Research on Oil Recovery Mechanisms in Heavy Oil Reservoirs

**Semi-Annual Report
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**RESEARCH ON OIL RECOVERY MECHANISMS
IN HEAVY OIL RESERVOIRS**

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SEMI-ANNUAL REPORT

Stanford University Petroleum Research Institute
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OBJECTIVES

The goal of the Stanford University Petroleum Research Institute is to conduct research directed toward increasing the recovery of heavy oils. Presently, SUPRI is working in five main directions:

1. FLOW PROPERTIES STUDIES — To assess the influence of different reservoir conditions (temperature and pressure) on the absolute and relative permeability to oil and water and on capillary pressure.
2. IN-SITU COMBUSTION — To evaluate the effect of different reservoir parameters on the *in-situ* combustion process. This project includes the study of the kinetics of the reactions.
3. STEAM WITH ADDITIVES — To develop and understand the mechanisms of the process using commercially available surfactants for reduction of gravity override and channeling of steam.

4. FORMATION EVALUATION — To develop and improve techniques of formation evaluation such as tracer tests and pressure transient tests.
5. FIELD SUPPORT SERVICES — To provide technical support for design and monitoring of DOE sponsored or industry initiated field projects.

GENERAL INFORMATION

SUPRI presented research results and participated in technology transfer at a variety of meetings this year. These include the Geothermal Resources Council 1997 Annual Meeting, Burlingame, CA (October 12-15, 1997) and the Society of Petroleum Engineers Annual Technical Conference and Exhibition, San Antonio (October 5-8, 1997)

Technical papers were presented at all of these meetings and are listed in this section:

1. Akin, S. and E. Okandan: "Geothermal Reservoir Characterization by Tracer and Well Testing," presented at the GRC 1997 Annual Meeting, Burlingame (October 12-15, 1997).
2. Castanier, L.M. and W.E. Brigham: "Modifying In-situ Combustion with Metallic Additives," *In Situ* **21(1)** (1997) 27-45.
3. Kovscek, A.R., T.W. Patzek and C.J. Radke: "Mechanistic Foam Flow Simulation in Heterogeneous and Multidimensional Porous Media," *Society of Petroleum Engineers Journal*, **2(4)** (1997) 511-526.
4. Sagar, N., L.M. Castanier, and W.E. Brigham: "Pore Level Visualization of Oil/Foam Interactions in a Silicon Micromodel," SPE #39512, SPE India Conference, New Delhi (February 17-19, 1998)

Several other papers will be presented at the SPE/DOE Improved Oil Recovery Symposium in April 1998, the Western Regional meeting of the SPE in May 1998, and at the Fall meeting of the SPE in October 1998.

TOTAL has joined our industrial support group. This increases the number of companies supporting our efforts to ten.

ACCOMPLISHMENTS BY PROJECTS

Details of the work performed during the last six months will be presented according to the organization of SUPRI in five project areas.

Project 1: Flow Properties

Three experiments are in progress in this project:

(1) Effect of temperature on relative permeability. Several experiments have investigated the effect of temperature on oil/water relative permeabilities in unconsolidated sands similar to California reservoirs. Viscous fingering was found to have a large impact on the results. Interpretation of the experiments using numerical simulation and history matching is in progress. A paper summarizing the results to date and the interpretation of the experiments by numerical simulation will be presented at the Fall meeting of the Society of Petroleum Engineers in October, 1998. This project will continue and a technical report is scheduled for July, 1999.

(2) Imbibition in low permeability media. Experiments of water imbibition in sandstone, diatomites and chalk cores are underway. The results follow the well known linear relationship between amount of water imbibed and square root of time. Diatomaceous rocks contain large quantities of oil and are unusual in that they exhibit large porosity and low permeability. Understanding the mechanisms of water imbibition in unusual rocks is important. Next year work will focus on oil/water systems and the computation of relative permeability from imbibition tests. A preliminary report on this topic is scheduled for December 1998.

(3) Two and three phase-flow in fractured media. A technical report on this project will be submitted to DOE in the winter of 1998. Experiments in water/air systems under the CT scanner have shown the importance of assessing the correct capillary pressure within the fractures in order to match numerically experimental results. This work will be expanded to the more interesting case of water displacing oil in fractured media.

Project 2: In-situ Combustion

Work has focused on literature review and renovation of a combustion tube apparatus. The aim of this part of the study is to investigate the effect of slugs of aqueous metallic salts on the combustion process. Wilmington field crude oil obtained from THUMS will be used in a series of runs made with different sized slugs of water containing iron nitrate. Temperature profiles and pressures will be measured. This will

allow determination of the relevant field parameters such as fuel burnt, air/oil ratios and air/fuel ratio. An initial control run failed because of bad insulation of the tube. This project will restart in the fall of 1998 after the researcher returns from working in industry.

Project 3: Steam Injection with Additives:

Modeling and simulation efforts to describe foam flow in one-dimensional sand packs continue. Results from the experiments and the models will be compared. A correlation taking into account the permeability and porosity of the medium has been developed and tested against population balance models. A paper on this subject will be presented at the SPE Annual Meeting in October 1998.

Experiments on foam generation and transport in a heterogeneous porous medium were conducted and completed. Heterogeneous systems in which the heterogeneous layers communicate and do not communicate were studied. Foam significantly improved sweep as compared to the injection of only gas. A paper on this work will be presented at the SPE/DOE Symposium on Improved Oil Recovery in Tulsa, OK in April 1998.

A report on foam observations in micromodels was sent to DOE. A paper summarizing the first series of experiments was presented at the SPE conference in India (February, 1998). Experiments have included fluorosurfactants, oil based foam flow and polymer fortified foams in addition to classic alpha olefin sulfonate water based foams. In this last case (the most common for field projects) emulsions have been observed in the porous media. This work will continue with a new researcher in the Fall, 1998. Focus will be on the role of emulsions in foam destruction by oil. Experiments on foam flow in cores and sand packs will continue. Future work will include an attempt to pressurize the micromodels to study the effect of pressure on foam and oil/foam systems.

A study aimed at understanding silica dissolution and precipitation during steam injection in diatomite focuses on possible permeability and porosity changes caused by silica transport during steam injection. This problem is especially important because of the low initial permeability of the diatomite. Capillary pressure curves for several diatomite samples have been obtained in order to study pore and neck size distributions of these rocks. Network modeling of this process has been compared with experimental results from Mobil. The agreement is excellent. A paper on this work will be presented at the SPE Western Regional meeting in Bakersfield (May 11-13, 1998). A technical report on this work will be sent to DOE in December, 1998.

Project 4 : Reservoir Definition

A study on the effect of mobility ratio on pattern displacement behavior has started. For mobility ratios other than unity, results can only be obtained numerically. Using a streamline simulator developed previously at Stanford and with streamline and

saturation distributions, we are studying differences in displacement for five-spot and staggered line drive patterns. Comparison with the analytical solution for the case of mobility ratio equal to one is excellent. A topical report on this project is expected by March 1999.

Project 5: Field Support Services

A report on methods to improve oil recovery economics at the end of a steam flood was sent to DOE in March 1998. The main result: reducing the mass rate of the steam while keeping the quality high gives better oil recovery and economic results than injecting steam at a high rate and reduced quality. A summary of the report will be presented as a paper at the UNITAR meeting in October, 1998.