**MODIFICATION OF RESERVOIR CHEMICAL AND
PHYSICAL FACTORS IN STEAMFLOODS TO INCREASE
HEAVY OIL RECOVERY**

Contract Number: DE-FG22-90BC14600

University of Southern California

Contract Date: February 22, 1990

Anticipated Completion Date: February 21, 1993

Government Award (for *current* year): \$150,000

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Reporting Period: October 1 - December 31, 1992

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MODIFICATION OF RESERVOIR CHEMICAL AND PHYSICAL FACTORS IN STEAMFLOODS TO INCREASE HEAVY OIL RECOVERY

OBJECTIVES

Thermal methods, and particularly steam injection, are currently recognized as the most promising for the efficient recovery of heavy oil. Despite significant progress, however, important technical issues remain open. Specifically, still inadequate is our knowledge of the complex interaction between porous media and the various fluids of thermal recovery (steam, water, heavy oil, gases, and chemicals). While, the interplay of heat transfer and fluid flow with pore- and macro-scale heterogeneity is largely unexplored.

The objectives of this contract are to continue previous work and to carry out new fundamental studies in the following areas of interest to thermal recovery: displacement and flow properties of fluids involving phase change (condensation-evaporation) in porous media; flow properties of mobility control fluids (such as foam); and the effect of reservoir heterogeneity on thermal recovery. The specific projects are motivated by and address the need to improve heavy oil recovery from typical reservoirs as well as less conventional fractured reservoirs producing from vertical or horizontal wells.

VAPOR-LIQUID FLOW

Work continued during this quarter in three areas related to vapor-liquid flow in porous media: Experiments in Hele-Shaw cells, glass bead-packed cells and glass micromodels, pore network simulation and a macroscopic analysis of such flows. Experiments involved steam displacement of various model oils to understand the physical mechanisms involved, particularly spreading during film flow, and should be particularly pertinent to steam displacement in naturally fractured systems. The latter are modeled by appropriate glass micromodels designed to probe the interaction between matrix and fractures. This work, still in progress, complements our recent study of Hele-Shaw cells (1). Displacement experiments involving only a single species were also conducted to study the mechanisms of steam condensation in

the absence of oil. Various effects have been identified, as summarized in our forthcoming Annual Report (2).

Theoretical work included further studies of steam zone growth driven by a specified heat flux or a specified superheat in a pore network. Typical examples of the patterns obtained are shown in Figure 1 for these two cases. In conjunction with the pore network simulation, we developed a theory that delineates the regimes obtained, in terms of the size of the "bubble", the degree of superheat and the effective capillary number. Our approach parallels that of Lenormand (3) and leads to conditions under which percolation regimes exist. The findings are summarized in (4). When the percolation boundary is exceeded, the growth pattern is affected by additional factors and can be fingered. To understand this behavior, we conducted a stability analysis of radial growth in an effective pores medium. It was found that in the absence of capillarity, such processes are unstable, despite the effect of heat conduction. These results are to be contrasted with steam injection, where heat conduction and heat losses, in general, stabilize the growth pattern (5). Pore network simulation of steam injection also continued. We are presently working on the solution of some computational problems that arise due to phase-change.

HETEROGENEITY

In the area of heterogeneity our research involves fractured systems and effects of heterogeneity on displacement processes. In the area of fractured systems we completed a study of mechanism of drainage that includes visualization experiments and pore network simulation (6). Drainage of a matrix block-fracture element can be represented as an invasion process, where both viscous and capillary forces compete, where a curve equivalent to a capillary pressure curve for homogeneous systems can be constructed, with the exception that it is the capillary number rather than the capillary pressure which is related to saturation (Figure 2) and that this curve also depends on the viscosity ratio M . Based on the analogy with homogeneous systems, steady-state relative permeabilities for drainage in a fractured system were constructed (6). Similar work is about to be completed for the case of imbibition. In parallel, we completed an investigation on the use of fractal geometry for the representation of fractured systems and the use of pressure transients for its identification (7).

Complementing our previous works on capillary heterogeneity (8), (9) we also completed a comprehensive study involving theory, experiments and pore network simulations for drainage in media of variable heterogeneity (10). The pore network simulations, in particular, lend validity to many of the predictions of the continuum theory in processes involving heterogeneous media. The analogous study of imbibition is currently in progress. These works are done in collaboration with researchers at the Université Pierre et Marie Curie. Finally, progress was made with the development of a theory based on Vertical Flow Equilibrium for steam injection processes. The VFE predictions for miscible displacement were simulated numerically and were found to be in excellent agreement with expectations (Figure 3). This work continues with the use of correlated permeability fields.

CHEMICAL ADDITIVES

Work continued in the area of non-Newtonian flow in porous media. A technical report was prepared describing aspects of displacement involving power-law fluids and Bingham plastics (11). Experiments using glass micromodels and Hele-Shaw cells are under way. In parallel, we continued our investigation using pore networks to model foam formation and mobilization. A particular objective of this study is to test recent theories on critical pressure gradient for the onset of foam flow. Our numerical results do not fully support the previous theories, either qualitatively or quantitatively. The disagreement is due to differences in pore network structure (Bethe lattice vs. regular network), but also in the mechanisms used to represent the onset of mobilization. This work continues.

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Figure Captions

Figure 1. Numerical Simulation of Steam Bubble Growth in a Pore Network due to (a) Applied Superheat at Boundaries, (b) Applied Heat Flux on the Left Side.

Figure 2. Numerical Simulation of Wetting Saturation vs. Capillary Number at Steady-State During Drainage in a Fractured System.

Figure 3. Simulation of Viscous Fingering at Conditions of VFE.

a

b

Figure 1

Figure 2

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