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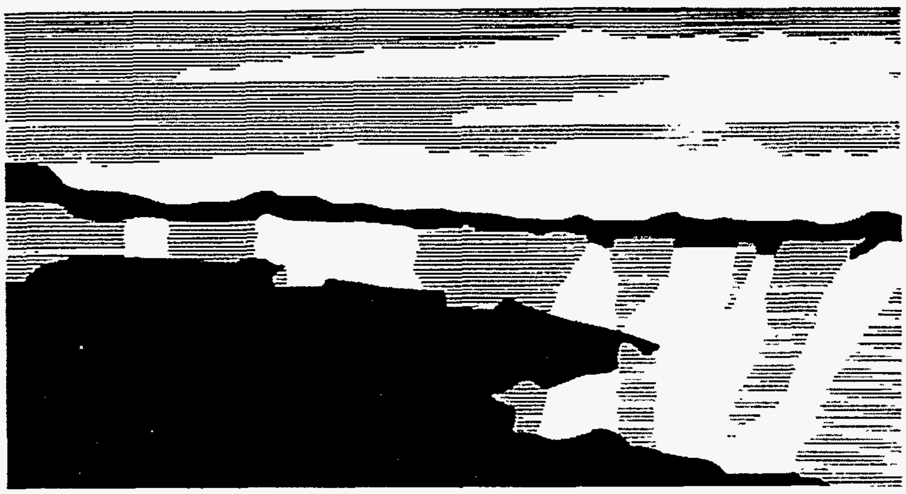

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Coupled Transport and Chemical Interactions in Petroleum Reservoirs: Multicomponent Tracer Demonstration Large Scale Application

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Abstract

This is the final report for a two-year, Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). Enhanced tracer approaches for characterization of oil reservoirs were demonstrated and evaluated for both transport and chemical interactions. Existing tracer technology is limited in numbers of tracers and relies heavily on radioactive species. Using expertise developed at Los Alamos through applications of chemical, analytical, and geologic techniques to testing, alternative energy and environmental programs, we have defined new classes of conservative and reactive non-radioactive tracers for both laboratory and field experiments. Reservoir experiments are critical to improved reservoir management, characterization of CO_2 flooding, and validation/development of significantly enhanced simulators utilizing advanced computational technology. A demonstration field tracer experiment has been performed in the Salt Creek Field Unit in West Texas to characterize a section of the reservoir under water-flood. An initial robust set of tracers, field experience in their application, and interpretation methodology was demonstrated for large scale multi-well, multi-tracer flow and connectivity tests.

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1. Background and Research Objectives

Injection flooding results in significant production of petroleum in US fields. Because much oil (probably most of the resource) remains in the reservoir under present production approaches, improvement in flood production (using water and CO_2 in particular) is economically important in that it both extends the life of reservoirs and increases our recoverable resource. In the case of the Salt Creek Field Unit in West Texas, Mobil Exploration & Producing US (MEPUS) has committed to a major investment of capital and operations for CO_2 flooding, with initial production enhancement of approximately 50%. The near future is critical to significant improvement of flood system approaches because fields are increasingly being abandoned and the wells plugged (some analyses indicate only ten years before most US wells are abandoned). Better reservoir characterization through field measurements and simulation is basic to improvements. Tracer experiments most directly address the essential diagnostic evaluation of flow and chemical processes between wells. Chemical processes are of especially increasing importance as production must shift from physical extraction (pump or simple flood driven) to include more subtle chemical mobility and profile control processes. Improvement in understanding and control of enhanced oil recovery operations is essential, due to the high cost and capital intensive nature of such operations. Coupled multicomponent tracer and computational simulation approaches allow direct evaluation of the chemical environment within a reservoir and sequential experiments to evaluate production strategies.

Development and demonstration of multicomponent tracer approaches involves coupled analytical, experiment operation and analysis/interpretation improvements. Los Alamos has developed a unique range of capabilities/experience and the integrated technical staff necessary to drive a significant quantum jump in this area, through integrated large-scale programs in testing, analysis and simulation in defense and alternative energy (oil shale and geothermal). Both producers and oil service companies have interests in technology components of our efforts, particularly with the strength of a field application/demonstration.

2. Importance to LANL's Science and Technology Base and National R&D Needs

This project supports Los Alamos core competencies in earth and environmental systems as well as theory, modeling, and high performance computing. Field demonstration of large-scale, multicomponent tracer, reservoir characterization is the critical benchmark for entry into a broad range of long-term collaborations and development efforts within the petroleum production industry. This project enhances LANL's visibility in these areas and positions the Laboratory to respond to initiatives in these areas. These efforts also have direct applications in greatly enhancing the speed, efficiency, reliability and cost of environmental site characterization, *in situ* treatment, and both short- and long-term monitoring, where many of the issues of chemical transport and recovery are directly analogous. A more stable and long term petroleum supply is of significant importance to strategic issues, while characterization of environmental systems on short and long time scales is a critical component of industry and DOE operations.

3. Scientific Approach and Results to Date

A staged multicomponent interwell tracer experiment has been executed, in collaboration with MEPUS and Petrolite Chemical. The field in Permian basin reef carbonate rocks has been undergoing water flooding since 1952, is now in transition to CO_2 flooding, and is the focus of intensive reservoir characterization studies by the operator. The opportunity to characterize tracer behavior prior to CO_2 injection and subsequently examine multiphase injection/production behavior provided a significant demonstration of multicomponent tracer capabilities and definition of production processes as new approaches are implemented. In addition, the data set developed by this experiment is critical to enhancement and evaluation of computational simulation approaches for chemical transport and detailed characterization of the transition from water-flood to a CO_2-based water-alternate-gas (WAG) production approach.

A multi-well, multi-tracer injection was accomplished in March, 1994. The analytical program was performed at Los Alamos, while MEPUS/Petrolite operated detailed production/injection monitoring and sampling activities. Twenty nine compounds were selected for use as water tracers in the initial experiment in the Salt Creek Reservoir. Of these, twenty compounds were delivered in sufficient quantity to inject in early March, into six wells. The majority of the compounds selected contained bromine, chlorine, or both. This resulted in compounds that have no natural background and can either be detected in the presence of naturally occurring organics or can be separated effectively for analysis. Of the initial twenty compounds, eight were organic acids, as are three of the remaining nine compounds. Selection criteria were balanced between chemical properties (acid, non-acid volatile organic compound or solvent), detection capabilities, and cost. The resulting tracer suite covered a range of properties, including aqueous solubility, volatilization, petroleum solubility, and reactivity, which may provide important chemical information about the paths through the reservoir as well as well-to-well connectivity. We predicted that at the analytical detection limits expected, sufficient amounts would remain in the water phase, even for those compounds with strong partitioning behavior into gas and petroleum. Based on analyses, this expectation has apparently been met. Analytical results were qualitatively evaluated for immediate application to production operations.

A second suite of tracers was injected into the field at the end of September, 1994, following initiation of CO_2 flooding in a select number of wells within the tracer experimental area. Test samples were provided to commercial analytical laboratories selected by our industrial partners for evaluation of capabilities and technology transfer, and Mobil defined a second field for tracer injection that has contrasting characteristics and a short-term operational payoff from better characterization of reservoir transport processes.

There are three elements to accomplishing this effort, with our project effort focusing primarily on the first element. Definition and implementation of a baseline multicomponent tracer experiment in a reservoir is the first element. This included identification of tracers to be injected, analytical methods, sampling and injection strategy, and collection of the range of operational information necessary for interpretation. Follow-on field experiments are being defined based on the early tracer returns of the initial injections. The second element is model enhancement, development, and validation to provide capabilities necessary to integrate, interpret and predict tracer experiment results. Geochemical and transport models are necessary to evaluate tracer processes adequately with respect to strengths and weaknesses of selected versus potential suites of chemicals. Simultaneously, reservoir evaluation will be necessary to define reservoir performance based on tracer and other data, with implications to production and operations. The third element is definition and implementation of follow-on multicomponent tracer experiments and simulations. Thus, definition and initiation of a field tracer experiment, followed by collection and analysis of the early stages of tracer breakthrough was the focus of our project.

The collaborative approach of this project, in which industry provided access to a petroleum reservoir, was an essential opportunity for initial demonstration of multicomponent tracer technology. Results included evaluating the costs and capability requirements, and development of technology transfer to major oil producers and their associated service companies, while simultaneously answering a series of near-term reservoir operation questions. Gas flood operations are viable approaches to petroleum recovery, but are costly and capital intensive. Field demonstration of enhanced production, recovery and operating costs through improved reservoir characterization was the focus of this effort. Stage one involved multi-well, multi-tracer characterization of water-flood operation in a section of the field prior to CO_2 introduction. Stage two involved a tracer experiment following inception of CO_2 flooding, during the water injection phase of the WAG flooding cycle. In a small parallel phase, we worked with Mobil in designing and running an experiment in a second field (East

Fitz at Stonewall, OK). Integration with laboratory and simulation studies is the final phase, in which the thousands of analyses, tracer information and natural composition information will be integrated and conclusions synthesized. While LANL scientists focused on validating analytical and tracer methodologies, the overall project developed critical information for direct near-term industrial applications to strategies to maximize oil field production.

Reference

Janecky, D. R., and Spall, W. D., "New Tracer Technology for Geochemical Tomography'" in Proceedings of the SPE/UH Emerging Technologies Conference, 281-283 (1990).