energy. He coordinates and monitors DOE funded Chemical and Gas Flooding and related research activities. He has been involved in EOR research for more than 20 years that includes gas and chemical flooding research at Amoco Production Research and Cities Service Research. He holds a patent in polymer flooding. He participated in the 1984 National Petroleum Council EOR study and was a member of the Program Committee for 1990 SPE/DOE EOR Symposium and Co-chairman of 1988 SPE/DOE EOR Symposium Section on Carbon Dioxide Field Test. Between 1981 and 1983 he was on the Editorial Review Committee for SPE in Chemical and Gas flooding. He holds a B.S. in Chemistry-Mathematics from Northeastern State College, a M.S. and a Ph.D from the University of Arkansas in Physical Chemistry. His postdoctoral research in the areas of nonaqueous solvents was performed at the University of Kentucky.

G. Paul Willhite

G. Paul Willhite is the Ross H. Forney Professor of Chemical and Petroleum Engineering and codirector of TORP (Tertiary Oil Recovery Program) at the University of Kansas in Lawrence, where he also chairs the Chemical & Petroleum Engineering Department. He holds a B.S. degree from Iowa State University, and a Ph.D. degree from Northwestern University, both in chemical engineering. A Distinguished Member and author of the SPE textbook *Waterflooding*, Willhite received the 1986 Lester C. Uren Award and the 1981 Distinguished Achievement Award for Petroleum Engineering Faculty. He was University of Kansas Student Chapter faculty sponsor during 1981-84 and served on the 1982-85 Education and Accreditation Committee. He also served on steering committees for the 1985 and 1988 Forum Series and on program committees for the 1988 Annual Meeting and the 1988 SPE/DOE Symposium on Enhanced Oil Recovery.

K. D. Dreher

K. D. Dreher is Manager, Chemical and Metallurgical Technology, at Marathon Oil Company's Petroleum Technology Center. Previously, Dreher was a research scientist emphasizing micellar/polymer flooding, thermal recovery techniques, and improved well completions. He has served the SPE as Chairman of the Oilfield Chemistry Symposium

Committee (1979) and as a technical reviewer (1985-86). He joined Marathon in 1967 after completing two years postdoctoral work in surface chemistry at Columbia University.

Joseph J. Taber

Joseph J. Taber was the first director and is now director emeritus of the New Mexico Petroleum Recovery Research Center, New Mexico Institute of Mining and Technology, where he continues his study of advanced recovery methods. He previously was a professor of petroleum engineering and chemistry at the University of Pittsburgh and a senior project chemist working on new oil recovery methods at Gulf R&D Co. He has 8 patents on improved oil recovery and a number of publications on surfactant and solvent flooding. Taber's recent papers have dealt with CO₂ flooding (including some environmental issues) and the use of horizontal wells for EOR or waterflooding. He holds a B.S. degree from Muskingum C. and a Ph.D. from the U. of Pittsburgh. Taber was a 1989-90 Distinguished Lecturer on EOR.

Gary A. Pope

Gary A. Pope is the Director of the Center for Petroleum and Geosystems Engineering at The University of Texas at Austin. He holds the Getty Oil Co. Centennial Chair in Petroleum Engineering and is the former chairman of the Department of Petroleum Engineering, where he has taught since 1977. Before that, he worked in Production Research at Shell Development Company for 5 years. He earned a B.S. degree from Oklahoma State University in 1967 and a Ph.D. from Rice University in 1971, both in Chemical Engineering. His teaching and research are in the areas of enhanced oil recovery, reservoir engineering, reservoir simulation, environmental remediation, the use of tracers for reservoir characterization, and phase behavior.

Richard C. Nelson

Richard C. Nelson retired from Shell in 1989 after 35 years of service. The last 15 of those years were devoted to research and field testing of chemical methods of enhanced oil recovery. He has published 12 technical papers and holds five patents on surfactant flooding and cosurfactant-enhanced alkaline flooding. He now consults in those fields. Nelson is a member of SPE; he was Program Chairman for the Fourth SPE/DOE Symposium on Enhanced Oil Recovery. He holds a Ph.D. in physical chemistry from the University of Washington.

Malcolm J. Pitts

Malcolm Pitts is Director of Petroleum Technology of Surtek, Inc. He has been a consultant in chemical enhanced oil recovery for 13 years and has designed micellar-polymer, mobility control polymer, alkaline-polymer, and alkaline-surfactant-polymer floods for fields in the United States, Canada, North Sea, Hungary, Indonesia, Japan, Germany, People's Republic of China, Colombia, and Argentina. He has also applied chemical enhanced oil recovery concepts to clean-up of two super-fund sites contaminated with oily waste. He has 14 publications dealing with removal of oil from porous media using chemicals. He has been involved with the Society of Petroleum Engineers on local and international levels and has served as the Denver Petroleum Section Chairman. He received a B.A. degree in chemistry from the University of Colorado, a M.Sc. in Biochemistry from Purdue and a Ph.D. in chemistry from Georgetown University.

Lanny Schoeling

Lanny Schoeling is enhanced oil recovery liaison engineer between the Tertiary Oil Recovery Project (TORP) at the University of Kansas and the oil industry. He is responsible for designing and implementing EOR processes with an emphasis on reservoir evaluation and simulation. For the past year he has been working with the U.S. Department of Energy Bartlesville Project Office in the development of a technology transfer program. Prior to joining TORP in 1983, he was employed by Amoco Production Co. He holds a masters in chemical engineering from the University of Kansas, and is currently working on his Doctorate in engineering. He is a registered professional engineer.

Robert D. Sydansk

Robert D. Sydansk is an Advanced Senior Engineer at the Petroleum Technology Center of Marathon Oil Company. During his 26 years in improved-oil-recovery research, he has developed a number of new improved-oil-recovery processes that have been translated to field-scale applications. Bob has amassed substantial field experience resulting from extensive involvement in the field demonstration programs relating to four of this newly developed technologies. He is presently concentrating on the development of new chemical-EOR diverting-treatment fluid systems. He was the principal inventor and developer of the quite successful and now widely applied Cr^{III}-carboxylate/acrylamide-polymer gel diverting-treatment technology. Bob is a chemistry

graduate of the University of Colorado, with minors in mathematics and psychology. He is the inventor or co-inventor of 36 U.S. and 68 foreign patents relating to improved oil recovery. He has also authored or co-authored 20 technical papers in the area of improved oil recovery.

Lawrence A. Burkholder

Lawrence A. Burkholder is Vice President and General Manager of OFPG Inc., a subsidiary of SNF France. He has been involved in chemical EOR since 1974. Prior to his current position, he was Technical Director for Pfizer's Oil Field Products Division, which was sold to SNF in May, 1993. His area of focus has been xanthan and polyacrylamide polymer flooding and conformance and water shut off gels. OFPG Inc. has provided polymers and services for over a dozen floods and 1000 well treatments around the world. Mr. Burkholder holds a B.S. in Chemical Engineering from Ohio University.

Paul D. Moffitt

Paul Moffitt is a Senior Reservoir Engineering Specialist with Phillips Petroleum Company in Bartlesville, Oklahoma. He holds a BS degree from Oklahoma State University in agricultural engineering and an MS degree from the University of Oklahoma in petroleum engineering. He has worked for Phillips for 16 years in the areas of reservoir engineering, reservoir simulation and enhanced oil recovery. He is currently working in the Improved Oil Recovery Section and specializes in waterflooding, polymer gels and polymer flooding and reservoir simulation. He has authored or co-authored eight technical papers in the area of enhanced oil recovery.

A. M. Sam Sarem

A. M. Sam Sarem is the president of the Improved Petroleum Recovery Consultants. He recently retired from Unocal Science and Technology after 38 years of oil industry service in various technical, teaching, and managerial capacities in improved oil recovery, reservoir engineering, and wellbore mechanics. Prior to retirement, he held the highest technical position in the Production and Development Technology of Unocal Energy Resources concentrating on Improved Oil Recovery Problems. He has over 30 patents and over 20 publications on Improved Petroleum Recovery, was 1983-84 SPE Distinguished Lecturer on the Application of Reservoir Characterization to Infill Drilling and EOR, 1989 SPE Distinguished Author on Infill Drilling, 1992 SPE Distinguished

Member, and a member of SPE Century Club. He holds a BSPE and a MSPE from Tulsa University and a Ph.D. in Engineering Science from OU and is registered as a PE in Oklahoma.

APPENDIX III
AGENDA FOR CHEMICAL EOR WORKSHOP

Tuesday 6/22/93

5:30 to 7:00 PM Registration – Lobby Landing

Wednesday 6/23/93

7:00 to 8:30 AM Registration – Preconvention Area

7:30 to 8:30 AM Breakfast – Atrium Terrace

Presentations – Corpus Christi
Session Chairman Rebecca Bryant (NIPER)

8:30 to 8:40 AM	Opening remarks (Alex Crawley, Program Coordinator, DOE/BPO, and Tom Burchfield, Director, EPR, NIPER)
8:40 to 9:20 AM	Chemical Flooding — Will it Survive? (Karl D. Dreher—Marathon Oil Co.)
9:20 to 9:50 AM	Can Horizontal Injection (and Production) Wells Save Chemical Flooding? (Joseph Taber—New Mexico Tech)
9:50 to 10:20 AM	Observations About Surfactant Field Tests and Future Implications (Gary A. Pope—University of Texas at Austin)
10:20 to 10:30 AM	Break
10:30 to 11:00 AM	Laboratory and Field Performance of a Surfactant/Alkali Flood (Richard C. Nelson—Consultant)
11:00 to 11:30 AM	Alkaline-Surfactant-Polymer Flood of the West Kiehl, Minnelusa Unit and Alkaline-Polymer Flood of the David Pool (Malcolm Pitts—Surtek, Inc.)
11:30 to 12:00 AM	Permeability Modification – A Chemical Technology with Potential for Independent Oil Operators (Lanny Schoeling—TORP)
12:00 to 1:30 PM	Lunch – South Padre (keynote speaker: Don Juckett—Acting Deputy Assistant Secretary for Gas and Petroleum Technology)
1:30 to 2:00 PM	Chemical-EOR Diverting Treatments for Improving Sweep and Reducing Water Production (Robert D. Sydansk, Marathon Oil Co.)
2:00 to 2:30 PM	OFPG Field Experiences with Well Treatment Gels (Larry Burkholder, OFPG)
2:30 to 2:45 PM	Break

Wednesday 6/23/93

- 2:45 to 3:15 PM Mobility Control Projects in the North Burbank Unit
 (Paul D. Moffitt, Phillips Petroleum Co.)
- 3:15 to 3:45 PM The Current Status of Mobility Controlled Caustic Flooding
 (A. M. Sam Sarem, Consultant)
- 3:45 to 4:30 PM Discussions

Reception – Atrium Terrace 6:30 to 8:30 PM

Thursday 6/24/93

- 7:30 to 8:30 AM Breakfast – Preconvention Area

Workshops

- 8:30 to 9:00 AM DOE funded chemical advanced oil recovery projects –
 Corpus Christi (Jerry Casteel, DOE)
- 9:00 to 9:15 AM Explanation of the objectives and format of the workshops
- 9:15 to 10:30 AM Surfactant/alkali flooding workshop – Brownsville
 (Moderator: Jerry Casteel, DOE)
- Profile modification/polymer flooding workshop – Port
 Aransas (Moderator: Paul Willhite, University of Kansas)
- 10:30 to 10:45 AM Break
- 10:45 to 12:00 AM Surfactant/alkali flooding workshop (continued)
- Profile modification/polymer flooding workshop (continued)
- 12:00 to 2:00 PM Lunch – Atrium Terrace
- 2:00 to 3:00 PM Summary of group recommendations – Corpus Christi

APPENDIX IV WORKSHOP ATTENDEES

Name	Company
Iqbal Ahmed	Phillips Petroleum Company
Ron Braun	Texaco
Rebecca S. Bryant	NIPER
Lawrence A. Burkholder	OFPG
Thomas E. Burchfield	NIPER
Fred Burtch	
Jerry Casteel	U.S. Department of Energy
Harry Chang	ARCO
Ralph Cooke	EPT
Alex Crawley	U.S. Department of Energy
Dwight Dauben	Keplinger & Associates
Gene DeBons	Texaco
Randy E. Dobson, Sr.	Akzo Chemicals Inc.
Karl Dreher	Marathon Oil Company
Kamel H. Fotouh	Prarie View A&M University
Barbara J. Franklin	Texaco
Troy R. French	NIPER
Bonnie Gall	NIPER
Hong Gao	NIPER
George Hirasaki	Rice University
Tom Jacob	OFPG
Don Juckett	U.S. Department of Energy
Bayram Kalpakci	Westport Technology Center International
Dan Kieke	Texaco
Quintin Lai	ARCO
Sonny Llave	NIPER
Michael L. Lunceford	MetFuel Inc.
Jim Mack	TIORCO
Calvin C. Mattax	Consultant
Bharat G. Mody	Oil Water Ratio Control Inc.
Paul Moffitt	Phillips Petroleum Company
A. Moradi-Araghi	Phillips Petroleum Company
R. C. Nelson	Consultant
Leo Noll	NIPER
Kofi Ofosu-Asante	Procter & Gamble
Joe Papir	Chevron Chemical Company

Name**Company**

Kant Patel	Chevron USA Inc.
James Paul	Consultant
Craig Phelps	Mobil Research & Development Corp.
Malcolm J. Pitts	SURTEK, INC.
Larry Plonsker	Ethyl Corporation
Gary A. Pope	University of Texas
Sam Sarem	Consultant
Lanny G. Schoeling	TORP
Randy Seright	New Mexico Petroleum Recovery Research Center
Stacey Smyre	James E. Russell Petroleum Inc.
E. Thomas Strom	Mobil Research & Development Corp.
Harry Surkalo	SURTEK
Jim Sutphen	OFPG
Robert D. Sydansk	Marathon Oil Company
E. U. Syed	Chevron
Joe Taber	New Mexico Petroleum Recovery Center
Min Tham	NIPER
Scott Wellington	
Paul Willhite	University of Kansas
Larry Whittington	Texaco

APPENDIX V
ADDITIONAL COMMENTS AND RECOMMENDATION FROM
CHEMICAL RESEARCH PERSONNEL

INTRODUCTION

During and after the workshop, the organizing committee solicited additional comments from chemical research personnel. Five letters were received and are reproduced in their entirety in this appendix.

July 14, 1993

Dr. Min Kwan Tham
Senior Science Advisor
National Institute for Petroleum and Energy Research
P.O. Box 2128
Bartlesville, Oklahoma 74005

Dear Dr. Tham:

I thought the NIPER-DOE Chemical EOR Workshop was very useful. I hope the Department of Energy found it worthwhile as well. Considering the problem of where this country will obtain a reliable on demand energy source for my children's future needs, I hope some ideas for direction were defined.

Prior to my giving my recommendation and comments on about the meeting, I would like to give you a summary of the questionnaire Surtek sent out prior to the meeting. The results of the survey were presented at the Chemical Flood Workshop. The survey results are presented in the appendix. A few of the results are worth reiterating. First, the respondents felt that chemical enhanced oil recovery was less risky than exploration. Second, the majority of the respondents felt enhanced oil recovery was less expensive than other enhanced oil recovery technologies. Third, the majority of the respondents felt that a chemical enhanced oil recovery project was not simple to implement. This should be a concern to the Department of Energy if it is their intent to simulate wide spread use of the different technologies. Fourth, the good news is that each of the respondents felt that the Department of Energy could simulate their interest in using chemical enhanced oil recovery. Fifth and finally, 10 of the 36 respondents had not heard of the 15% federal income tax credit. This suggests that an information gap exists - a real area of concern.

Some of the direct answers to the question of "What could DOE do to stimulate your interest in chemical EOR?" ranged from benign to angry. The following a select few which might give DOE a feel for independent's thoughts.

- "More information on Tax Credit. Histories of chemical EOR projects close to Eastern Kansas made available. Inform us of the parameters used to select the chemical EOR projects"
- "Increase tax benefits, federal grants, aid in applying for federal grants. The DOE needs to impress upon President Clinton the importance of EOR and the petroleum industry to this country."

- "Financial incentives - cost sharing of feasibility studies, lab work and implementation."
- "The DOE has shown little or no interest in the domestic oil and gas industry. Before the DOE can stimulate my interest in any new or emerging technology, it must show a desire to see the oil industry survive, given the hostile attitude the federal government has shown toward it in the last 10 years."
- "Economics drive all we do. Since the DOE can not control our revenue (ie the oil price), they can help us by keeping the government from driving costs up through regulation and taxes. Government regulations are also accelerating the loss of access to our resource base (through early abandonment of wells). The sale of many large fields by majors to independents (as majors go overseas to a better investment environment) has created opportunities for the independents but has separated those fields from the technical know-how and capital required to fully develop the resource base available in these fields."

It is obvious from the workshop that there are a number of technologies available today which can improve oil recovery. None of the technologies are a "silver bullet" in that each can be applied to only to a limited number of reservoirs. A second item which is obvious is that the future oil production in the United States will be the result of action of the independents and not the majors. The majors are selling their properties to pursue more profitable production overseas. The logical conclusion then is the independents are the primary group in the United States which must implement the chemical enhanced oil recover processes which currently exist as well as ones which will be developed.

While research is necessary to build a future, any increases in United States oil production in the next 10 to 20 years must be performed primarily with the technologies which are either proven or emerging today. Therefore, my recommendations to the Department of Energy in prioritized order are:

- The Department of Energy needs to put emphasis on stimulating independent and major implementation of chemical enhanced projects in fields before they are abandoned. Since the independents will most probably be the United States producer of the future, DOE should concentrate on the independent sector. The PONS program is a good start and so is the 15% tax credit. However, more emphasis needs to be placed on actually putting chemical in the ground. Economics are what drive a project, so DOE should key on reducing monetary risk exposure to improve the rate of project implementation.
- The Department of Energy needs to sponsor some form of information exchange that will go to the engineer in his or her office. SPE meetings, workshops, etc are great but they reach a limited number of individuals.

With budgets and time in short supply, many companies have curtailed participation in these types of information exchange activities. In a video world, perhaps short informative video might serve as an interest inducement with written technical information and a staff or a consultant list available for further education.

- Continue research into innovative ideas. No industry can expect to survive without continual improvements!

Thank you for the opportunity to participate in the NIPER-DOE Chemical EOR Workshop and the chance to give you my recommendations.

My extended abstract is enclosed.

Sincerely,
SURTEK,

Malcolm J. Pitts, Ph.D.
Director - Petroleum Technology

cc: Don Junkett, DOE
Jerry Casteel , DOE
Thomas Burchfield, Niper

Appendix
SURTEK's Survey Response

Informal survey sent to 150 companies - 36 responded. Respondents ranged in Size from 9,100 Employees to 1.5 - average = 103 (excludes high and low). Total oil production of this group was 4.26 MM STB/mth.

The questions and answers are listed below.

Is _____ involved in any enhanced oil recovery projects?

<u>yes</u>	<u>no</u>
22	14

What type?

Waterflood (7), Miscible Gas (5), Polymer (8)
Thermal (2), Alkaline-Surfactant-Polymer (3)

Were tax benefits a deciding factor to implement the project?

<u>yes</u>	<u>no</u>
5	16

Are you aware of the current 15% Federal Income Tax Credit for qualifying EOR projects?

<u>yes</u>	<u>no</u>
26	10

What economic parameters would justify an EOR project?

Stable Oil Cost of \$22 (ave. of 7)
23.3% ROR (ave. of 7)
2.9/1 ROI (ave. of 4)
3.75 year payout (ave. of 4)

What are your finding costs per barrel?

\$5.50/bbl (ave. of 20)

What level of risk do you consider EOR compared with exploration in increasing your reserves?

<u>more</u>	<u>less</u>
5	24

*What is your impression of the simplicity of
implementing a chemical EOR project?
(1 simple to 5 complex)*

<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
0	2	12	7	10

*Do you feel that chemical EOR is more or less expensive
to implement than other EOR technologies (miscible gas, thermal, etc.)?*

<u>more</u>	<u>less</u>
7	19

What could the DOE do to stimulate your interest in chemical EOR?

Oil Import Tax (2)

Publish Case Studies (5)

Tax Credit (6)

Provide Some Screening Techniques for
Various EOR Technologies (2)

Funding to Offset Initial Investment (5)

Partial Funding of EOR Demonstration Projects (2)

Technical Assistance (3)

Robert J. Blackwell
8904 MEMORIAL DRIVE
HOUSTON, TEXAS 77024

August 16, 1993

Dr. Min Kwan Tham
Senior Science Advisor
National Institute for Petroleum and Energy Research
P.O. Box 2128
Bartlesville, Okla. 74005

Dear Min,

Thank you for sending me a Review Copy of your final report on the NIPER-DOE Chemical EOR Workshop. I regret not being able to attend the Workshop. I do not know what I did to hurt my back about a week before the meeting but I was certainly in no shape to contribute very much to your meeting at that time. Fortunately for me, my back is much better now; although I will probably continue to have reminders to be careful for some time to come.

I certainly agree with the comments which are expressed in the Introduction to the report concerning the potential loss of the industries expertise in the area of Advanced Oil Recovery process technology. Unfortunately, the cutbacks which all companies have been forced to make as a part of an overall cost reduction strategy within the industry has not been confined to Advanced Oil Recovery Research only and the magnitude of the overall problem facing the industry is greater than many people realize. Effective utilization of advanced oil recovery processes also requires input from geologists, geophysicists and other people with "Exploration" backgrounds, input from experts in drilling and completion technology, etc as well as input from "Downstream" research personnel such as the chemists, chemical engineers who provide the expertise needed to manufacture cost effective surfactants, mobility control polymers etc. Many man-years of valuable experience and knowledge in all of these areas are likely to be lost. Even though much of the research information is contained in the "archives" of the various research organizations, new production research employees often find it is difficult to go through 40 years of reports and separate the "wheat from the chaff;" and research conducted in company refinery research groups is often "lost for good." (I remember learning from Dr. W. K. Lewis, a long time professor at MIT and ESSO consultant starting sometime in the 1920's, about work done in 1928-29 in ESSO's lab's in N. J. which would have saved us a lot of work in the middle 60's on the use of polymers to increase the viscosity of enriched gas mixtures for use in miscible displacement processes. Doc Lewis remembered a "rule of thumb" which we had just "re-learned" (in 1965-66) for being able to incorporate a high molecular polymer into the enriched gas. Incidentally, even though it is possible to

increase the viscosity of the enriched gas up to several cp, it is not feasible economically.)

I am not particularly worried about the loss of EOR knowledge within the industry in the area of Advanced Secondary Recovery processes such as polymer-enhanced waterflooding, profile modification, etc because they are relatively inexpensive methods for improving the recovery of mobile oil. Similarly, I am not particularly worried that miscible displacement technology will be "lost" as long as the industry continues to conduct at least a few miscible gas (CO₂, etc) projects.

I concur with most of Gary Pope's " paper entitled "Observations about Surfactant Flooding and Future Implications." Although I think the industry may be closer to solving technological questions concerning the use of surfactant flooding processes than is generally recognized, I fear that most companies will be reluctant to undertake a surfactant flood even after real oil prices (in terms of current dollars) have increased sufficiently to ensure that the flood would be economically attractive surfactant at that price. The problem which arises is that the front end cost of initiating a large surfactant flood is so high that a relatively small drop in the oil price could lead to a large loss from the project.

Surveys of the amounts of kaolin, montmorillinite, and other "lower" order clays in several reservoirs in Texas, Illinois, etc, suggest that alkali consumption (accompanying the conversion of these clays into albite and feldspar by a long term alkali/clay/quartz reaction) would prevent the Surfactant/Alkali/Polymer process will be economically viable in those reservoirs. (The amount of kaolin in a reservoir near Houston was four times the amount needed to make an alkaline process uneconomic.) Thus, TORIS should be updated, if possible, to include information on the amounts and various clay types which are present in sandstone reservoirs.

I believe that several groups investigated the feasibility of using surfactant-aided imbibition technology to improve production from fractured reservoirs starting in the late 50's (58-60). I know that the idea was mentioned in an SPE paper by Joe Richardson and John Graham and I believe by groups from other companies also. However, I don't believe that the literature contains very much information about the use of use of surfactants to stimulate imbibition processes in fractured reservoirs. However, I am aware that a field test of the process was conducted in West Texas near the end of the 60's. (I assume that it is generally recognized that corrosion inhibitors used in water distribution lines often contain an oil wetting surfactant which, if injected accidentally into a fractured reservoir, can render the fracture surfaces oil-wet and thereby eliminate any possibility for counter-current imbibition. It is possible to correct this problem using an extremely water-

wetting surfactant; however, other factors can still limit the effectiveness of conventional imbibition processes--especially by repressuring the reservoir with water following a solution gas drive.)

As you know, I am a strong proponent of the development of better reservoir description methods and better methods for monitoring reservoir performance (ie project surveillance.) Nevertheless, I tend to become rather exasperated whenever I see a statement in a report which states that "failure of this project might have been prevented if the proper reservoir description had been available." Far too often, the person would not have been prepared to modify his process sufficiently to have improved the performance of the process very much, even if he known the reservoir geology precisely. (In some cases, the only thing the person could have done would have been to cancel the project before it was started!) Everyone recognizes these days (although that was not the case 30 years ago) that injection of enriched gas or CO₂ into a horizontal reservoir is inherently an unstable displacement process. Reservoir heterogeneities tend to aggravate the problem. The best approach to follow normally is to reduce the mobility of the injected fluids. Unfortunately, this may extend project life unduly unless the effective well spacing can be reduced in some way. This is a long winded way of introducing the next two paragraphs.

The possibility of drilling horizontal wells has often been proposed as a feasible way to reduce project life and to improve the overall sweep efficiency of a surfactant flood, for example. Joe Taber mentions a number of the advantages and disadvantages one can encounter using horizontal wells in a surfactant flooding project; and the potential advantages of using horizontal well is mentioned several times by other authors. Joe mentions that the performance of horizontal wells in a stratified reservoir with barriers to vertical flow can affect reservoir performance adversely. The possibility of drilling horizontal wells parallel to the orientation of hydraulic fractures and generating a vertical fracture has often been proposed in the past as a way to alleviate the stratification problem (and is usually followed by a discussion of the difficulty of fracturing a reservoir from a horizontal well). However, very few completion experts are willing to say, "It can't be done." And I suspect that it would be possible to find some company who would be willing to try if encouraged by the DOE!!

Although Texas laws would probably preclude the use of the following procedure in many areas of Texas, I want to mention that a procedure tested by Shell using a 36 well pilot in South Texas (I believe in the Big Indian field?) in which the line drive was created by lining up the wells along the fracture-trend for hydraulic fractures and then fracturing between injection wells and between producers. It is possible to still limit the total number

of wells to one per 40 acres and still reduce the spacing between successive injection and production lines considerably. Shell subsequently expanded the procedure to include about 360 wells. I believe the successful pilot results appeared in an article in the Oil and Gas Journal; however, I am not aware that the results obtained in the 360 well project were ever published. I mention this because whenever it is necessary to redrill very many wells in the reservoir, this is an alternative approach which could provide a somewhat better flood performance, especially in a highly stratified reservoir, than could be achieved by drilling a system of horizontal wells (unless the horizontal wells can be fractured sufficiently to connect up the overlying zones in the stratified reservoir. (This is another reason for encouraging work in the general area of finding better ways of utilizing horizontal wells in Chemical Recovery Applications.)

Finally, I want to put in a plug for your proposal to support research on better methods for "Remote sensing and monitoring of chemical EOR field tests, and controlling the process as the field tests are in progress." I would not be surprised if there are devices which have already been developed for the Dept. of Energy utilizing advanced fiber optic systems with multiple downhole detectors which could be cemented in place and used for monitoring "between well" seismic data, making downhole injection or production pressures as well as for making pressure transient (both single well and pulse test) measurements, etc.

Sincerely,

Rab

R. J. Blackwell

July 14, 1993

Dr. Min Kwan Tham
Senior Science Advisor
National Institute for Petroleum and
Energy Research
P.O. Box 2128.
Bartlesville, Oklahoma 74005

Re: Comments - NIPER - DOE Chemical EOR Workshop

Dear Dr. Tham:

I recently attended the NIPER-DOE Chemical EOR Workshop held in Houston on June 23 and 24. I would like to comment on this workshop and on your luncheon talk.

DOE is the organization that can play such an important part in the application of chemical EOR technologies to our rapidly depleting oil resource target. The PON program is a big step in partially funding field projects that can illustrate the recovery of additional oil. This program focuses entirely on the geological setting with little to no regard to the in place fluid characteristics. All aspects of an oil reservoir need consideration. Also, I would suggest that some portion of the total available funding be ear-marked totally for chemical EOR processes.

The workshop was encouraging to me in that the major tone was that chemical EOR does have a future. It was discouraging in that:

1. The major oil companies have abandoned this area of oil recovery. Texaco has a modest effort of about 15 people in chemical flooding.
2. The "old" experience is fast disappearing.
3. The technology transfer to independents is non-existent.
4. The universities are vying for the capital available to, in most part, re-invent the technology and knowhow done by the majors in the 1960's and 1970's.
5. There is little to no effort to educate the independent that chemical EOR technologies are being applied economically today at current oil prices.

My comments and suggestions are based on over 30 years of direct experience in chemical flooding. More than two hundred clients in eleven countries have been served during my 15 years as an independent contractor specializing in chemical EOR. I would like to list some of my thoughts on future DOE functions as follows:

1. Establish a program to show the independents that chemical EOR is economic based on field experience.
2. Help the independent in evaluating his resource base and what can be done to improve the recovery and economics.
3. Help fund field projects to maximize the accumulation and evaluation of the results.
4. Focus the research dollar on the application of presently available commodity chemicals to the oil reservoirs containing the largest oil resource.
5. Establish a close working relationship with the IPAA because this organization will represent the independent producing our domestic oil in the years to come.

It was a very enjoyable experience spending a couple of days discussing chemical EOR. We would be willing to help in developing a plan to further the application of chemical EOR technologies.

Sincerely yours,

SURTEK, INC.

A handwritten signature in dark ink, appearing to read 'H. Surkalo', is written over the printed name.

Harry Surkalo
President

COMMENTS ON
CHEMICAL ENHANCED OIL RECOVERY

BY

ARLIE M. SKOV, P.E.

There can be little doubt, looking at the record, that chemical EOR has failed to live up to either its potential or its expectations. According to statistics recorded by the *Oil & Gas Journal* in surveys of the industry every two years starting in 1980, oil production from chemical EOR grew from 2,000 BOPD in 1980 to a peak of 33,000 BOPD in 1988 and then declined to only 7,000 BOPD in 1992. During this 13 year period, only about 55 million barrels total have been produced by chemical EOR. By contrast, miscible EOR has grown from 75,000 BOPD to 305,000 BOPD in the same interval and thermal recovery methods has grown from 256,000 BOPD to a peak of 480,000 BOPD in 1986 and declined only to about 461,000 BOPD in 1992.

During this 13-year time interval, oil recovery from thermal recovery methods has been nearly 1.9 billion barrels and from miscible recovery has been over 500 million barrels. Of the total enhanced oil recovery produced during this period, only two percent can be attributed to chemical EOR.

In contrast, research dollars committed to chemical methods have been quite significant. Research expenditures are notoriously difficult to obtain or to understand, the National Petroleum Council in a report in 1987 endeavored to cover total private corporate research and development in exploration and production activities for the time period 1975 through projected budget expenditures for 1988. Total expenditures were about \$8.4 billion during that 14-year period. Of this, nearly \$900 million were spent on enhanced oil recovery and chemical flooding, with an expenditure of nearly \$400 million, had contributed about 0.14 BOPD per R & D dollar expended. This compares to 7.8 barrels of oil per dollar of R & D for thermal EOR and 2.2 barrels of oil recovered for each dollar of R & D expenditure on miscible flooding. On this basis, R & D expenditures to date for chemical

flood research have indeed been a poor investment; poorer, in fact, by over an order of magnitude.

However, the failure of past R & D dollar expenditures for chemical EOR does not necessarily preclude its consideration as a viable method for the future. It simply means that to date we have not unlocked the secret of economically producing more oil by chemical methods. It is also, of course, a measure of the difficulty of the problem and will undoubtedly suggest to many that the problem is simply too difficult to consider further R & D dollars.

Perhaps the most definitive industry-wide study on EOR in general was the National Petroleum Councils' 1983 study of EOR potential in the U.S. In the base case, using implemented technology (as opposed to advanced technology) and a base economic case of \$30 per barrel nominal crude price in 1983 dollars, it was anticipated that chemical oil production rate would grow from the 4 or 5,000 BOPD existing in 1984 to 10,000 BOPD in 1993 (as compared to an actual 1992 production rate of only 7,000 BOPD) and that production from chemical methods would continue to increase to about 16,000 BOPD in the year 2,013 or the end of the study period covered. Ultimate oil recovery anticipated to be recovered from chemical EOR was estimated to be about 2.5 billion barrels for the base case of implemented technology in \$30 per barrel. This number increased to about 17 billion barrels ultimate recovery with oil at \$50 per barrel and using advanced technology.

Actual results, of course, have been much less robust and a major reason is that oil prices have declined since 1983 in real terms by about 40%. In fact, \$30 per barrel in 1983 dollars corresponds to over \$42 per barrel in 1993 versus an actual price in '92 of less than \$16 per barrel on average for first purchase price as reported by the EIA. Similarly, \$50 per barrel -- the highest price considered in 1983 -- equates to over \$70 per barrel in 1993 dollars when correcting for inflation. Actual price is less than that by a factor of 4. So even though the actual results of chemical EOR as experienced in the past decade have been quite disappointing compared to the 1983 NPC study, it is quite evident that the estimated oil prices used in that study were horribly optimistic compared to the actual fact. There is,

of course, no way of knowing what chemical EOR production would actually have been had oil prices stayed in the \$30 to \$50 per barrel range as expressed in 1983 dollars.

It is doubtful if any individual, or group of individuals (experts or economists) today, can do any better at predicting future oil prices. However, it is easier today to be pessimistic about the future than it is to be optimistic. For example, world reserves have essentially doubled since 1983 and demand worldwide has essentially remained flat. So long as there is surplus capacity, it seems unlikely that we will return to the high prices experienced in 1973 to 1985, and it is equally unlikely that we will ever make the tremendously optimistic forecasts of future oil prices, which we did at that time. Nonetheless, world affairs continue to be unpredictable, the bulk of the surplus oil capacity remains in the hands of OPEC, and the likelihood of sporadic warfare any place on the globe remains a high probability. In short, prices remain unpredictable, but looking today, both at history and into the future, it would seem that excess optimism for high prices is simply unwarranted.

Also, the definition of chemically enhanced oil recovery needs to be reviewed. The conventional and widely accepted definition is "the addition of some chemical substance to an aqueous solution, which will mobilize oil in a watered-out reservoir and produce to a lower average residual oil saturation." However, it seems to me that a much broader definition is justified. First of all, the term *enhanced oil recovery* has too narrow a meaning. Our goals should be increased oil recovery from existing reservoirs and our goal should be to achieve this in any means possible at existing oil prices. And if we confine our definition to increasing oil production, or recovery, by chemical means, it would seem that a more proper definition would be the recovery of additional oil by the use of chemistry. This, I think, is a much broader and much more useful definition. For example, the addition of a chemical to drilling fluids to permit horizontal drilling to greater distances before encountering torque and drag difficulties with a drill string would fit in that definition of chemically improved oil recovery. Also, the use of less damaging completion fluids or stimulation fluids through a proper understanding of chemistry and chemical interactions would also add recovery through use of chemistry. It seems to me that this would be a much more useful definition of "*chemically enhanced oil recovery*."

Let's consider for a moment the difficulties which prevent the economic application of the conventionally defined chemical enhanced oil recovery. They are fairly few, fairly simple, and fairly well known:

- The cost of chemicals;
- The interrelation between the cost of chemicals and the price of oil;
- Adsorption of chemicals on the tremendous surface area exposed within a reservoir;
- Identifying and reaching those areas of the reservoir where excess residual oil saturation resides;
- Producing the mobilized oil at high enough a rate to be economic.

All five of these factors work against the use of chemicals for enhanced oil recovery in the conventional sense. Hence, all are areas of research needed to improve the economic utilization of injected chemicals for improving oil recovery. Some of these require some new techniques. For example, adsorption -- or even wettability -- are poorly understood in most reservoirs. It's easy enough in the laboratory in a short sample of rock -- real or contrived -- to determine both adsorption and wettability. However, in real reservoirs of much greater complexity and much greater length of fluid movement between injection and production points, it is virtually impossible at present to meaningfully determine adsorption or to develop a meaningful way in which to predict adsorption.

Another problem common to most chemical fluid research is the belief that it is necessary to block off the more permeable channels in order that the chemicals can be forced to reach those portions of the reservoir which have higher residual oil saturations after water flooding. However, this approach is clearly self-defeating to the goal of improving production rates from chemical flooding. Hence, why not take the opposite approach: try instead to enhance the flow rate in the higher permeability channels and reduce further the already residual oil saturation existing there.

This can be illustrated in a hypothetical example as shown in the attached Tables I and II. Table I describes a "uniform" reservoir with an average porosity of 25%, average water saturation of 30% and an average oil saturation after water flooding in the swept portions of the reservoir of about 26%. Note that this excludes oil which may be trapped in parts of the reservoir which have not been adequately flooded either through poor areal coverage or through low permeability layers, or which may have been bypassed because of fractures in the reservoir. However, even within a "uniform" sandstone of 25% porosity, we find statistical variations. In fact, porosity measurements frequently have a normal distribution and permeability measurements have a log normal distribution. Hence, in our example on Table I, we have assumed that there is a 5% standard deviation in the porosity measurements meaning that about two-thirds of the actual porosities in this uniform layer will be between 20 and 30 percent and the other one-third will be outside of those ranges. Hence, in Table I, we have divided this 25 percent average porosity into six "statistical layers" in which the four center "layers" represent the range of plus or minus one standard deviation. Although not shown, one would expect that there would be two or three, or even four, orders of magnitude difference in permeability in these "statistical layers" in a normal reservoir and these would impact both water saturation and residual oil saturation negatively.

This is illustrated in a hypothetical fashion in the next few columns showing an assumed water saturation of 50 percent in the lowest permeability layer and of only 20 percent in the highest permeability layer, and correspondingly, a 40 percent residual oil saturation in the lowest permeability layer and a residual oil saturation of 20 percent in the highest permeability layer. Hence, although the average oil recovery is 62 percent, the actual oil recovery is only 20 percent from the lowest layer and 75 percent from the highest porosity layer.

If we then take this same uniform sandstone to Table II and calculate chemical EOR targets, we find first of all (in column 4) that the remaining target total oil in each layer is almost equal. However, normally we consider that there is some lower limit below which it is unlikely to reduce the residual oil saturation, and (in column 6), we recalculate

recoverable oil by chemical methods assuming a 15 percent residual oil saturation overall. Now, the bulk of recoverable oil seems to be in the lower porosity "layers" meaning also lower permeability layers and there is very little oil recoverable from the high porosity layers where most of the permeability exists. In fact, exactly half of the "recoverable oil" is in the one-third of the reservoir which has the lowest porosity and only one-fourth of the recovery is projected from those layers which have the highest porosity.

While this is simply a statistical exercise on a hypothetical reservoir, it illustrates the problems both in practice and in conception of using chemicals for improving oil recovery. The conventional wisdom would say that you must block off the high permeability layers because the bulk of the "recoverable oil" is in low permeability layers even in a "uniform sandstone". However, one could use an upside down mode of thinking and look instead at recovering 100 percent of the oil out of the small fraction of the reservoir which has the highest permeability with the use of chemical and not worry about the rest of it and perhaps do much better economically.

There may be, in fact, some actual examples of "chemical EOR" in a few strong water drive reservoirs such as the Woodbine Sand in the East Texas field. New theories are being devised there to explain the unusually low residual oil saturation in this excellent sandstone reservoir. There are a few other examples in the Texas and Louisiana Gulf Coast areas, which suggest that we really don't understand conventional water flooding recovery to the extent necessary to move forward to chemically enhanced oil recovery. This suggests another needed research program, i.e., how exactly does water flooding work when recoveries are much higher than would be predicted by a normal Buckley-Leverett displacement process. It also suggests that we may not really understand relative permeability at low residual oil saturations.

On another topic, it seems that research dollars which in the past have been generated essentially by the major oil companies are apt to dry up even further. I'm sure that if an NPC study of the 1987 type were attempted today, six years later, there would be a tremendous reduction in the amount of private industry dollars being applied toward

enhanced oil recovery of any type. And traditionally, this type of research has been done by the major oil companies, not by independents, service contractors or anyone else unless the work was funded by a major producer. This suggests that if any further research is to be done on enhanced oil recovery, a new source of funding must be found. And if the funding is from the government, as opposed to a producing company which owns oil wells and oil fields, then there must further be found an effective way of transferring and implementing that technology. I'm not convinced that the demonstration projects which have been funded in the past, and currently, by the Department of Energy are an effective way of achieving that. So new thinking is needed in this regard as well.

The total target for chemical enhanced oil recovery is undoubtedly large. Numbers which are currently in the TORIS data base maintained by DOE at the Bartlesville project office are probably not only the best we have, but also the only real source. However, these numbers are an outgrowth of the 1983 NPC study which in turn are an outgrowth of two different API subcommittee studies on recovery efficiency dating from the 50's and 60's. I believe there is ample reason for believing that these numbers err on the high side. However, even if they do, there is without doubt, a lot of oil left in the ground unrecoverable by existing methods in the United States. And certainly chemical methods have the potential for recovering a very large amount of this.

It must be recognized at the start that chemical methods are far more difficult to both devise and apply than are thermal or miscible methods. Reasons are fairly simple. Miscible methods require essentially just good knowledge of two fluids -- the oil in place and the injected miscible substance. Thermal methods are even less demanding since heat flows by conduction regardless of permeability barriers which exist in a reservoir and will mobilize heavy oil wherever it is in. Chemical methods, on the other hand, require a detailed understanding of the chemical interactions between the injected fluid and its contained chemicals, the oil existing in the reservoir, the water existing in the reservoir, and the reservoir rock itself. The chemistry of all of these are different from reservoir to reservoir and are probably significantly different even within a reservoir. Hence, chemical flooding is apt to be a complex chemical analysis problem without any broad scale application of a

specific technology even possible. Hence, the topic requires an immense amount of research, a tremendous detailed knowledge of reservoirs and/or contained fluids, of fluid movement mechanics within those reservoirs, and of a tricky set of topics such as wettability, adsorption, relative permeability, etc. And worst of all, the research dollars are disappearing at the same time as actual experience suggest that chemical flooding is not a viable option based upon the statistics compiled by the *Oil & Gas Journal* every two years.

TABLE I

PROPERTIES OF A HYPOTHETICAL RESERVOIR
WITH
"AVERAGE" PROPERTIES:

- Porosity: 25% (with std. dev. $\pm 5\%$)
- Water Saturation: 30%
- Original Oil Saturation: 70%
- Oil saturation after Waterflood
(in the swept portions of the reservoir): 26%

"STATISTICAL LAYER" NO.	POROSITY, %	WATER SATURATION, %	INITIAL OIL SAT., %	RESIDUAL OIL SATURATION, %	OIL RECOVERY, %
1	16	50	50	40	20.0
2	21	40	60	33	45.0
3	24	31	69	28	59.4
4	26	29	71	25	64.8
5	29	24	76	22	71.1
6	34	20	80	20	75.0
AVERAGE	<u>25</u>	<u>30.1</u>	<u>69.9</u>	<u>26.5</u>	<u>62.1</u>

TABLE II
CHEMICAL FOR TARGET
HYPOTHETICAL RESERVOIR

"STATISTICAL WATER" NO.	POROSITY, %	RESIDUAL OIL SAT., %	TOTAL $\phi * S_{or}$	% OF TOTAL	TOTAL $\phi * (S_{or} - 0.15)$	% OF TOTAL
1	16	40	.0640	16	.0400	23
2	21	33	.0693	17	.0378	22
3	24	28	.0672	17	.0312	18
4	26	25	.0650	16	.0260	15
5	29	22	.0638	16	.0203	12
6	34	20	.0680	17	.0170	10
TOTAL OR AVG.	<u>25</u>	<u>26.5</u>	<u>.3973</u>	100	<u>.1723</u>	<u>100</u>

DAUBEN INTERNATIONAL

Energy Consultants

July 10, 1993

Dr. Thomas E. Burchfield
NIPER
P. O. Box 2128
Bartlesville, OK 74005

Dear Dr. Burchfield:

In response to your letter of June 29, I am hereby enclosing some additional thoughts relative to the NIPER-DOE Chemical EOR Workshop. First, I thought that the meeting was a success. It was surprising to me that the attendance was high and remained so even until the last hour. The number and caliber of the people attending the conferences indicate that a good core level of expertise still remains in the industry. In spite of the success of the meeting, the trends are evident. A considerable amount of chemical flooding expertise is being lost due to retirements, transfer of personnel outside of the energy industry, and to a lack of funding. This loss of technology may be disastrous for the domestic oil industry. Chemical flooding is the only potentially viable technology for recovering residual oil from the shallow to mid-depth reservoirs. The prospects for increased funding by industry appear bleak since the major efforts and expenditures are concentrated in the international market. It is therefore imperative that DOE take a strong leadership role in preserving and further developing chemical flooding technology.

One of the key questions raised at the meeting is the preservation of the technology. I concur with the need. Furthermore, I think that a program should be implemented which will insure the continuation of research. The following major steps are suggested:

1. Preparation of a Comprehensive Document. A comprehensive document should be prepared which captures the evolution, development, and current status of the technology. This document should cover all aspects of the technology, including the status of chemical systems, laboratory test procedures, field test procedures and results. The document should be properly balanced between theoretical and practical concepts so that a future investigator can understand the full spectrum of the technology. It is imperative that practical field experience should be captured in the document. It is further suggested that the document should concentrate on surfactant systems for the miscible displacement of oil. The current commercial activities in polymer flooding and profile control should insure the future success and continuity of this technology. In contrast to the other EOR processes, there is no SPE Monograph or other comprehensive document which captures the state-of-the-art of the technology.

2. Specialized Workshop. A draft copy of the above report should be provided in advance to those attending the workshop. The individuals attending this workshop should be comprised of the industry's leaders in chemical flooding technology together with selected "outside" experts. The purpose of the workshop is to review and to suggest revisions in the document. A basic consensus is needed that the document fairly depicts the state-of-the-art of the technology. A further purpose of the workshop is to "brainstorm" ideas for further development. These advancements may come from outside of the current mainstream efforts in chemical flooding research. For example, horizontal drilling could provide the means for significantly improving performance. Another example could be the adaptation of surfactants which are currently being developed outside of the oil industry. Consistent with these ideas, it is suggested that experts in horizontal drilling, surfactants, and other technologies be included in the invitation list for the workshop. The ideas from this workshop will be captured in a document.

3. Preparation of a Final Document. A final document will be prepared, with input from the workshop session. This document will capture the state-of-the-art of the current technology and provide a road map for future developments. It will have the endorsement of the experts in the industry. This document will be very valuable in guiding the future efforts of DOE's research program.

I hope that the above comments are helpful. Please advise if you would like to discuss any aspect.

Sincerely,

Dwight L. Dauben

APPENDIX VI
TEXACO'S LIGNIN SURFACTANT TECHNOLOGY

Texaco

E&P Technology Department
PO Box 770070
Houston TX 77215 0070
713 954 6000

August 2, 1993

Dr. Min K. Tham
Senior Science Advisor
Energy Production Research
National Institute for Petroleum and Energy Research
P. O. Box 2128
Bartlesville, Oklahoma 74005

Dear Dr. Tham:

Congratulations on your successful NIPER-DOE Chemical EOR Workshop here in Houston recently. We, as Texaco representatives, enjoyed the opportunity to participate. I think the discussions served to focus everyone's attention, not only on the problems facing chemical flooding currently, but also on possible solutions for reviving interest in the technology.

As I discussed during the workshop, Texaco is developing a lignin-based chemical flooding system. The technology development has progressed to the stage where we are proposing to conduct a field test. We believe that this Lignin Technology addresses the major problems that were identified during the workshop. As you requested during our informal conversation, we have prepared a short report of Texaco's Lignin Technology for inclusion in the workshop report.

Thank you for your interest in our technology. If you need additional information or have questions, please call me at (713) 954-6021.

Sincerely,

Larry Whittington
Manager, Chemical Oil Recovery

RWB:cfs
cor.7

Attachment

Texaco's Lignin Surfactant Technology

During the 1970's and early 1980's, the oil industry's experience with chemical flooding showed that technical successes could be achieved in field pilots, but economic success remained elusive. From this experience Texaco researchers recognized that high chemical cost and limited chemical supply were serious impediments to expanded chemical flooding application. This recognition led Texaco to develop and patent Lignin Technology for the recovery of additional oil after waterflood. Lignin Technology uses lignin, a by-product from the paper industry, to produce the surfactants used as primary chemicals in flooding operations, as opposed to the well-recognized lignin sacrificial agents. These lignin-based surfactants address three basic problems associated with chemical flooding: chemical costs, dependence of chemical prices on crude oil price, and chemical availability.

Chemical Flooding

Texaco has conducted eight chemical flood pilots. The largest was a 60-acre pilot in the Salem Benoist reservoir (Salem, Illinois) in 1981. This pilot used conventional petroleum-based surfactants and produced over 590,000 bbls of oil, representing more than 54% of the oil remaining in the target zone after waterflood. The Salem pilot was technically successful in demonstrating that chemical flooding can recover waterflood residual oil. However, the process was not expanded to the entire field because of poor economics and inadequate chemical supplies. The petroleum sulfonate surfactants used in the Salem pilot were too expensive for a field-wide chemical flood unless the selling price of oil was in the range of \$40 per bbl.

These problems are typical of those encountered by all companies attempting to utilize chemical flooding. With the oil price decline in 1986, chemical flooding became economically impossible.

Texaco's Lignin Technology

To address the cost and availability problems, Texaco, in 1982, embarked on a strategy to use lignin as a source chemical. Lignin is a naturally-occurring substance present in all plants. It is a primary part of wood fiber and gives plant matter its strength and rigidity. It is a very stable chemical compound and makes up about 25 per cent of a tree's weight. To dispose of the lignin, paper mills burn it as a low-quality boiler fuel and to recover inorganics from the ash.

Lignin offers a solution for each of the chemical flooding problems. First, lignin is very cheap, only pennies per pound. Second, the huge amount of lignin produced in the paper pulping industry, over 40 billion pounds annually in the U. S. alone, can easily meet the oil industry's, as well as Texaco's, chemical needs. Third, lignin is a non-petroleum chemical, and its price is unaffected by fluctuations in crude oil prices.

Texaco's research work has led to two new technologies based on lignin. These technologies have been designated Lignin I and Lignin II. The Lignin I technology uses lignosulfonates in a surfactant blend with fatty amine and a water soluble surfactant. The Lignin II technology uses two chemical reactions to convert lignin into new surfactants for chemical flooding. Texaco has numerous patents that cover Lignin I and Lignin II technologies.

Each lignin technology gives substantial reductions in the cost of the chemicals used in chemical floods. For example, the Lignin I surfactant blend costs 40 - 60% less than a conventional petroleum-based surfactant system. In the case of a U.S. chemical flood, this cost reduction leads to an economical oil recovery process if the crude oil price is about \$20 - \$24/bbl. We anticipate that the Lignin II technology will provide further cost reductions. These substantial cost reductions greatly improve the economics and make chemical flooding a practical EOR method at even lower oil prices.

The current state of the Lignin Technology is summarized in the following sections.

Lignin I

The Lignin I technology is a chemical flooding surfactant system that is a blend of three commercially available components:

- 1) lignin, most often as a lignosulfonate;
- 2) a fatty amine such as tallow amine; and,
- 3) a petrochemical surfactant.

This mixture is sometimes called a *lignin amine* blend.

The Lignin I technology has been through extensive lab testing and development. The utility of Lignin I surfactants has been demonstrated in hundreds of laboratory corefloods for a wide variety of field conditions, from room temperature to 187°F and up to 190,000 ppm TDS salinity. The Lignin I surfactant system requires special blending to match each reservoir, but once this is done, tertiary oil recoveries are generally 75 - 80% of the waterflood residual oil.

For example, a laboratory coreflood with injection of a 25% PV, 2% concentration Lignin I system gives a 76% tertiary recovery of the oil remaining after waterflood. The Lignin I system and a conventional petroleum sulfonate system give identical oil recoveries and rates of production. While the Lignin I system greatly lowers the cost of chemical floods, it still uses a significant amount of a conventional surfactant in the blend.

Lignin II

The goal of the Lignin II technology is to develop new chemicals to replace the remaining petrochemicals in the Lignin I system. This will produce an all-lignin surfactant system and will lead to even further cost savings in chemical floods.

The Lignin II technology is built around two chemical reactions:

Lignin ----> *Lignin Phenols* ----> Lignin Surfactants
"new oil recovery chemicals"

In the first reaction, lignin is converted to a new chemical feedstock, called *lignin phenols*, by a liquefaction process. This process is similar to coal liquefaction in that it requires high temperatures ($\geq 350^{\circ}\text{C}$) and a reducing gas such as hydrogen. The liquefaction reaction both reduces the lignin molecular weight and lowers the oxygen content of the lignin.

The second step in the process is the conversion of the lignin phenols into "Lignin Surfactants" for direct use in a chemical flood surfactant system such as the Lignin I system. The lignin surfactants can be made by several chemical routes. Reactions such as sulfonation (reaction with SO_3), ethoxylation (reaction with ethylene oxide, $\text{C}_2\text{H}_4\text{O}$), and sulfation (conversion of the ethoxylates to sulfate esters) produce effective surfactants.

Summary

The use of a low-cost, abundant, natural-product source material to produce EOR surfactants will allow significant chemical cost reductions to make chemical flooding not only technically successful, but also economical. This will allow a revival of chemical flooding technology as a viable EOR method.

END
Date
1-11-94